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DIVISION OF GEOLOGY AND EARTH RESOURCES

VAUGHN E. LIVINGSTON, JR., State Geologist

BULLETIN NO. 70

ZINC AND LEAD ORE DEPOSITS IN CARBONATE ROCKS, STEVENS COUNTY, WASHINGTON

By

JOSEPH W. MILLS

With a section on the
GEOLOGY OF THE CALHOUN MINE
By
JAMES BROWNE

1977

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FOREWORD

Since the early days of its history Stevens County has been recognized as having geology favorable for the occurrence of mineral deposits. George Bethune in his Annual Report of the First State Geologist, 1890, to Governor Laughton said: "Dame Nature was lavish in her gifts to all that vast domain we know and revere as Washington. . . . But especially kind and generous, it would seem, she has been to that portion of Washington lying away over in her northeastern corner . . . ." Although Bethune's evaluation may have been overly optimistic, Stevens County has been the home of many mining operations over the years.

During the early years of mining in the county, silver was the metal that received the most attention, but as time went on more and more attention was paid to other metals, not the least of which were lead and zinc.

Because there are many mineral deposits in Stevens County and over the years mining has made a significant contribution to the county's economy, it was thought by Marshall T. Huntting in 1967 (former Supervisor of the Division of Geology and Earth Resources) that a study on ore genesis of the county would be very beneficial. Mr. Huntting was able to recruit Dr. Joseph W. Mills of Washington State University to undertake the study. In his preliminary work Dr. Mills found that the scope was too large and so, with the consent of Huntting, restricted his study to the lead-zinc deposits associated with carbonate rocks. Dr. Mills has done an excellent job in assembling existing information on these deposits in Stevens County and has added considerable new data through his own efforts.

Even more important, he has presented new hypotheses on the nature of the contact between the Metaline Limestone and Ledbetter Slate and on the origin of the Josephine Breccia and the mineral deposits it hosts. We are fortunate in being able to present here, in Bulletin 70, the results of his research, which add significantly to our knowledge of Stevens County zinc-lead deposits, and which should lead to better-directed exploration and renewed scientific interest in the zinc-lead deposits of Stevens County.

Vaughn E. Livingston, Jr.
Washington State Geologist

April 27, 1977

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STEVENS COUNTY, WASHINGTON

By

Joseph W. Mills

PURPOSE AND SCOPE

The purpose of this report is to provide an up-to-date, comprehensive account of the zinc and lead ore deposits in carbonate rocks in Stevens County, emphasizing (1) textural, structural, and stratigraphic relations recently recognized in the deposits, (2) the geological factors that are now considered to have been instrumental in this localization, and (3) their probable means of formation.

Although a few publications dealing with the regional geology and the general nature of the zinc and lead deposits of northeastern Washington exist, relatively little has been written about specific zinc-lead deposits in Stevens County in the 50 years since the early 1920's. Deposits like the Sierra Zinc, Van Stone, Deep Creek, and Calhoun had very little production prior to that time or were discovered later. The recognition of the need to remedy this shortcoming led to the initiation of this study. Two other factors also gave impetus to it. First, two excellent reports on the geology of zinc-lead deposits in neighboring Pend Oreille County were published in 1943 and 1965 by the U.S. Geological Survey (see section "History of Geological Studies"). The many similarities between the deposits in Pend Oreille and Stevens Counties indicated a need to look more closely than heretofore at those in Stevens County and possibly draw some conclusions about a common means of formation of the deposits in the two counties. Secondly, recent studies of ore mineral textures in polished and etched sections of ores from Stevens County, as interpreted in the light of recent published accounts of textures in deformed and annealed sulfides, brought out many ambiguities or contradictions of the long-held views as to the means of formation of the deposits. Thus, this report attempts to bring us up to date on the geologic setting of these deposits, to compare them with the better known and described deposits in the neighboring county, and to suggest a different means of formation from those proposed heretofore. The hope is, of course, that a better understanding of the nature and origin of the deposits will lead to their more effective exploration and development.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND TOPOGRAPHY

Stevens County occupies an area of approximately 2,493 square miles in northeastern Washington. It is bounded on the west by the Columbia and Kettle Rivers and Ferry County, on the east by Pend Oreille County, on the south by the Spokane River and Lincoln and Spokane Counties, and on the north by British Columbia (fig. 1). The principal communities are Colville, Chewelah, Kettle Falls, Loon Lake, Spring-

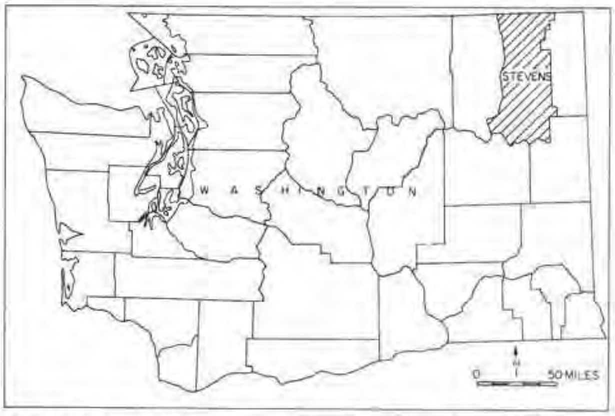

FIGURE 1.—Index map, showing location of Stevens County, Washington.

dale, and Northport. These communities are served by U.S. Highway 395 and State Highway 25, by a network of county and private roads, and by the Burlington Northern railroad.

The principal valleys are those of the south-flowing Columbia and Kettle Rivers and the north-northwest-flowing Colville River. The Colville River separates the Huckleberry Mountains to the west from the Pend Oreille Mountains to the east and northeast. Between the Kettle and Columbia Rivers are the Manashee Mountains. These three mountain ranges are the southward extension of the Columbia Mountains of British Columbia. Within Stevens County the average elevation along their summits is about 4,500 to 5,000 feet. The highest peaks are Calispell Peak (6,885 feet) in the Pend Oreille Mountains and Stensgar Mountain (5,817 feet) in the Huckleberry Mountains. All three ranges are rugged and heavily timbered.

HISTORY

Mining Activity

Lode mining activity began in Stevens County in 1883 with the discovery of lead-silver mineralization near Chewelah, and with the location of the Old Dominion mine east of Colville. Active development of the Old Dominion mine began in 1885 and it became the first important silver-lead producer in the area. Further significant mine development did not begin until a railroad into the county was completed in the 1890's. By 1906 at least eight of the county's major producers of silver and lead were producing or being brought into production. These were the United Copper and Copper King mines in the Chewelah district, the Cleveland mine in the Deer Trail district, the Old Dominion mine in the Colville district, the Young America and Bonanza mines of the Bossburg district, and the Great Western and Last Chance mines in the Northport district. No further major mines were brought to light until the discovery of high-grade galena on Gladstone Mountain in 1915, followed by the beginning of lead production at the Electric Point mine in 1916 and the Gladstone mine in 1917.

The earliest recorded zinc production in Stevens County was from the Great Western mine in 1916, the Young America mine in 1917, and from the Black Rock and Last Chance mines in 1920. Although the Sierra Zinc mine was first worked in 1889 and a small production was recorded in 1926, most of its production was from 1941 to 1944 after which the mine was closed. The remaining major zinc and lead producers, the Deep Creek, Van Stone, and Calhoun mines, though discovered much earlier, began production in earnest in 1945, 1951, and 1966, respectively. Since 1956, the only producing zinc-lead mines have been the Van Stone and Calhoun.

All of the mines just referred to, except the Van Stone, are now (1976) closed, and all but the Calhoun and Van Stone mines are partially to completely collapsed or inundated, or both, so that the reopening of the workings would be very costly.

A chart showing the productive life of the principal producers of lead, zinc, and silver in

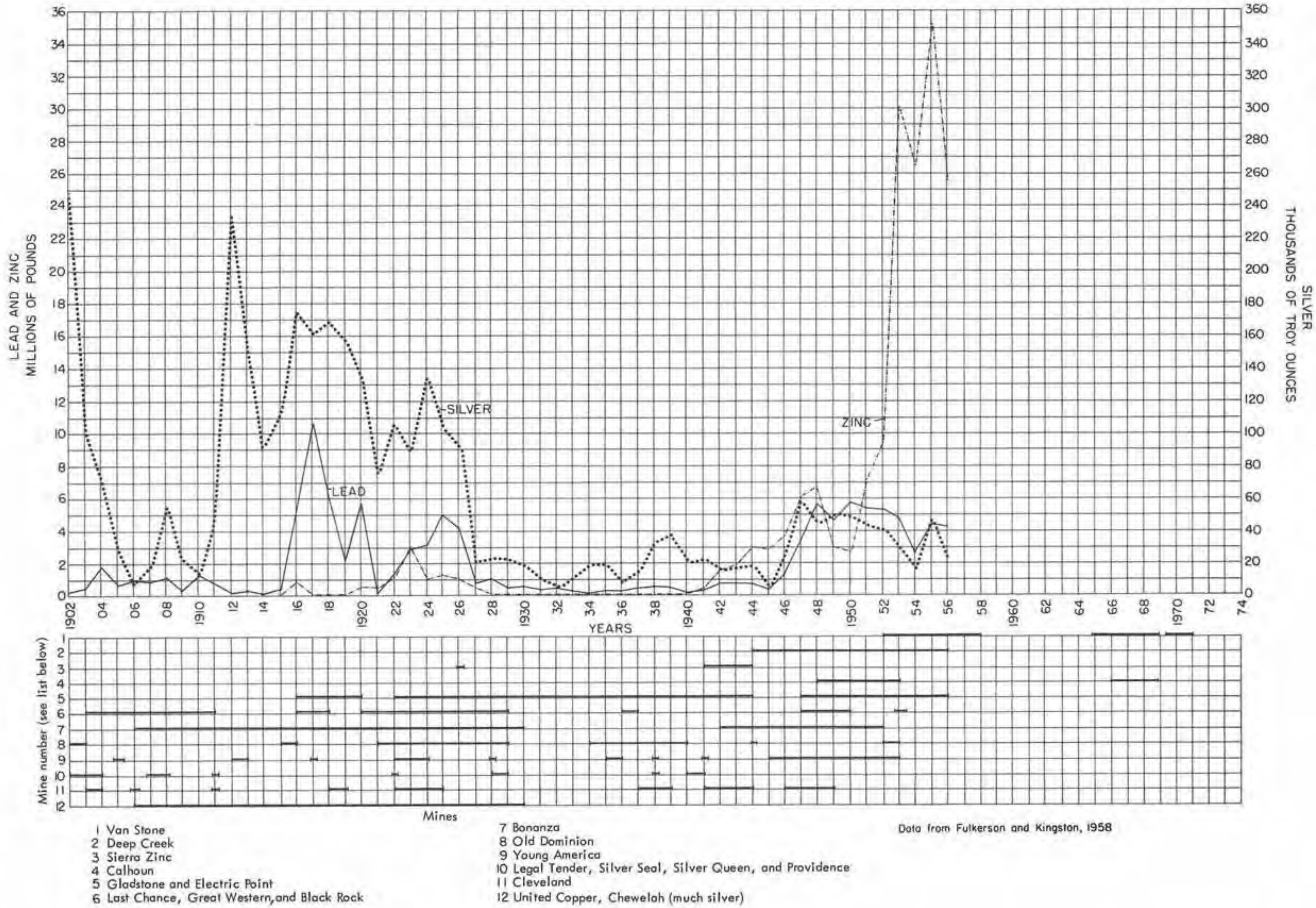

FIGURE 2.—Productive life of principal producers of zinc, lead, and silver since 1902, in Stevens County.

Stevens County and a graph of the total annual lead, zinc, and silver production for Stevens County since 1902 are given in figure 2.

Geological Studies

The first significant study of the character and geologic setting of the lead-zinc deposits of northeastern Washington is that of Bancroft (U.S. Geological Survey Bull. 550, 1914). At the time of his investigations no shipments were being made from any of the properties in the Northport district and little or no active development was in progress. Bancroft treated the geologic setting and character of only six lead-zinc deposits in carbonate rocks: the Last Chance, Lead Trust (Treadwell and Scaman), Anaconda, Copper King, Young America, and Ark. He categorized them as replacement deposits along fractures, faults, and shear zones in carbonate rocks.

Following Bancroft's work, the Washington Geological Survey published two reports in rather quick succession (Weaver, 1920, and Patty, 1921); its successor, the Division of Geology, published a report by Jenkins in 1924. These included discussions of 26 lead-zinc deposits in carbonate rocks in Stevens County, 18 of which had not been described by Bancroft. A list of the 26 properties discussed by Weaver, Patty, and Jenkins, and the page references, are provided in table 1. Weaver's report dealt with all of the mineral resources of Stevens County and included the first account and map of the geology of the whole county. To this day it remains the most comprehensive geologic study of the entire county.

After Jenkins' publication, nothing of consequence was written about the lead-zinc deposits for over 16 years. In 1941, the Colville Engineering Company prepared a report on minerals in Stevens County. It added nothing to our knowledge of the geology of the deposits but provided some rudimentary data on the location, shape, and extent of several lead-zinc deposits not mentioned by previous authors. These properties are the Advance, Copper King (Aladdin district), Cast Steel, Farmer, Galena Knob, Gladstone, Keystone, Magma, Maki, Plug, Red Top, Shoemaker, and Van Stone.

In 1941, the Bonneville Power Administration published a report (Gage, 1941) on the zinc-lead

TABLE 1.—List of lead-zinc deposits in carbonate rocks of Cambrian age, with page references to publications of Weaver, Patty, and Jenkins

Property	Reference		
	Weaver 1920 (page)	Patty 1921 (page)	Jenkins 1924 (page)
Ark	226-227	...	...
A and C	241-242	...	...
Anaconda	300-301	...	102
Bechtol	...	...	98-99
Big Chief	237-238	...	...
Black Rock	...	111-112	107-109
Botts	242	...	115-116
Chloride Queen	...	...	113
Copper King	299-300	...	102
Deep Creek	...	107-110	...
Electric Point	305-307	93-102	85-90
Galena Farm	245-246	...	...
Gladstone	307-308	102-104	90-94
Great Western	311	...	...
Hi Cliff	243-244	...	116-117
Iroquois	296-297	...	102-104
Last Chance	309-310	...	...
Lead King	...	106-107	96
Lead Trust	...	104-106	94-96
Lucile	298-299	...	100-102
Neglected	241	...	...
New England	312-313	110-111	...
Old Dominion	171-173	...	120-123
Sierra Zinc	...	...	109-111
Tenderfoot	239-241	...	...
Young America	176	119-121	117-118

mines of Washington. It was concerned principally with the potential power needs of future mines and provided no additional details about the geology of the deposits.

In 1943, the U.S. Geological Survey published Professional Paper 202 (Park and Cannon, 1943). Although it dealt entirely with the geology and ore deposits of the Metaline quadrangle, Pend Oreille County, it provided for a much better understanding of the mineral deposits of Stevens County because of the similarity in stratigraphy, structure, and mineral deposits in these two neighboring counties.

Later in the 1940's, the U.S. Geological Survey published a few open-file reports with details of the geology of selected mines and prospects: Bechtol (Campbell, 1945), Calhoun (Lorain and Gammell, 1947), Farmer (Reed and Gammell, 1947), Gladstone and Electric Point (Cole, 1949), and Young America (Hundhausen, 1949).

In 1956, the Washington State Division of Mines and Geology published an inventory of Washington minerals (Huntting, 1956), both text and maps, summarizing the location, ownership, mineralogy, geology, production, and literature references for all Washington mineral deposits, including essentially all lead-zinc deposits in carbonate rocks that are under consideration in the present study.

Two published symposia dealing with the geology of mineral deposits in British Columbia and northeastern Washington include papers of interest here. These are papers by Yates, Becraft, Campbell, and Pearson (1966), Huntting (1966), Muraro (1966), Yates (1970), and Kesten (1970). Weissenborn (1966) reviewed the geology and production of lead, zinc, and silver of northeastern Washington. Still later, publications dealing with or referring to the geology of the zinc-lead deposits in Stevens County are those of Neitzel (1972), Todd (1973), and Mills (1974).

In addition to publications having to do with zinc-lead deposits in Stevens County, there have been many geologic maps and reports, notably by the U.S. Geological Survey and the State of Washington Department of Natural Resources, treating the geology of the county with only casual reference to mineral deposits. Among them are reports and maps by Becraft and Weis (1957), Campbell and Loofbourow (1962), Yates and Robertson (1958), Yates (1964), Campbell and Raup (1964), Yates (1971), Clark and Miller (1968), and Miller (1969, 1974).

ACKNOWLEDGMENTS

Assistance by many persons took a variety of forms, including property access, providing both base and geologic maps of surface and underground workings, loaning of photographs, and direct field assistance. Such assistance was readily provided by William Calhoun, Gerald Carr, William Green, T. (Cy) Higginbotham, Norman Kesten, Austin McKelvie, Thomas Neitzel, Carl Sauvola, J. Eric Schuster, Stanley Todd, and Keith Whiting, for which the author is indeed grateful. David Brooks, Harold Nordstrom, and Robert Souders served ably as field assistants. James Browne was especially helpful and generous, having provided me with access to several maps that I would otherwise not have known about. He also provided the geologic map (fig. 41) of the Black Rock, Great Western, and Last Chance area, the geology of which was done by him and Gerald Carr. And most importantly, he wrote the section on the Calhoun mine for this report, thereby giving us the benefit of his experience as geologist at the Calhoun mine when it last operated. To each of these persons I express my appreciation and extend my thanks.

GENERAL GEOLOGY

KOOTENAY ARC

Introduction

The rocks of Stevens County are part of an arcuate belt of multiple deformation called the Kootenay Arc (Hedley, 1955). The Arc extends approximately 250 miles from north of Revelstoke, British Columbia, to the vicinity of the confluence of the Spokane and Columbia Rivers in Washington, where it disappears beneath the late Tertiary basalt flows of the Columbia Plateau (fig. 3 and fig. 4). Thus it includes portions of both the Selkirk and Purcell Mountains. The Arc is part of a much larger tectonic unit referred to as the Omineca Belt (Brown and others, 1971). Characteristic of the Arc are refolded folds, axial plane foliation, and reverse or thrust faults parallel to axial planes of folds. Ages of the deformed rocks within the Arc are from late Precambrian to Middle Jurassic. Metamorphism is generally of chlorite-muscovite grade but locally reaches sillimanite grade.

To the east of the Arc are the Precambrian rocks of the Belt-Purcell anticlinorium. Within the eastern part of the Arc are miogeosynclinal grits, sands, muds, and carbonate sediments now changed to quartzites, argillites, phyllites, mica schist, limestones, dolomites, and marbles. They range in age from late Precambrian to Ordovician; in Washington most are Lower and Middle Cambrian. The western part of the Arc in Washington incorporates eugeosynclinal metasedimentary rocks of Ordovician, Silurian, Devonian, Carboniferous, Permian, and Triassic age—principally argillite, siltstone, graywacke, angular chert-pebble conglomerate, with minor amounts of limestone. Also included in the westerly part of the Arc are metavolcanic rocks of both Permian and Jurassic age.

Folds

Typically these metasedimentary and metavolcanic rocks are intensely folded, often into isoclinal, recumbent, and overturned folds. Folds are northeasterly in trend and commonly overturned to the northwest (Yates, 1970; Crosby, 1968). These early folds and their accompanying axial plane foliation generally are refolded into a series of northeasterly trending open asymmetric anticlines and synclines (for example, Fyles and Hewlett, 1959, p. 70, 71). In some places, subsequent deformation developed tightly appressed chevron folds with an accompanying well-developed crenulation foliation (Mills and Nordstrom, 1973), which has a northwest-by-west to northwest strike and south to southwest dip. Still later, folding of a much milder kind locally generated gentle or monoclinal flexures. The first two-fold deformations probably took place between 100 and 200 million years ago; that is, after Early Triassic and before middle Cretaceous time (Mills and Nordstrom, 1973, p. 201). The third deformation, kink folds and crenulation foliation, though younger than the first two, is also more than 100 million years old (Yates, 1970, p. 33).

The large batholiths of the area have been variously dated as 90 to 160 million years old; that is, as Late Jurassic to Early Cretaceous. They were emplaced in rocks that had already been folded. Therefore, the time of major folding was probably Middle to Late Jurassic.

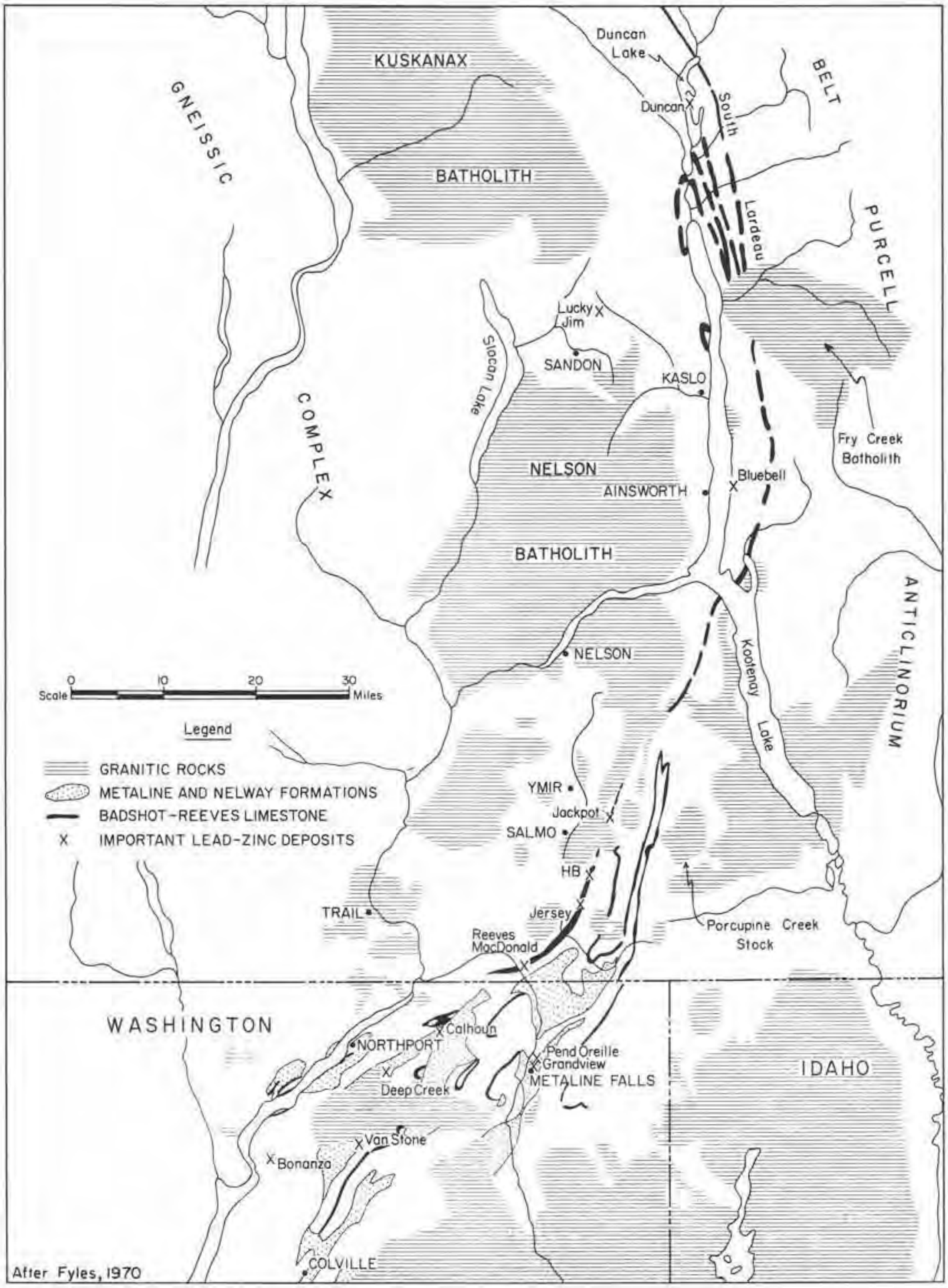

FIGURE 3.—Geologic map of the southern part of the Kootenay Arc.

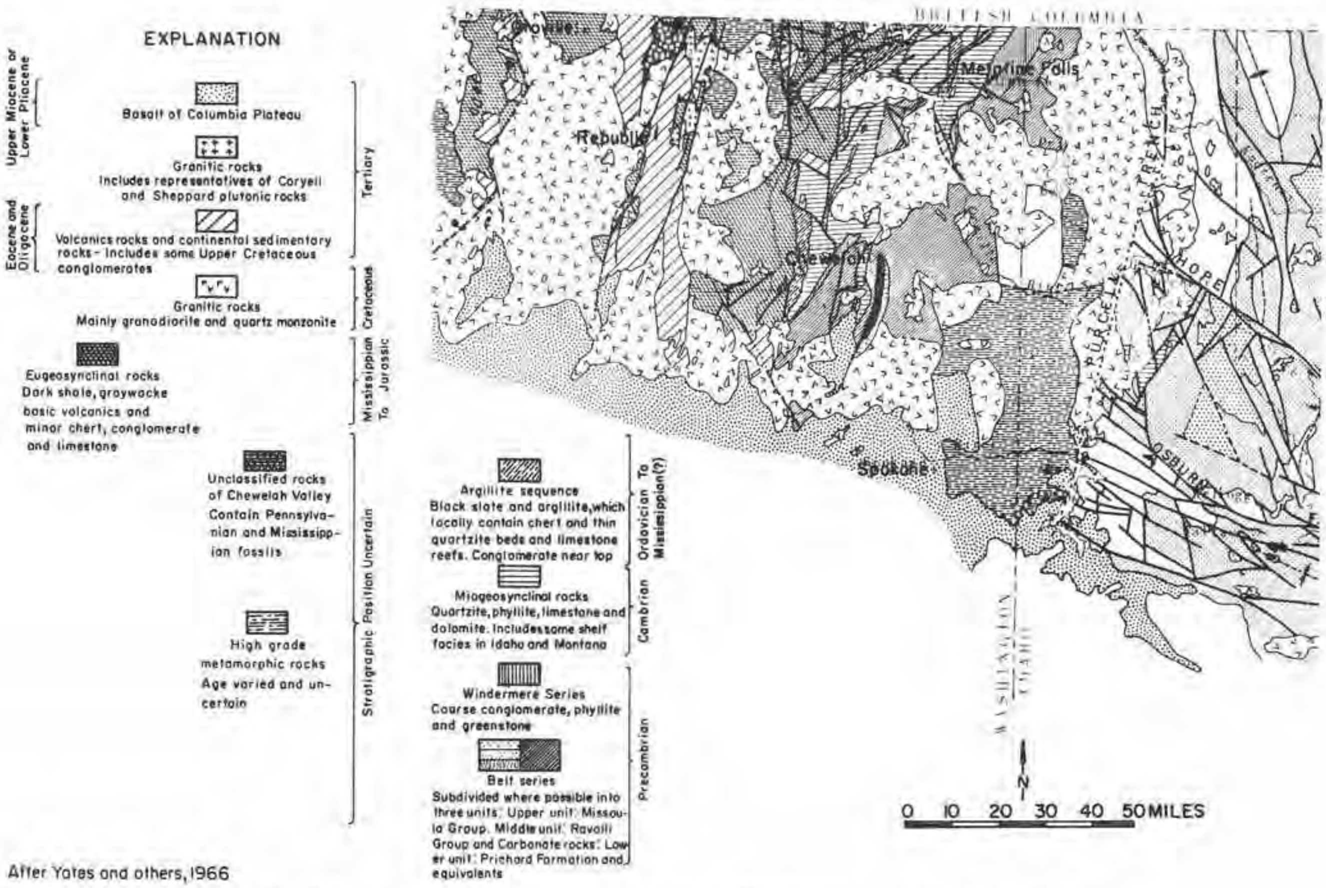

FIGURE 4.—Geologic map of northeastern Washington and northern Idaho.

Faults

The principal faults in the southern end of the Kootenay Arc are of two kinds—regional thrust faults and high-angle transverse faults. The regional thrust faults in the Salmo map area, British Columbia, separate the main structural belts in the area. They generally are parallel or at a low angle to the bedding and originated during the primary folding (Fyles and Hewlett, 1959, p. 63), though movement probably continued through the second period of folding. They are older than the granitic rocks of the Nelson intrusion, which Little (1960, p. 30) has shown to be pre-Late Cretaceous and post-Early Jurassic. Similarly in northeastern Washington, regional thrust faults are older than the granitic rocks of the Nelson and Kaniksu batholiths, including the Spirit pluton of Stevens County, but unlike those in British Columbia, they are regarded by Yates (1970, p. 33) as younger than and unrelated to the early folds. Possibly they are related to the chevron folding and crenulation foliation of the third deformation stage. Their strike is within a few degrees of east-west and is across the general northeast trend of the strata. Dips are commonly to the south; a few are to the north.

High-angle transverse faults of diverse attitudes are found in northeastern Washington (Leadpoint Fault and Black Canyon Fault, fig. 5), and to the north in British Columbia. Yates believes that some are tear faults related to and contemporaneous with the folding and thrusting, but Fyles and Hewlett (1970, p. 60) report that folds and regional thrust faults are cut by transverse faults. Most are apparently older than the plutons as they do not offset them. Other faults, notably those of the Williams Lake area of Stevens County, cut rocks as young as Eocene (Yates, 1970, p. 34). The displacements on some of the transverse faults are very large—12,000 to 20,000 feet on the Flume Creek Fault in Pend Oreille County, and on the order of 20,000 feet on the Leadpoint Fault in Stevens County. Movement on both of these major north-northeast trending faults is down on the east, up on the west.

Unconformities

The sedimentary or metasedimentary rocks record two prolonged periods of deposition during which conditions were relatively quiescent and uniform. The first is the Precambrian period when about 50,000 feet of fine-grained clastic sediments accumulated—the Belt Series rocks. The second was during the Cambrian when perhaps 15,000 to 20,000 feet of sediments accumulated in a miogeosynclinal environment on the western continental shelf and slope of the North American craton. On the other hand, there are gaps in our knowledge of the sedimentary record of the Paleozoic. Such gaps can be attributed to insufficient outcrop, some perhaps to faulting, but some are clearly attributable to a real hiatus in the sedimentary record through nondeposition or, more likely, through erosion. Such a hiatus is an unconformity.

One such unconformity exists (Park and Cannon, 1943, p. 9) between the Priest River Group (Purcell System, British Columbia) and the overlying Precambrian Shedroof conglomerate (Toby conglomerate, British Columbia). A second may account for the 12,000 feet or more of missing late Precambrian rocks in the Loon Lake quadrangle, Stevens County (Yates, 1970, p. 26). A third, a disconformity, probably exists at the contact of the Precambrian Leola Volcanics and Monk Formation (Yates, 1970, p. 26). The scarcity of fossils in the sedimentary rocks of post-Cambrian age and the intense deformation to which they have been subjected combine to make the recognition of younger unconformities very difficult. Yates (1970, p. 31) suggests the possibility of an erosional interval in northern Pend Oreille County during Early Mississippian time, and along the international boundary north of Stevens County in pre-Jurassic (probably Triassic) time. He also recognizes an unconformity between rocks of Late Cretaceous and Eocene age in northern Stevens County.

There remains one part of the Paleozoic sedimentary section that may harbor an unconformity that has escaped attention. This is the contact between the Metaline Limestone of Cambrian age and the overlying Ledbetter Slate of Ordovician age. This contact is particularly interesting because almost all of the lead and zinc produced in Pend Oreille County, and some from Stevens County, came from deposits less than a couple of hundred feet from the contact. That is, the contact appears to have exerted some control over ore deposition. Whether it is fault control, unconformity control, or some other control remains an open question. At any rate, the proximity of such extensive deposits to the contact is unmistakable. Consequently, the nature of this contact, unconformity or not, deserves more attention than can be justified in this section of the report. Therefore, it is considered at length in the section "Ore Deposits."

Igneous Rocks and Thermal Metamorphism

The batholiths and many of the stocks have local zones of intense deformation around their margins. They have also superimposed a contact metamorphism on the muscovite-chlorite subfacies of the regional greenschist facies metamorphism. The contact metamorphic aureole extends from a few hundred feet to as much as one-half of a mile from the intrusives in southern British Columbia (Fyles, 1970) and up to 2 miles or more from the Kaniksu batholith and Spirit pluton in Washington (Yates, 1970). Within the inner thermal metamorphic aureole, phyllitic rocks may be altered to mica schist or gneisses. Carbonate rocks have undergone grain coarsening; where silica was present as an impurity or was provided by the pluton, diopside and tremolite are present as felted masses or radiating clusters of needles or garnet-diopside skarn was formed.

Sulfides within the rocks of the thermal aureole may display textures indicating that they have undergone partial or complete annealing recrystallization and grain growth. Relatively little attention has been paid to these textures heretofore, but MacDonald (1970, p. 64) draws attention to annealing recrystallization of sulfides near the Jersey and Dodger stocks of the Salmo district, and Neitzel (1972) has amply documented annealing recrystallization and grain growth in the zinc-lead-iron sulfides near the Spirit pluton at the Van Stone mine. Additional evidence from several mines in Stevens County is provided in

TABLE 2.—Location, lithology, and age of igneous rocks

Rock body	Location	Rock type	Age
Lamprophyre dikes	SE. British Columbia and NE. Washington	Lamprophyre	50 m.y. - Eocene
Sheppard intrusions	SE. British Columbia and NE. Washington	Granite, mostly	50 m.y. - Eocene
Rossland pluton	Rossland, B.C.	Monzonite	90 m.y. - Cretaceous
Spirit pluton	Stevens County	Biotite granodiorite, quartz monzonite, granite, quartz diorite	100 m.y. - Cretaceous
Kaniksu batholith	Stevens County, Pend Oreille County, Wash.	Quartz monzonite, granodiorite	100 m.y. - Cretaceous
Loon Lake batholith	Stevens County	Granite, granodiorite	Late Jurassic to Early Cretaceous
Nelson batholith	Kootenay Lake, British Columbia	Quartz monzonite	160 m.y. - Late Jurassic to Early Cretaceous
Flowery Trail pluton	Stevens County, Washington	Granite	200 m.y. - Triassic

References: Yates, 1970; Yates and Engels, 1968; Fyles and others, 1973; Daly, 1912; Little, 1960; Waters and Krauskopf, 1941; Nguyen, Sinclair, and Libby, 1968; Fyles, 1970.

the present report.

The emplacement of granodiorite and quartz monzonite batholiths probably began in Late Jurassic time, following a protracted period of major folding, and continued through Early Cretaceous. By early Tertiary time, the batholiths must have been unroofed by erosion, for pebbles and cobbles of granitic rocks are found in the Tertiary conglomerates in the Republic graben and in several correlative deposits in other parts of northeastern Washington.

STEVENS COUNTY

Introduction

Stevens County is approximately rectangular in outline, with its north-south dimension about 2½ times as long as its east-west dimension. A line drawn along the northeast-southwest diagonal of this rectangle divides it roughly into two geologically dissimilar halves. The southeast half is composed of about equal parts of Precambrian, dominantly fine-grained clastic rocks and Mesozoic granitic intrusive bodies (fig. 5). Immediately west of the diagonal is a strip of Lower Cambrian, Middle Cambrian, and Ordovician miogeosynclinal metasedimentary rocks—quartzites, phyllites, limestones, dolomites, and argillites—of which the carbonates are of prime concern in this report as they house almost all the important zinc-lead deposits. The strip is much wider at the northeast than at the southwest end, reflecting the greater structural complexity of the northeast part.

West of the Cambrian-Ordovician strip to the county borders along the Columbia River and the Forty-ninth parallel is a great thickness of eugeosynclinal rocks, including argillites, siltstones, graywacke, angular chert-pebble conglomerate, volcanic lavas and tuffs, with minor amounts of limestone. They range in age from Silurian to Jurassic. In addition, at various places along the western side of the county there are fairly flat-lying or moderately tilted accumulations of early Tertiary volcanic and volcaniclastic rocks and continental sedimentary rocks.

The various kinds and ages of rocks within the post-Ordovician eugeosynclinal section and within the Precambrian terrain are not differentiated on figure 5 because, with the exception of the Bonanza mine, they contain no major producers of lead and zinc, and practically no production of any kind from carbonate rocks. Similarly, no attempt has been made to distinguish between the various intrusive rocks—partly because their range of composition is small (granodiorite to quartz monzonite), partly because most of them have not received much attention from geologists, and partly because they are devoid of lead and zinc deposits. Therefore, we will turn our attention to the Cambrian rocks, especially to the Cambrian carbonate rocks with their bountiful supply of zinc and lead, both in Stevens County and in Pend Oreille County to the east.

Paleozoic Rocks

Cambrian System

Rocks of the Cambrian System in northeastern Washington lie directly over and grade into the late Precambrian Monk Formation—predominantly phyllite with intercalations of gritty limestone, quartzite, and conglomerate. The separation of the Cambrian Gypsy Quartzite from the Precambrian Monk Formation is arbitrarily taken (Park and Cannon, 1943, p. 11) where quartzite predominates over phyllite.

The Monk Formation, being depositionally gradational to Cambrian lithologies, represents a

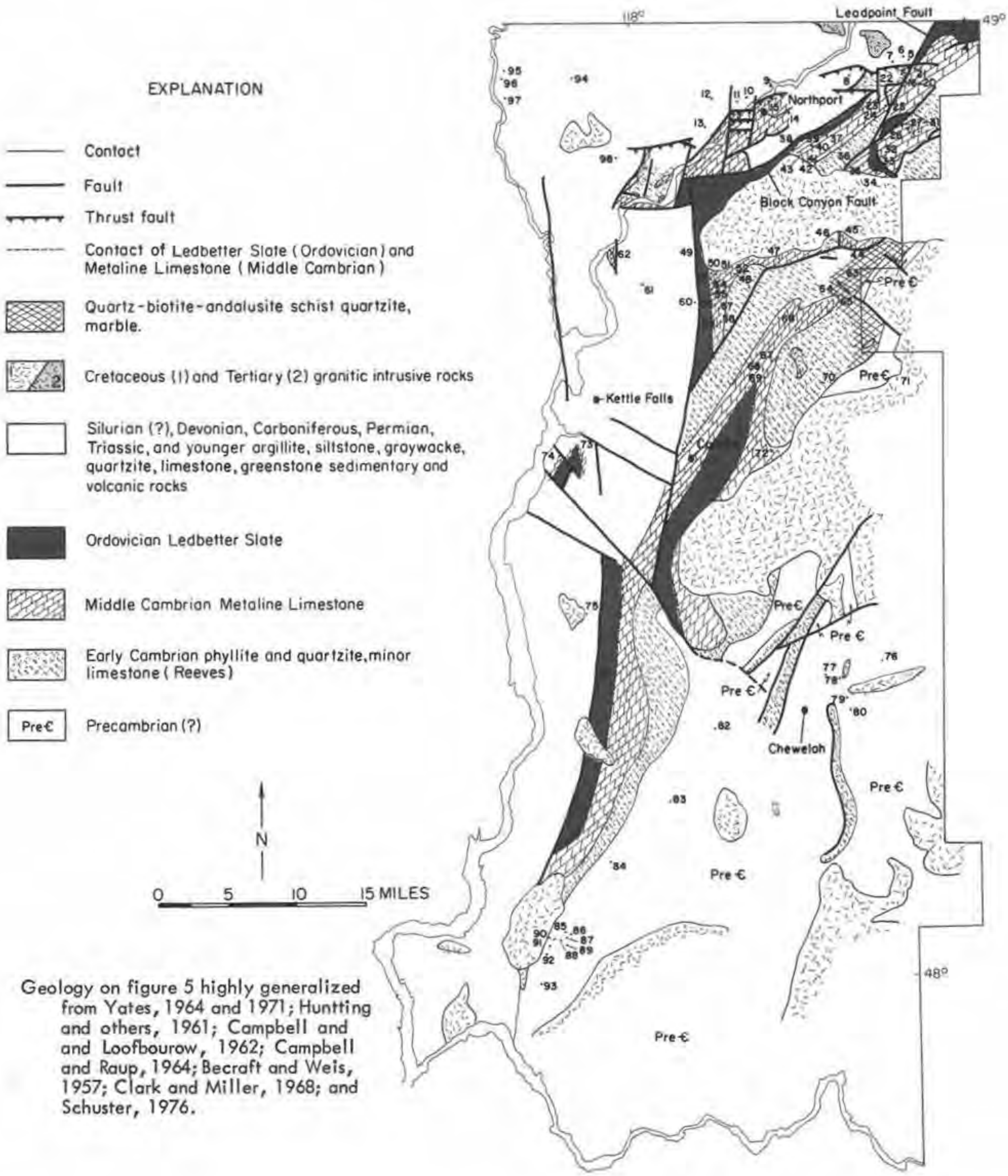

FIGURE 5.—Skeletonized geologic map of Stevens County, showing location of 98 lead- and zinc-bearing deposits.

MINES AND PROSPECTS SHOWN ON FIGURE 5[1/]

1. Frisco Standard
2. United Treasure
3. Myeera
4. Keough
5. Ranch View
6. Lakeview
7. Jackson
8. Melrose
9. Sunset
10. Mountain View
11. Providence
12. Hubbard
13. Bullion
14. Cast Steel
15. Silver Crown
16. Evergreen
17. Red Top
18. Copper King
19. Anaconda
20. Lucile
21. Iroquois
22. Admiral
23. Anderson
24. Calhoun
25. Lead Trust
26. Lead King
27. Red Iron
28. Wildcat
29. Gladstone
30. Electric Point
31. Keystone
32. Bechtol
33. Carbo
34. Maki
35. Farmer
36. Plug
37. Advance
38. Scandia
39. Black Rock
40. Great Western
41. Last Chance
42. Deep Creek
43. New England
44. Magma
45. Copper King
46. Sierra Zinc
47. Van Stone
48. Galena Farm
49. Silver Trail
50. A and C
51. Howard
52. Chollet
53. Hi Cliff
54. New Leadville (Botts)
55. Neglected
56. Echo
57. Big Chief
58. Chloride Queen
59. Tenderfoot
60. Lucky Stone
61. Bonanza
62. Young America
63. Morning
64. Burrus
65. Aladdin
66. Galena Knob
67. Michigan Boy
68. Cherry
69. Shoemaker
70. Longshot
71. Middleport
72. Old Dominion
73. Santiago
74. Ark
75. Daisy
76. Winslow
77. Jay Dee
78. Chewelah Eagle
79. Jay Gould
80. Mullen
81. Silver Summit
82. Nevada
83. Double Eagle
84. Cleveland
85. Little Frank
86. Legal Tender
87. Deer Trail
88. Brooks
89. Hoodoo
90. Silver Queen
91. Saturday Night
92. Aichan Bee
93. Orazada
94. Pomeroy
95. Perry
96. Rock Cut
97. Galena Hill
98. Minorca

[1/] The mines and prospects are listed alphabetically in Appendix B, p. 163.

change from the eugeosynclinal environment of late Precambrian time to the miogeosynclinal environment of Cambrian time.

There are very few published figures for the thicknesses of the Cambrian system in Stevens County, largely because the rocks have been complexly folded, thickened, thinned, and faulted so that accurate measurements are difficult to obtain. At least for northern Stevens County, it is thought (Yates, 1970, p. 28) that thicknesses are comparable to those measured by Park and Cannon in the Metaline district, Pend Oreille County.

No rocks of Late Cambrian age have been recognized in northeastern Washington. The Metaline Limestone is of Middle Cambrian age and the Maitlen Phyllite and Gypsy Quartzite are of Early Cambrian age. On figure 5, rocks of Early Cambrian age are shown in one map symbol, with no distinction made between lithologies. Similarly, the Metaline Limestone of Middle Cambrian age is shown by one map symbol. By not including the refinements of lithologies, the geologic map is less cluttered and better suited to generalization. This emphasizes certain relationships between zinc-lead ores and major rock units and rock contacts that might otherwise be lost in a more detailed map. Specific geologic map information is provided for certain areas under the section entitled "Mines and Prospects in Carbonate Rocks." The reader who requires more detailed information may refer to the various U.S. Geological Survey and Washington Division of Geology and Earth Resources maps and papers listed under "References."

Gypsy Quartzite

The most extensive exposures of the Gypsy Quartzite in Stevens County, previously referred to as the Addy Quartzite (Weaver, 1920), extend for about 12 miles south-southwest of the Van Stone mine, for 5 miles north of the Old Dominion mine, and along the crest of the Huckleberry Range, west of Chewelah. Thickness ranges from 5,000 to over 8,000 feet. The Gypsy Quartzite grades into the underlying Monk Formation and overlying Maitlen Phyllite by virtue of increasing intercalations of phyllite. The lower part contains quartzite grits and some conglomerate, but throughout at least half of its thickness the Gypsy Quartzite is a very clean, medium- to coarse-grained quartzite.

Maitlen Phyllite

The Maitlen Phyllite is well exposed both northeast and south of the Spirit pluton almost to Colville, where it is cut out by a north-south fault. Except for small exposures near the portal of the Ark mine and northeast of the Santiago mine, it is not known to occur farther south in Stevens County. Its thickness in the Metaline district is about 5,000 feet; such a thickness is not unrealistic for the formation north of Colville. In the vicinity of the Santiago mine it is not more than 2,000 feet thick.

The most common rock is a gray-green, well banded, thin-bedded phyllite, in some places grading to a mica schist. One or more planar elements, other than bedding and jointing, are recognizable in most exposures and may be so well developed as to conceal or erase bedding. Most commonly, this is an axial plane foliation related to one or another of the three stages of fold deformation. Less commonly, it is a shear foliation probably related to faulting.

Most of the section is phyllite with little or no quartzite or limestone. Toward the top of the section, thin limestone beds are intercalated with the phyllite. The top of the Maitlen is arbitrarily placed at that point above which limestone predominates over phyllite. The base is placed about 100 feet below a gray-white limestone band 200 feet thick (Park and Cannon, 1943). The phyllite is gradational into the underlying Gypsy Quartzite and the contact is placed at the top of a prominent bed rich in fucoidal impressions, where the quartzite becomes subordinate in quantity to the phyllite (Park and Cannon, 1943). Likewise, the base of the Laib Formation, the Canadian equivalent of the Maitlen, is said (Fyles and Hewlett, 1959, p. 23) to be about 100 to 300 feet below a distinctive limestone unit called the Reeves Limestone Member of the Laib Formation. The interval between the Reeves and the underlying quartzite is a sequence of phyllite, argillite, quartzite, and limestone. However, Little (1960) and Yates (1970, p. 25, 26) place the base of the Maitlen at the base of the Reeves Limestone Member; that is, a couple of hundred feet higher in the section than indicated by Park and Cannon and by Fyles. This limestone contains rich assemblages of archeocyathids, judged to be Early Cambrian, both in southern British Columbia and in the Colville area, Stevens County, Washington.

The Reeves Limestone Member of the Maitlen Phyllite is of particular interest for two reasons. First, it is an excellent stratigraphic marker horizon, for it extends almost the full length of the Kootenay Arc. Second, it or its correlative, the Badshot Formation, is an important host rock for lead-zinc deposits in the Kootenay Arc in British Columbia, notably the mines of the Salmo district and the Reeves-MacDonald mine, north of Metaline Falls. In Washington, the Reeves is known to be mineralized only on Red Top Mountain (at Red Top, Lucile, Anaconda, and other mines). However, the Sierra Zinc mine and the Longshot mine, Stevens County, are both in a marble that probably is the Reeves, thus adding to its reputation as a good host. The Reeves is found in Stevens County on Red Top Mountain, southeast and east of the Deep Creek mine, along the Columbia River southwest of Northport, and southwest from the Spirit pluton as far as Colville, Washington. It varies from a gray, fine-grained crystalline limestone to a light-gray to white, medium- to coarse-grained limestone or marble, and to a dolomite adjacent to some veins and intrusive rocks (Fyles, 1970, p. 46). In the Red Top Mountain and Northport areas, it is generally white, coarsely crystalline, with a few percent of muscovite parallel to the foliation of the phyllite that gives specular reflections to freshly broken pieces.

Metaline Limestone

The Metaline Limestone of Middle Cambrian age is the host for all stratiform lead-zinc deposits in Stevens and Pend Oreille Counties, except the Sierra Zinc mine, and all massive sulfide vein deposits, except the Bonanza and Double Eagle mines. It has been particularly productive in T. 38 N., R. 40 E.; T. 39 N., R. 40 E.; T. 39 N., R. 41 E.; and T. 39 N., R. 42 E. (fig. 5), Stevens County. Here, Yates (1970, p. 25) recognizes at least three distinctive units in the Metaline Limestone—a lower limestone unit, a middle dolomite unit, and an upper limestone unit (west of the Leadpoint Fault) or dolomite breccia unit (east of the Leadpoint Fault). The limestone-dolomite-limestone sequence, and a fourth unit, the Josephine, are present as well in Pend Oreille County (Park and Cannon, 1943).

The description of the Metaline Limestone that follows is largely that of Dings and Whitebread (1965, p. 9-21) for the Metaline quadrangle, as modified by Yates (1970, p. 28, 29), and by the author.

Lower limestone unit.—Most of the lower limestone unit is a gray to dark-gray, thin-bedded limestone with limy shale and dolomite interbeds.

Certain distinctive beds or sub-units described by Park and Cannon (1943, p. 19) are also present in Stevens County. For example, in the Metaline district thin beds of blue-gray, dense limestone are separated by undulating layers of shaly limestone. Some of these undulating shale layers join and leave isolated eyes of the limestone. On exposed surfaces, the shaly layers weather brown and contrast with the grayish limestone. Similar rocks from the lower limestone section in the Deep Creek area of Stevens County are described by Yates (1970, p. 28). The author has observed them in roadside rock cuts near the former site of Pinkney City, north of Colville, and in the adit of the 4th level of the Shoemaker mine. At the latter place, the limestone has been strongly dolomitized. Another example is the presence in the Metaline district of limestone and dolomitic limestone of the lower limestone unit, well populated with spherical to ellipsoidal concentrically layered algae up to an inch in diameter. In Stevens County, they are found in several places, one being along Marble Creek near its junction with North Fork Mill Creek, about 3¼ miles north-northeast of the Shoemaker mine.

The lower limestone unit becomes very fissile or "papery" toward its base where it grades into the underlying Maitlen Phyllite. Its contact with the overlying middle dolomite unit is sharp (Yates, 1970, p. 28).

The lower limestone unit has not yielded any lead-zinc ore from rocks north of the Spirit pluton or from the Metaline district. However, vein sulfides (galena and sphalerite) at the Shoemaker mine and scattered sphalerite and galena at the Cherry and Michigan Boy prospects, in Stevens County, are considered to be in the lower unit. Vein mineralization at the Ark and Santiago mines, south of Kettle Falls, is in limestone that strongly resembles part of the lower limestone unit of the Metaline Limestone.

Middle dolomite unit.—The middle dolomite unit is known in Stevens County only from the northern townships 37, 38, and 39. Its thickness is thought to be approximately the same as in the Metaline district, about 1,200 feet (Park and Cannon, 1943, p. 18). It is a fine-grained, massive, cream-white to gray dolomite in which bedding can rarely be recognized. Intercalated with the light-colored dolomite in the upper half of the section are a few beds or bands of black dolomite, with white mineral dolomite mottles. These intercalations become more numerous toward the base of the unit. Their dark color is due to carbonaceous matter. Several other varieties of dolomite make up a minor part of the middle dolomite unit. These include gray sublithographic dolomite, uniformly black dolomite, and an enigmatic variety of banded dark- and light-gray dolomite in which the bands are frequently en echelon at an angle to bedding. It is referred to as zebra rock (Park and Cannon, 1943, p. 42), and has been variously explained as fossil algae and as the product of recrystallization along shear planes, but as yet no explanation is satisfactory. Zebra dolomite is not confined to the middle dolomite unit but is found in the lower and upper units where they have been dolomitized. It is especially prevalent in the intraformational breccia unit of the Leadpoint area (Yates, 1970, p. 35).

Small cavities, many of them lined with dolomite rhombs and quartz crystals, and patches of white quartz, are widely scattered through all parts of the dolomite.

In Stevens County, the middle dolomite unit is the host for the ores of the Calhoun, Deep Creek, New England, Van Stone, Gladstone, Electric Point, Keystone, Wildcat, Red Iron, Black Rock, Great Western, Last Chance, Big Chief, Chloride Queen, and Tenderfoot mines, and probably others. These properties are responsible for about 75 percent of all the lead and more than 97 percent of all the zinc ever produced in Stevens County. In Pend Oreille County, most of the lead and zinc production has come from the upper limestone unit; however, ore mineralization is found in the middle dolomite unit at the Yellowhead and Lucky Strike mines and the Scandinavian and Lakeview prospects (Dings and Whitebread, 1965, p. 65), and probably at others. It is not possible to assign stratigraphic positions to these mineralized bodies, but Dings and Whitebread believe that they lie in a zone from 500 to 1,200 feet below the top of the Metaline. The term Yellowhead horizon has come to be used for this rather broad interval in which sulfide mineralization is encountered so often. Its name derives from the Yellowhead mine, and from the relatively high proportion of pyrite typical of the ores to be found in it. Such pyritic ores are found in Stevens County at the Calhoun, Deep Creek, New England, and Van Stone mines. The Yellowhead horizon and its associated ores are discussed further under "Ore Deposits."

Upper limestone unit.—The uppermost rock unit of the Metaline Limestone throughout much of the Metaline district, in Pend Oreille County, and the Deep Creek and Clugston Creek districts, of Stevens County, is a light- to medium-gray mottled, very fine-grained, soft, massive limestone. It lacks the well-developed thin bedding typical of the lower limestone unit. Chert nodules are abundant in the lower part of the upper limestone unit. Park and Cannon (1943, p. 18) estimate its thickness to be 600 feet; Dings and Whitebread measured sections of the unit up to 1,500 feet thick.

The upper limestone unit may be dolomitic where it is mineralized. When strongly dolomitized, it is very difficult to differentiate from the middle dolomite unit. Coarse white dolomite, jasperoid, and breccia are often found associated with zinc and lead sulfides near the top of the unit in a zone called the Josephine Breccia.

The uppermost rock unit east of Leadpoint Fault in Stevens County is of quite a different character. It consists of intraformational dolomite breccia overlain by dolomite breccia, limestone, and dark argillite (Yates, 1970, p. 28). It is host to the mineralization in the Iroquois, Lead King, Lead Trust, and Bechtol mines.

The Metaline Limestone is overlain abruptly by the Ordovician Ledbetter Slate.

Other Limestones

In the Colville area and to the south, limestone of Middle Cambrian age was named the Old Dominion Limestone by Weaver (1920). In its type locality on Old Dominion Mountain, Weaver describes the rock (1920, p. 67) as follows:

> . . . the limestone is nearly a pure white color, has a uniform texture, and is highly crystalline. It varies greatly in the magnesian content and some varieties become true dolomite. In places it is largely replaced by silica especially in the near vicinity of the intrusive granite batholith . . . . The pure white phase grades over into fine and coarsely crystalline types which are interbedded and which are in places very decidedly dolomitic.

Elsewhere, Weaver describes the Old Dominion as well bedded and often argillaceous, grading into argillite.

In the southwestern quarter of Stevens County, Weaver has mapped "undifferentiated limestone" of Paleozoic age in several places. Most of these are within the Hunters quadrangle where they have been mapped by Campbell and Raup (1964) as "Old Dominion Limestone of Weaver (1920)." They describe the rock as follows:

> Heterogeneous sequence of thin-bedded light- to dark-gray limestone, slate, dolomite, and mixtures of these types; many

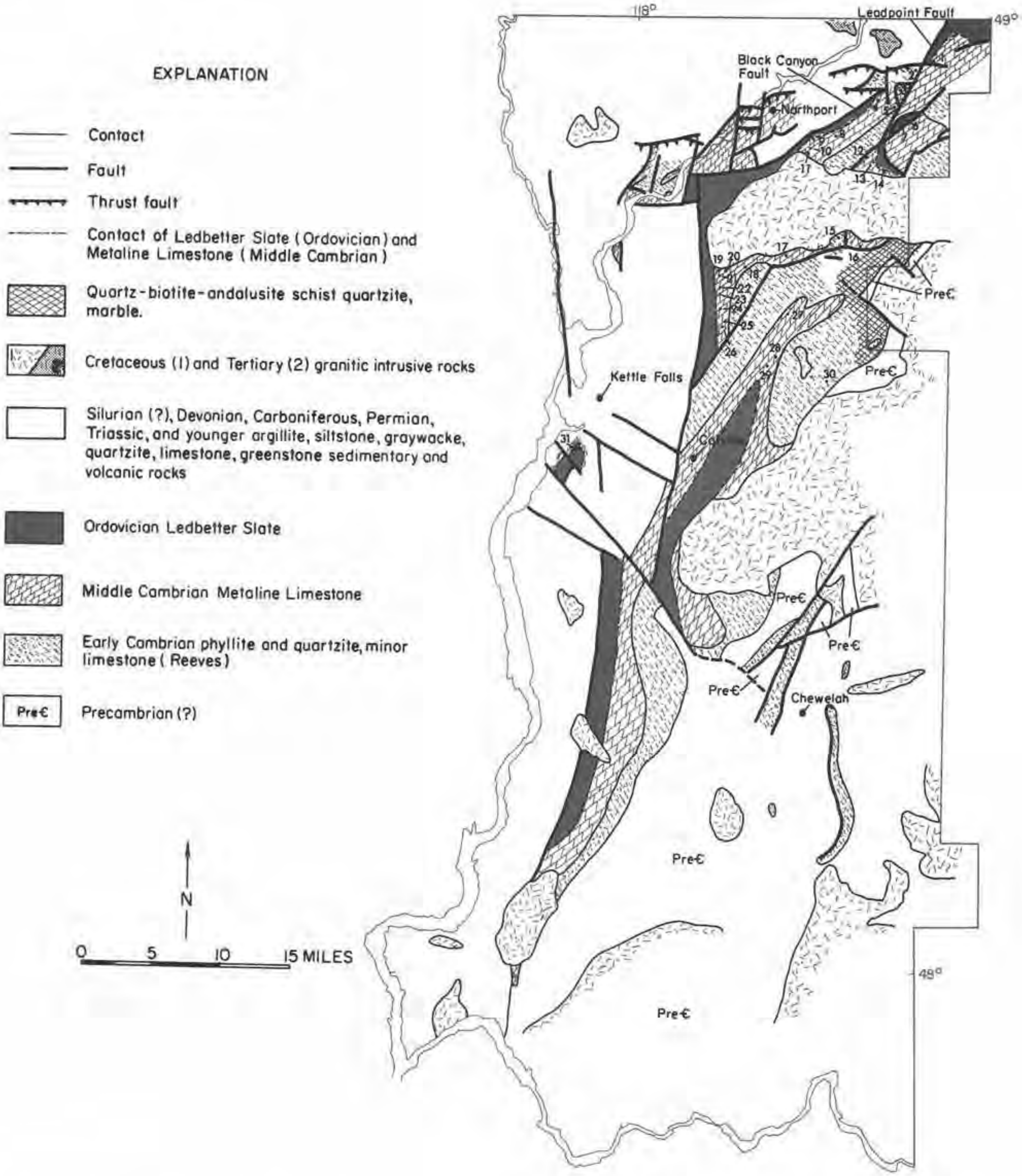

FIGURE 6.—Location and geologic setting of concordant zinc-lead deposits in carbonate rocks, Stevens County.

MINES AND PROSPECTS SHOWN ON FIGURE 6

X 1. Iroquois
O 2. Red Top, Lucile
X 3. Admiral
X 4. Anderson
O 5. Calhoun
X 6. Lead Trust
X 7. Lead King
X 8. Advance
X 9. Scandia
O 10. Deep Creek
O 11. New England
O 12. Plug
O 13. Farmer
O 14. Maki
O 15. Sierra Zinc
O 16. Magma
O 17. Van Stone
O 18. Cholett
O 19. A and C
O 20. Howard
X 21. Hi Cliff
X 22. New Leadville (Botts)
X 23. Neglected
XO 24. Big Chief
X 25. Chloride Queen
X 26. Tenderfoot
X 27. Galena Knob
X 28. Michigan Boy
X 29. Cherry
O 30. Longshot
X 31. Santiago

X Galena and(or) sphalerite, minor quartz, little or no pyrite, in coarse dolomite matrix of dolomite breccia; less than 250 feet from slate; silver less than 2 ozs per ton

O Sphalerite, galena, pyrite, some pyrrhotite, as disseminations, streaks, lenticles, lenses and stringers parallel to layering in marble; zinc is greater than lead; silver less than 0.5 ozs per ton

Geology highly generalized from Yates, 1964 and 1971 (north of Spirit Pluton); Huntting and others, 1961; Miller, 1969; Campbell and Raup, 1964; Clark and Miller, 1968; and Schuster, 1976.

chert nodules in carbonate rocks; zebra dolomite common locally; much carbonate rock is fetid.

South of the mouth of the Colville River, in the vicinity of the Santiago mine (fig. 6), limestone and dolomite breccia are overlain by black argillite and slate and underlain by phyllite. Ruzicka (1967) correlates these principal rock units with the Metaline Limestone, Ledbetter Slate, and Maitlen Phyllite, respectively. The Metaline Limestone here is described by Ruzicka as being 1,285 feet thick; the upper 575 feet is mostly medium- to dark-gray dolomite and dolomite breccia, and the lower 710 feet is mostly thin-bedded to thinly laminated limestone, varying from light-gray to dark-gray and black.

This author has observed the limestones and dolomites in each of the three areas just described. There is no doubt in his mind that each is the Metaline Limestone, for each is overlain by Ledbetter Slate; in at least two of the three areas, the limestone grades into and is underlain by phyllite similar to the Maitlen Phyllite. The carbonate section is much thinner than in the Metaline district and most of it is very similar in lithology to the lower limestone unit of the Metaline Limestone elsewhere in northeastern Washington.

Ordovician System

Ledbetter Slate

The Ledbetter Slate of Early and Middle Ordovician age is widely distributed in Stevens County from the northeast corner almost to the southwest corner (fig. 5). For the most part it is a black, carbonaceous, fine-grained argillite or slate. In some places it contains dark, fine-grained limestone or quartzite. Most of the slate or argillite is of uniform grain size and composition so that bedding is not pronounced. The rock often has a well-developed cleavage. Its Ordovician age has been established by fossils, chiefly graptolites (Park and Cannon, 1943). Graptolites have been found, but not identified as to genus and species, at several places in Stevens County, including the vicinity of the A and C mine along Bruce Creek, near the Neglected mine, east of the Ark mine, and about 3 miles north of the Daisy mine.

The base of the Ledbetter Slate is generally a sharply defined surface; in the few places where its unfaulted contact with the underlying Metaline Limestone can be observed, bedding in the slate is apparently parallel to bedding in the limestone (Park and Cannon, 1943, p. 20; Dings and Whitebread, 1965, p. 21). However, in view of the close areal association of this contact with zinc-lead mineralization in the Josephine Breccia of the Metaline Limestone, the nature of the contact is explored more fully in the following section, "Contact Between Metaline Limestone and Ledbetter Slate."

Above the Ledbetter Slate is black slate of Silurian age, black chert, and black bioclastic limestone of Middle Devonian age. In northern Stevens County, Yates (1971) recognizes still younger (Carboniferous?) argillite, chert, limestone, and greenstone.

As no zinc-lead mines or prospects of any importance have been found in carbonate rocks younger than the Metaline Limestone in northeastern Washington, no further attention is given to these younger strata in this report.

METALINE LIMESTONE—LEDBETTER SLATE CONTACT

INTRODUCTION

In view of the intimate association of many of the lead-zinc deposits with the Ledbetter Slate-Metaline Limestone contact in northeastern Washington, it is worthwhile to review the facts and inferences about the character and origin of the contact. The review is not limited to the part of the contact in Stevens County because (1) more has been written about the contact in Pend Oreille County than the part in Stevens County, and (2) whatever observations and conclusions can be drawn must apply to the contact in both counties.

The contact has an aggregate length of approximately 100 miles in northeastern Washington, though only a small fraction of this length is well exposed in mines and outcrops. Its position and pattern is simplified and generalized in figure 7, on which the geology is skeletonized to direct attention to the contact on a regional scale. Where the contact is designated as a fault, there is abundant evidence to support its fault nature. Wherever it is designated merely as a contact, either it is definitely not a fault or, in the author's view, evidence for faulting is open to question and other interpretations.

The contact must be a normal depositional sedimentary rock contact, or a fault contact, or an unconformity, or some combination of these. Other authors, insofar as they considered its origin, concluded that the contact was formed by normal processes of sediment deposition, or by faulting, or by both. This author believes that it is an unconformity which, though it appears locally to be a disconformity, on a regional scale truncates the underlying strata at a low angle and is therefore an angular unconformity. In the following review of observations and interpretations, objectivity is sought. However, in weighing and presenting evidence it is seldom possible to express opposing points of view as convincingly as one's own. Therefore, the reader to whom the nature and origin of the contact may be of real concern is urged to review the earlier writings himself.

OBSERVATIONS

1. Several authors (Park and Cannon, 1943, p. 20; Dings and Whitebread, 1965, p. 21; Yates and others, 1966, p. 49) point out that, except where the contact is known to be a fault, bedding in the slate is conformable with the contact and with bedding in the underlying Metaline Limestone.
2. The slate adjacent to the contact may be crumpled, schistose, and graphitic where there is known to be a fault, as for example along the Lead Hill Fault in Pend Oreille County and in the Shoemaker mine, Stevens County. Dings and Whitebread (1965, p. 21) say that "at most places in the mines the contact is marked by an irregular zone, a foot or more thick of broken, crumbled, and sheared slate and dolomite." However, there are many places where the slate adjacent to the contact is disturbed only a little or not at all, as for example west of the Pend Oreille River in Pend Oreille County (fig. 8) and south of the west end of the Spirit pluton and at the Santiago and Ark mines, in Stevens County.
3. The top of the Metaline Limestone has been described as "sharply defined against overlying black slate (Park and Cannon, 1943, p. 18).

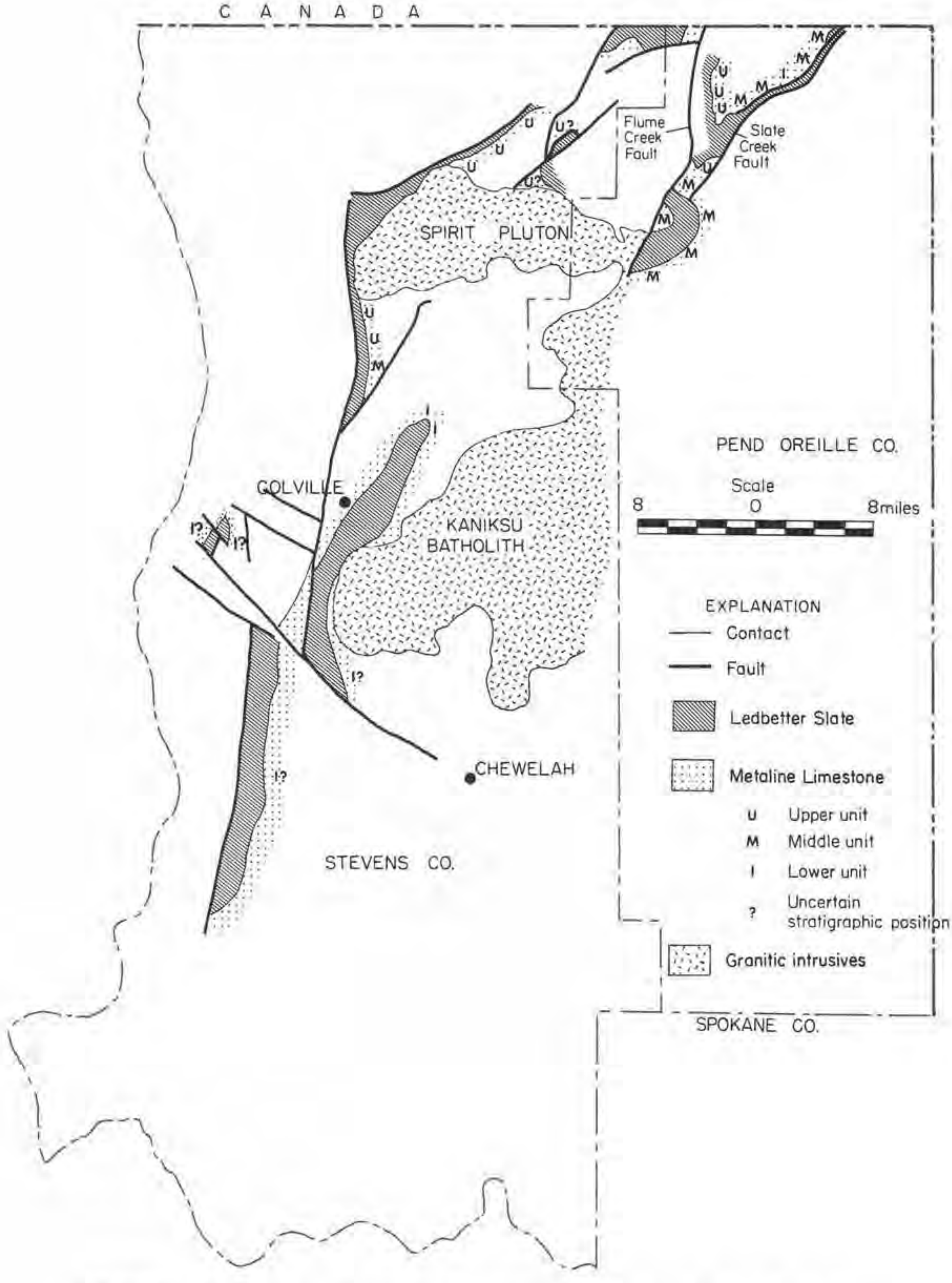

FIGURE 7.—The Ledbetter Slate-Metaline Limestone contact in Stevens County.

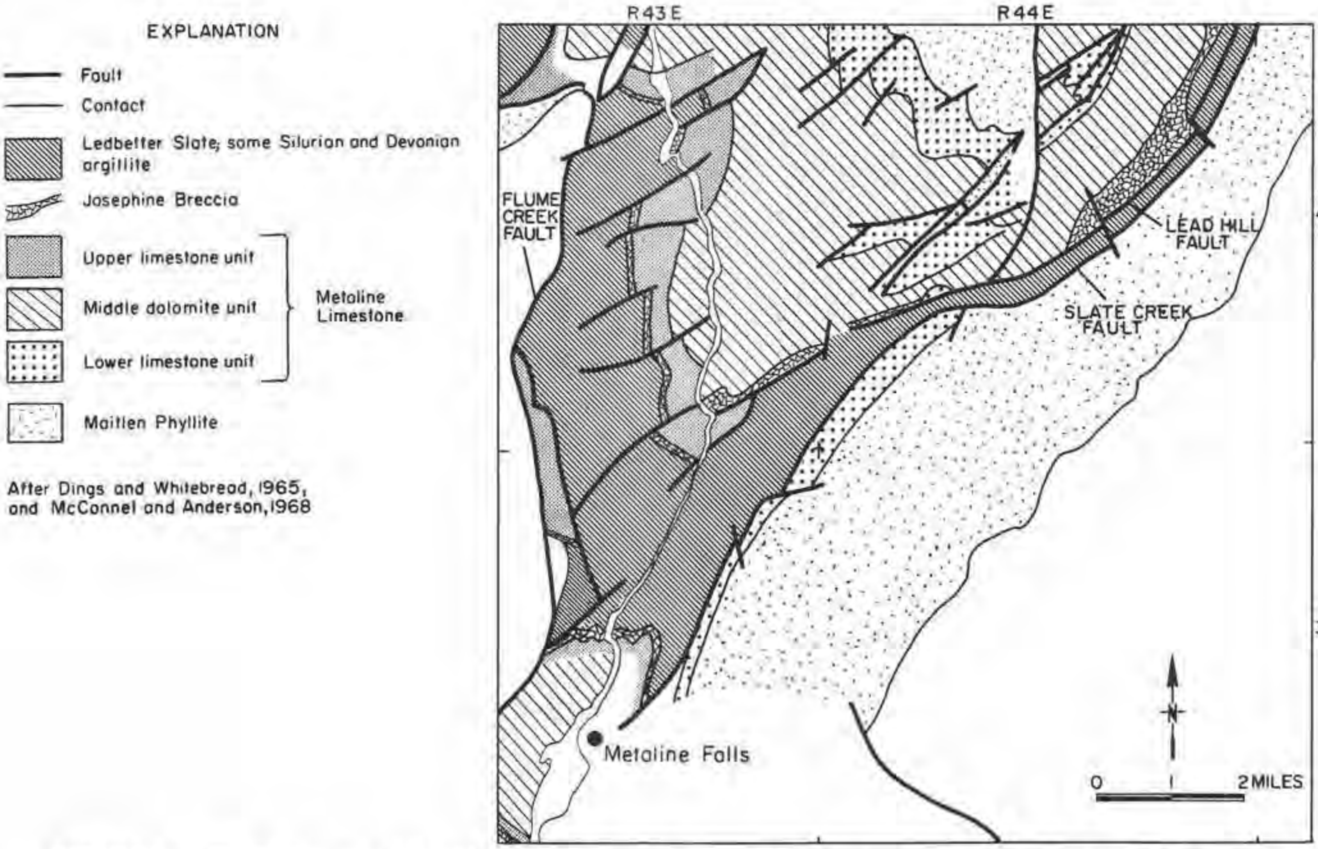

FIGURE 8.—Geologic map of the Metaline mining district, showing the position of the Josephine Breccia, Pend Oreille County.

Dings and Whitebread (1965, p. 21) note that "a few thin beds, lenses, and partings of black, generally gougy, shale occur irregularly distributed through the uppermost part of the Metaline."

4. The contact has a sinuous curvilinear trend over a length of at least 100 miles in Washington.
5. At one locality near the top of the hill northeast of the Giant prospect, Pend Oreille County, "there is evidence of at least a local erosion surface on the Metaline strata beneath the Ledbetter" (Dings and Whitebread, 1965, p. 21).
6. The Ledbetter Slate is in contact with different stratigraphic levels of the Metaline Limestone at different places, even where there is no evidence whatsoever of faulting. Such is the case in the Metaline mining district (fig. 8) where the contact is between Ledbetter Slate and the upper limestone unit of the Metaline Limestone west of the Pend Oreille River, whereas it is between Ledbetter Slate and the middle dolomite unit near the 49th parallel in the northeast corner of the Metaline district.

A vertical cross section (fig. 9, after McConnel and Anderson, 1968) across the Metaline mining district shows the Ledbetter-Metaline contact and the associated Josephine Breccia overlying gray limestone (upper limestone unit), which thins eastward and finally vanishes where the slate rests directly on dolomite (middle dolomite unit).

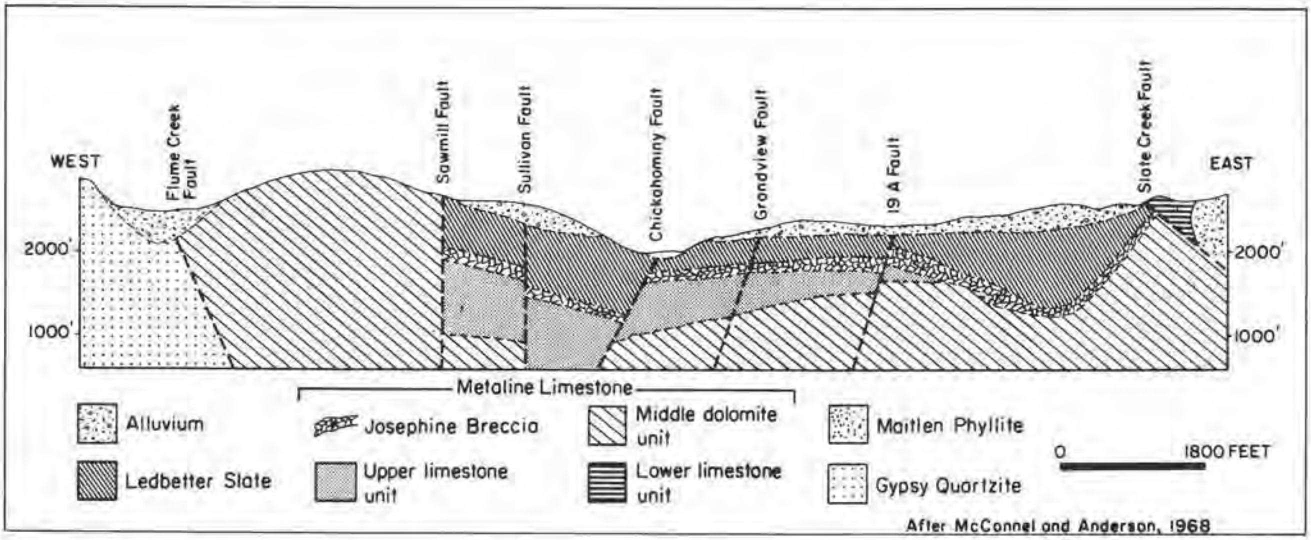

FIGURE 9.—Vertical west-east section across Metaline mining district, Pend Oreille County, in vicinity of Grandview and Pend Oreille mines. Shows the west-to-east truncation of Metaline Limestone by the Ledbetter Slate and Josephine Breccia.

In Stevens County, the Metaline Limestone at the contact is the uppermost unit (near the Spirit pluton), or the middle unit (8 miles north of Colville), or the lower unit (Shoemaker mine, 7 miles northeast of Colville; and probably all of the limestone south of Colville).

7. The strike and dip of the strata below the contact may not parallel the contact everywhere. On the Dumont properties on Slate Creek, the bedding, taken on the black spotted limestone layer (50 feet below the slate), if continued on strike, "would abut against the slate" (Park and Cannon, 1943, p. 64).

8. The geological record appears to be incomplete, for there are no rocks known to be of Late Cambrian age in northeastern Washington. Park and Cannon write (1943, p. 20):

> . . . the difference in age, Middle Cambrian of the Metaline Limestone and Ordovician of the Ledbetter Slate, indicates that a disconformity may exist.

and Yates (1970, p. 28) writes:

> In the Metaline district . . . if a hiatus exists, it is a disconformity. If there is no hiatus, the upper part of the Metaline Formation extends into the Ordovician, because Middle Ordovician graptolites occur only a few feet above the limestone-slate contact.

9. The rock unit referred to as the Josephine Breccia lies along or just below the Ledbetter-Metaline contact. Although it is given much more attention later in the report because of the mineralization it contains, its close association with the contact is sufficient reason for briefly indicating some of its features here, especially those features which may throw some light on the problem of the origin of the contact.

a. The top of the brecciated and mineralized zone (Josephine) is sharp as compared to its lower side which is ragged (fig. 10).

b. Almost all fragments in the Josephine Breccia are dolomite, though some are limestone and,

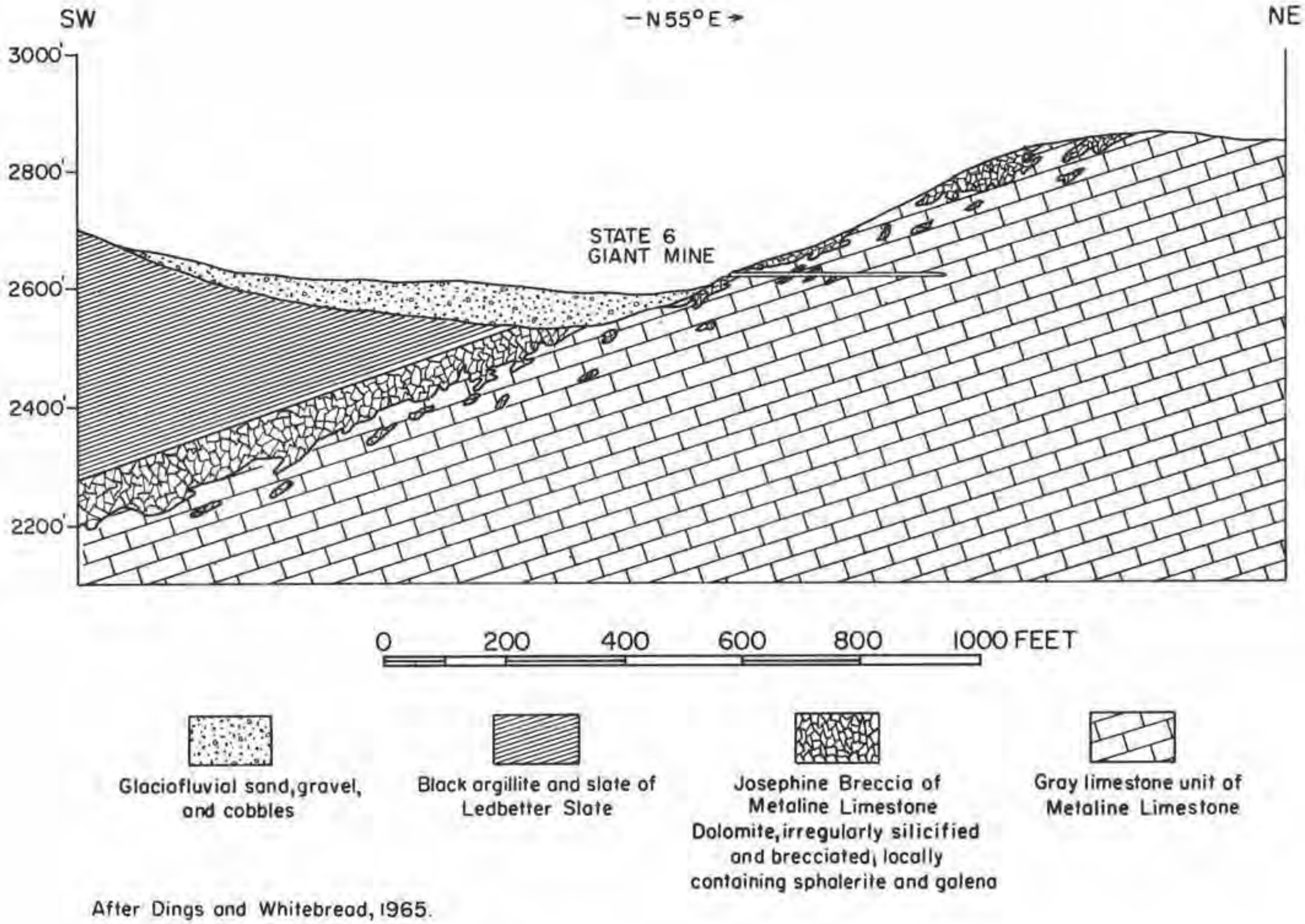

FIGURE 10.—Vertical section in the vicinity of the Giant mine, Pend Oreille County, showing relation of slate, ore-bearing dolomite, and limestone. Note contrast in upper and lower contacts of Josephine Breccia.

rarely, some are black argillite. Most fragments are angular to subangular.

c. The matrix of the breccia is jasperoid, quartz, or dolomite, with or without sulfides. Vugs are common. There is an almost total absence of interfragmental sedimentary rock filling or of fault gouge. Caves are common in the breccia, not outside it.

d. The breccia zone follows faithfully the fold structures in the enclosing strata, is broken and offset on hundreds of faults, and is truncated by granitic intrusives (figs. 4, 8).

ORIGIN

In this section each of the possible means of formation of the Ledbetter Slate-Metaline Limestone contact is considered in order to determine which one seems best to accommodate the facts presented in the previous section. To aid in the selection, various observations, opinions, and conclusions of previous authors are included.

Sedimentary Depositional Origin

All previous authors, though recognizing that in places the contact is a fault, are of the opinion that the contact is essentially a normal sedimentary one. The fact that in many places the bedding in the slate appears to be conformable with the contact and with the bedding in the limestone supports this belief. It is supported also by the observation (Dings and Whitebread, 1965, p. 21) that in some places the uppermost part of the Metaline Limestone contains a few thin beds, lenses, and partings of shale; the inference is that this zone is transitional between Metaline Limestone and Ledbetter Slate. Running counter to these observations is (1) the recognition that at least one place the contact is an erosion surface, not a depositional surface (Dings and Whitebread, p. 21; (2) the bedding in the Metaline Limestone may not be parallel to the contact (see Observation 7); (3) the observation of this author that the contact actually truncates the underlying rocks on a regional scale; and (4) the observation by Park and Cannon (1943, p. 18) that no gradational beds have been seen.

The fact that sedimentary rocks of Ordovician age lie above sedimentary rocks of Cambrian age is in accord with there being a normal sedimentary contact between them. However, the difference in age of the Ordovician Slate and the Middle Cambrian Metaline Limestone suggests that some of the geologic record (at least Late Cambrian) is missing and that the possibility of the existence of a disconformity at the contact cannot be ruled out (Observation 8).

Also in accord with the normal depositional contact hypothesis is the suggestion that the Josephine Breccia between the unbrecciated Metaline Limestone and the Ledbetter Slate is a sedimentary breccia (McConnel and Anderson, 1968, p. 1473). Arguments against such an origin are given later in this report where the breccia horizon is considered at length. The arguments do not bear repetition here except to report that the characteristics of the breccia in the Metaline mining district that led McConnel and Anderson to that suggestion are not present everywhere in the Josephine horizon, and even when present may be accounted for equally well by other means.

In short, it can be said that at some places the contact is a fault, at others it is an erosion surface, and although the suggestion has been made that the contact may mark a hiatus, there is no compelling evidence that would deny the possibility that part of the contact is a normal sedimentary one.

Fault Origin

There is abundant evidence in many places of faulting at the contact between the slate and the limestone. For example, about 6 miles southwest of Northport, Stevens County, northeast-striking Cambrian limestone and Ordovician rocks are in contact along a discordant east-west fault (Yates, 1971). Also, in Pend Oreille County, the northeast-striking contact along Slate Creek (fig. 8) in the northeast corner of the county is regarded as a fault—the Lead Hill Fault (Dings and Whitebread, 1965, plate 1). These authors mention (p. 21) that "contacts between the Metaline Limestone and overlying Ledbetter Slate showing little or no evidence of faulting are rare in the district." Nevertheless, they do not show a fault on their map along the 5-mile stretch of the contact, extending south from the 49th Parallel west of the Pend Oreille River. With reference to the Ledbetter-Metaline contact in the Metaline Mining district Yates (1970, p. 31) makes the following comment:

> . . . an undeformed contact . . . is rarely seen, but considering the deformation the district has undergone, movement is expectable at the junction of such contrasting rocks.

Recalling that in Stevens County the rocks in question have been subjected to at least three periods of folding, some of which were severe enough to produce recumbent and overturned folds, and to regional faulting as well, it would be quite unrealistic to expect to find the slate-limestone contact showing no sign of movement between the two dissimilar rock units.

Except for minor indications of slippage, the Ledbetter Slate-Metaline Limestone contact extending northeast of the western extremity of the Spirit pluton (fig. 5) has been mapped as a normal sedimentary rock contact (Yates, 1964) over its exposed length of more than 6 miles. Similarly, the contact extending south from the west end of the Spirit pluton (fig. 5) shows little or no sign of fault movement. Without giving additional examples, the point is that, although marked by a fault in places, the contact is not a fault over its entire length or even over a major part.

The observation (see Observation 6) that the contact truncates the older rocks at a low angle is one that is compatible with the contact being a depositional contact, a fault, or an unconformity, though a depositional contact is thought to be the least likely of the three.

All who have studied the ores of the Metaline district have been impressed with the fact that most of the ore has come from breccia within the Josephine Breccia. The origin of the breccia is considered in more detail under "Ore Deposits," but insofar as it has been regarded as a breccia in some way related to faulting, it is appropriate to consider certain aspects of it here briefly. The term "crush breccia" has been given to it by Park and Cannon (1943, p. 52) and Dings and Whitebread (1965, p. 2). Attributing it almost entirely to tectonic forces, Dings and Whitebread emphasize the fact that ore bodies in the Metaline, Pend Oreille, and Grandview mines are all in strongly faulted areas. Yet they do not state positively that they believe the "crush breccia" to be a fault breccia, and do not, in fact, give any explanation for the breccia. They confess that "a completely satisfactory explanation is not at hand to account for the stratigraphic position of the major ore bodies in the upper part of the Metaline" (Dings and Whitebread, 1965, p. 65).

Faults are numerous in Stevens and Pend Oreille Counties; hundreds are well exposed in the mine workings of the Metaline mining district. Previous authors emphasize their discordant attitudes with respect to bedding, their sharp near-planar walls with excellent polish and slickensides, the frequently rounded character of the fault breccia fragments, and the strong development of fault gouge between these fragments. It is interesting to observe that descriptions of the breccia zone (Josephine) are exactly opposite. That is, the Josephine breccia zone is roughly concordant, but with highly irregular and ragged boundaries, sharp angular fragments, and no gouge whatsoever. Furthermore, in the eastern workings of the Pend Oreille mine the breccia zone is separated from the Ledbetter Slate-Metaline Limestone contact by from 5 to 25 feet of Metaline dolomite (Dings and Whitebread, 1965, p. 21; Addie, 1970, p. 73); whether or not the breccia zone is a fault breccia here, the contact apparently is not a fault.

Several other characteristics of the contact or of the breccia zone below it, such as the frequency of caves in the breccia zone and the presence of a few black argillite fragments in the breccia, are compatible with the suggestion of faulting at the contact, but they are by no means diagnostic of faulting for they can be accounted for equally well by other means than faulting.

In short, several aspects of the Ledbetter Slate-Metaline Limestone contact deny or seriously question the likelihood of it being a fault contact. Other aspects are not in disagreement with a fault origin but can be accounted for as well or better by other means.

Unconformity Origin

The possibility that the Ledbetter Slate-Metaline Limestone contact is an unconformity is by no means a new idea, for it has been entertained by Park and Cannon (1943), Dings and Whitebread (1965), Mills and Eyrich (1966), and Yates (1970). On the basis of the difference in age of the slate (Ordovician) and the limestone (Middle Cambrian), these authors decided that the possibility of there being a disconformity at the contact could not be ruled out, but it is clear from the writing of all but Mills and Eyrich that they believe its existence to be very unlikely. This reluctance to give credence to the existence of an unconformity is understandable because, as they point out, where the contact can be seen, bedding in the slate appears to be conformable with the contact and with bedding in the limestone. One exception to the general "conformability" is the observation by Park and Cannon (1943, p. 64) that on the Dumont property in Pend Oreille County, the Metaline Limestone, if continued on strike, "would abut against the slate."

The common observation that bedding in the slate and limestone appears to be conformable is worth considering for a moment. In many exposures in northeastern Washington, both rock units have been greatly disturbed by folding and faulting, rendering it very difficult to make reliable distinctions between their attitudes. Furthermore, because of their thin bedding or strong slaty cleavage, the shales and slates are subject to much soil creep, thereby compounding the problem of obtaining reliable structural attitudes. However, even assuming that the measured values are reliable indicators of the bedding attitudes, if the contact were a regional disconformity or an angular unconformity of low angularity, then it is to be expected that at any single locality the bedding in the two units would appear to be parallel.

The author is of the belief that such a regional angular unconformity or disconformity does exist. This belief is based to a large extent upon the recognition (see Observation 6) that Ledbetter Slate rests on different stratigraphic horizons of the Metaline Limestone at different places in northeastern Washington (figs. 5, 7) where no fault is present. The vertical section across the Metaline mining district (fig. 10, after McConnel and Anderson, 1968), shows the Ledbetter above gray limestone (upper unit of the Metaline Limestone) that thins rapidly eastward as it is truncated by the contact and the Josephine Breccia, until the Ledbetter rests on the underlying dolomite (middle unit of the Metaline Limestone) in the east.

Of course, the best evidence for an unconformity would be the presence of an erosional surface on the rocks beneath the unconformity. Such evidence is wanting over all of the exposed contact except at the Giant prospect in Pend Oreille County, where there is evidence of at least a local erosion surface on the Metaline Limestone beneath the Ledbetter, according to Dings and Whitebread (1965, p. 21). The same authors remind us (p. 21) that "a minor erosion surface at the top of the Metaline could easily go undetected along the undulating and deformed contact."

Several other observations, such as the great extent of the contact (Observation 4) and the presence below the contact of a coextensive breccia zone (Observation 9) with a sharp top and ragged bottom with angular fragments of Metaline Limestone and a

TABLE 3.—Principal characteristics and possible origins of the Ledbetter Slate-Metaline Limestone contact

		Origin		
Site	Characteristics	Sedimentary	Fault	Unconformity
Rocks above contact	Apparent parallelism of bedding in slate, bedding in limestone, and the contact	++	+	++
	Slate not schistose, brecciated, gougy or graphitic over most of its 100-mile extent	+	-	+
Contact	100-mile extent, folded	++	o	++
	Regional truncation of older strata	o	++	++
	Metaline Limestone not parallel to contact at some places	o	++	++
	Contact is an erosion surface in at least one place	-	-	++
	Hiatus at contact	-	++	++
	Slate-limestone contact generally sharp	+	+	+
	Known faults at contact are typically clean cut, planar to curviplanar, with steep dips, discordant attitude, smooth walls, slickensides, gouge	+	o	+
Breccia below contact	Top of breccia zone sharp, bottom ragged	o	o	++
	Some angular fragments of Ledbetter Slate	o	+	++
	Most breccia fragments are dolomite sharp and angular	++	o	++
	Breccia matrix lacks sediment and gouge	-	-	++
	Caves common in breccia zone, not outside	o	++	++

Categorization of evidence: ++ strongly supportive; + compatible; o incompatible; - completely incompatible few fragments of Ledbetter Slate (see especially Neglected mine), are precisely the kinds of features to be found in unconformities the world over.

In short, an unconformity origin for the contact accounts for all of the "observations." The one fact that seems least well accommodated by the unconformity hypothesis is the seeming conformability of strata above and below the unconformity. However, even this poor fit is readily accommodated when we recognize that the contact is a regional disconformity or low-angle angular unconformity.

Summary and Conclusions

The principal characteristics and possible origins of the Ledbetter Slate-Metaline Limestone contact are summarized in table 3. An examination of this table reveals that, of the three possible origins—deposition, faulting, or erosion (unconformity)—deposition and faulting explain only relatively few of the characteristics and are contradicted by several others. An unconformity origin is the only one that accounts for all characteristics and is denied by none.

JOSEPHINE BRECCIA

DEFINITION

For many years, the rock assemblage just beneath the Ledbetter Slate in the Metaline district has been referred to locally as the "Josephine horizon." McConnel and Anderson (1968, p. 1467) consider the complex rock assemblage to be a distinctive stratigraphic unit, which they refer to both as the Josephine horizon and the Josephine unit. Interest in this assemblage stems from the fact that it is the major ore-producing zone in the Metaline district. McConnel and Anderson describe it as follows:

> . . . a complex mixture of gray dolomite and gray limestone, breccia, and finer clastic material, the matrix being black dolomite and(or) black jasperoid; sporadic masses of white calcite are common, and galena, sphalerite, and more rarely pyrite are pervasive in extremely variable amounts. This is the principal ore-bearing unit of the Metaline Formation.

However, Addie (1970, p. 73) distinguished two distinctly different rock types in the Josephine horizon at the Pend Oreille mine: an upper dark-gray to black dolomite, usually slightly mineralized with sphalerite; and a lower unit, the ore zone, consisting of sulfides in a brecciated jasperoid zone that ranges from 20 to 25 feet in thickness. Earlier, Dings and Whitebread (1965, p. 21) described the Metaline Limestone of the Pend Oreille mine as follows:

> . . . the upper 5-25 feet of the Metaline is a fine- to medium-grained black crystalline dolomite or dolomitic limestone, locally strongly to sparsely silicified and mineralized. It grades irregularly downward into a somewhat lighter colored and coarser grained dolomite and dolomite breccia that is also irregularly, and in places almost entirely, replaced by silica, calcite, and ore.

It is clear then that Addie, as well as Dings and Whitebread, recognize that the ore zone in all of the principal mines and prospects of the Metaline district is a sulfide-bearing breccia zone in the Metaline Limestone that extends upward to within a few feet of the Ledbetter-Metaline contact or right to the Ledbetter Slate itself. Similarly, mineralized dolomite breccia occurs in the Metaline Limestone next to the Ledbetter Slate in 17 mines and prospects in Stevens County (fig. 6). The author proposes that this widespread breccia zone henceforth be called the Josephine Breccia.

The term Josephine Breccia is preferable to Josephine horizon or Josephine unit, for the latter two suggest a particular stratigraphic position or a particular origin. In fact, McConnel and Anderson (1968, p. 1477) propose that the Josephine horizon is a sedimentary rock, a stratigraphic unit of the Metaline Limestone, and they place it (p. 1463) stratigraphically above the gray limestone unit of the upper Metaline. However, this interpretation is contradicted by their map (fig. 1, p. 1466) and section (fig. 3, p. 1473) in which the Josephine horizon is underlain not by the upper limestone unit but by the middle dolomite unit of the Metaline Limestone in the northeastern part of the map area and on the east side of the section.

The term Josephine Breccia should be reserved for breccia in carbonate rocks of the Metaline Limestone just below the Ledbetter Slate, regardless whether the underlying carbonate rock belongs to the upper, middle, or even the lower unit of the Metaline Limestone. Although at most places it is mineralized with sphalerite and galena, the term Josephine Breccia is appropriate whether or not it is ore bearing and even if it should lack base metal sulfides altogether.

In view of the economic importance of the Josephine Breccia with regard to the control it appears to exert over ore localization, it is discussed in considerable detail in the following section and in the section on "Ore Deposits."

DESCRIPTION

The following description is a composite of the observations of Park and Cannon (1943), Dings and Whitebread (1965), McConnel and Anderson (1968), and those of the author. In order not to riddle the text, page references are kept to a minimum.

The Josephine Breccia is a rudely blanketlike body of dolomite breccia, with dimensions measured in miles roughly parallel to the enclosing strata, and a thickness varying from a few to as much as 200 feet. It has been recognized at various places along its 100-mile extent in northeastern Washington. On a smaller than regional scale or district scale, such as mine or outcrop scale, the breccia body is not strictly conformable to bedding, and in fact may cut directly across bedding for several tens of feet. Similarly on this scale, its thickness may change abruptly. Descriptions of the breccia by previous workers repeatedly refer to its irregular shape and how it grades from normal breccia through a crackle breccia, in which there has been relatively little rotation of fragments, into unbrecciated rock. In the mines of the Metaline mining district, where exposures are infinitely better than elsewhere, it grades upward into somewhat fractured and slightly mineralized dolomite from 5 to 25 feet in thickness, just beneath the Ledbetter Slate.

Typically, the breccia fragments are angular to subangular pieces and blocks of dolomite, ranging from sand size to blocks from 8 to 10 feet on a side. Their color varies from white to gray to dark gray or black, and their grain size is generally given as fine to medium grained. Some are light- and dark-gray banded zebra rock. Most commonly, the fragments have sharp distinct margins (figs. 11, 12, 13), often rimmed with white or light-gray dolomite cockade (figs. 12, 13, 14), but in some deposits or parts of deposits the fragments are highly irregular, wispy, with indistinct borders that appear to grade into the adjacent dolomite matrix. Fragments of black shale, argillite, or slate, though quite conspicuous, are not abundant. They have been reported from the Pend Oreille mine (Park and Cannon, 1943, p. 73; Dings and Whitebread, 1965, p. 93), the Z Canyon Mutual

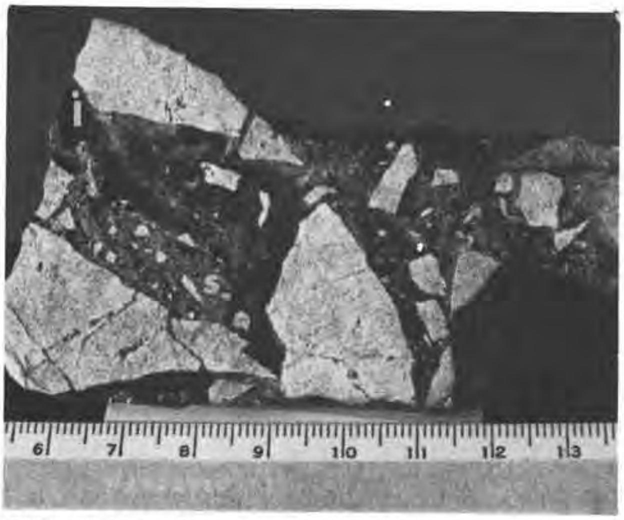

FIGURE 11.—Photograph of hand specimen of zinc ore of Josephine Breccia, Pend Oreille mine. Light-gray, sharply angular fragments of dolomite cemented by a mixture of dark-gray to black cryptocrystalline quartz or jasperoid(j) and yellow-brown sphalerite(s). Scale is in cms and mms.

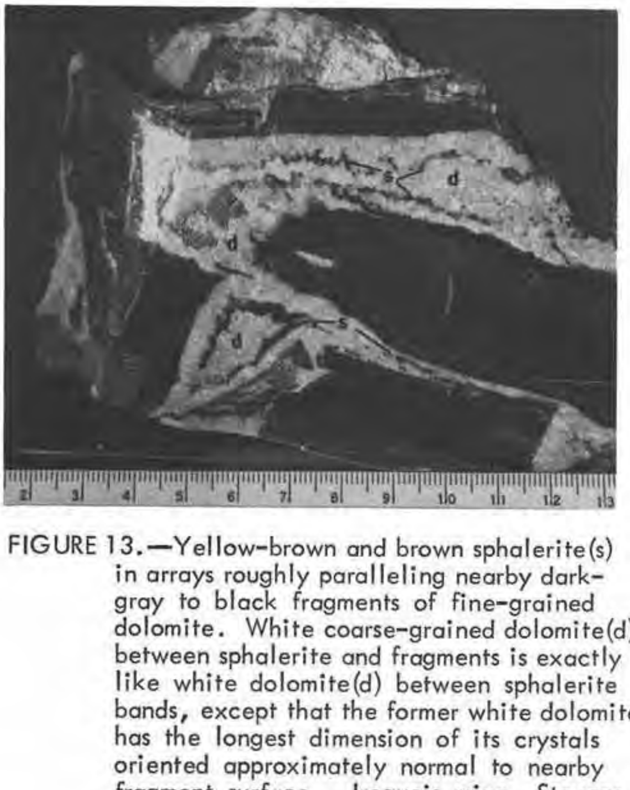

FIGURE 13.—Yellow-brown and brown sphalerite(s) in arrays roughly paralleling nearby dark-gray to black fragments of fine-grained dolomite. White coarse-grained dolomite(d) between sphalerite and fragments is exactly like white dolomite(d) between sphalerite bands, except that the former white dolomite has the longest dimension of its crystals oriented approximately normal to nearby fragment surface. Iroquois mine, Stevens County.

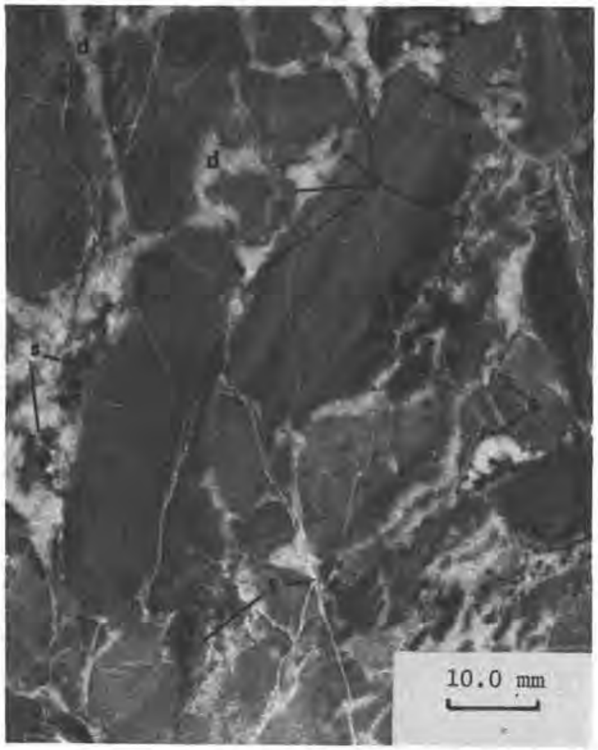

FIGURE 12.—Photograph of sulfide-bearing breccia of the Josephine Breccia. Angular to subangular, sharp-sided, gray and dark-gray, fine-grained dolomite fragments cemented by white coarse-grained "crystalline" dolomite (d) and sphalerite(s). Note how sphalerite is confined to the cement or matrix and is distributed in concentrations that parallel fragment margins. Iroquois mine, Stevens County.

and Z Canyon mines (Park and Cannon, 1943, p. 75, 76), the Bailey property (Dings and Whitebread, 1965, p. 70), and they have been recognized by the author in breccias of the Iroquois, Galena Knob, Neglected, and Admiral mines of Stevens County. Sulfide fragments and jasperoid fragments have been reported by McConnel and Anderson (1968, p. 1467, 1475, 1477).

By far the most common and widespread breccia cement or matrix is white to gray, occasionally dark-gray, coarse-grained (1-10 mm) dolomite. It is coarser grained than any of the fragments on which it often forms a distinct rind or cockade (figs. 13, 14). Where the longest crystal dimensions in the rind are about

FIGURE 14.—White to light-gray, coarse-grained dolomite cockade(d) on fine-grained dark-gray dolomite fragment(f). Sphalerite(s) and pyrite(p) are at the juncture of this cockade and the neighboring one (top of photo) belonging to a dolomite fragment out of the field of view. Gray area at right side of photo is epoxy. Lead King mine, Stevens County.

normal to the surface of the small fragments, the dolomite crystal aggregate has a fan or radiating pattern. Coarse crystalline dolomite may fill the entire interclast space or there may be a void roughly halfway between nearby fragments, into which rhombs of crystalline dolomite project. Often this space is partly or completely filled with white quartz or galena or sphalerite or some combination of these (fig. 15). In places it is partially occupied by a "button of anthracite" (Park and Cannon, 1943, plate 23).

A second kind of breccia matrix is a very fine-grained, dark-gray to black dolomite, in which the grains are generally so small as to be indistinguishable to the unaided eye. This matrix is always finer grained than the dolomite fragments it cements. It is common in the Pend Oreille mine and some has been observed in the Iroquois mine in Stevens County. It may be rich in sphalerite and galena.

A third kind of breccia matrix is "jasperoid," an exceedingly fine-grained holocrystalline quartz. It is especially abundant in the mines about Metaline Falls where most of it is dark gray to black. To the northeast, on the properties near Slate Creek, Pend Oreille County, it is more likely to be light gray or gray. It may be the sole mineral of the matrix or it may share the matrix with very fine-grained, dark-gray to black dolomite. This cement may be rich in sphalerite, less often in galena. Jasperoid often grades into white quartz.

White to light-gray calcite, with cleavage surfaces 6 inches or more across, is present in the breccia and outside it, as fracture fillings and as coarsely crystaline masses several tens of feet across.

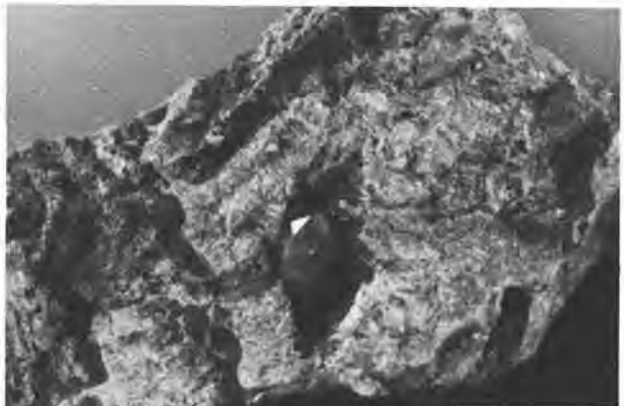

FIGURE 15.—Light-gray, coarse-grained "crystalline" dolomite with large vug lined with dolomite rhombs and containing a single large euhedral quartz crystal. The light color, coarse-grain size, and vuggy nature are common characteristics of the dolomite breccia cement. Lead King mine, Stevens County.

Both pre-ore and post-ore calcite are recognized (Park and Cannon, 1943, p. 45), but their relation to the breccia and to the ore is not clear.

The least abundant cement is sphalerite and galena. One or the other or both are generally disseminated throughout the breccia matrix, occasionally in such amounts as to constitute almost the entire matrix. At many places, sphalerite forms rims on fragments (fig. 12), isolating them from the rest of the matrix, or it forms a thin layer on the dolomite fragment cockade (figs. 13, 14).

Fine-grained sphalerite is also reported (McConnel and Anderson, 1968, p. 1473) to occur within the Josephine Breccia in thin laminae and interlaminated with thin-bedded siliceous dolomite "intermingled with irregular breccia masses."

Vugs are quite common in the breccia, especially in the breccia with a coarsely crystalline dolomite matrix. Vugs are often lined with small, white quartz crystals; occasionally they contain crystals of galena, or sphalerite, rarely barite.

ORIGIN

The Ledbetter Slate-Metaline Limestone contact, the sulfide mineralization, and the Josephine Breccia are so closely associated that a discussion of the origin of any one of them is bound to overlap on discussions of the origin of the other two. This is particularly true of the origins of the contact and the breccia.

Fault Origin

The term "crush breccia" has been used by previous authors (Park and Cannon, 1943, p. 52; Dings and Whitebread, 1965, p. 2), who attribute the brecciation to tectonic forces. Dings and Whitebread (p. 68) attribute the brecciation to "repeated settling of the graben block during mineralization, resulting in the development of crushed zones, fractures, and faults . . . ." This explanation of the enormous body of nearly conformable breccia was not substantiated. In fact, the authors acknowledge (p. 65) that "a completely satisfactory explanation is not at hand to account for the stratigraphic position of the major ore bodies" and hence for the breccia.

There are many aspects of the breccia that cannot be accounted for by appealing to a fault origin. Although faults are very common in northeastern Washington, most (all?) are younger than the breccia and they displace it. There is no evidence, such as slickensides, fragment rounding, associated gash fractures, or shearing, that would support a fault origin for the breccia. At places where the breccia body extends right to the slate, the slate may show little or no evidence of deformation, certainly nothing commensurate with the great size of the breccia zone. For example, in northern Pend Oreille County (fig. 8) the Josephine Breccia and enclosing strata are folded into a southwest-plunging anticline. Throughout most of the southeast limb of the anticline the Josephine Breccia is adjacent to the Lead Hill Fault. However, in the extreme northeast corner (fig. 8) and along the northwest limb, the Josephine Breccia is still present, though the slate-limestone contact adjacent to it is <u>not</u> a fault. Nor does the great extent and sinuous pattern of the course of the breccia zone in northeastern Washington support a fault origin. Possibly the most critical evidence against a fault origin is the fact that the breccia matrix is not a fault gouge, but is mostly a coarsely crystalline dolomite that clearly has been precipitated from solution on and between angular breccia fragments. This mass of fragments must have had very high porosity and permeability and its constituent fragments had little grain or clast support. A fault breccia with such a high ratio of void to solid is out of the question. Even after extensive filling of the original voids by coarsely crystalline dolomite, vugs are still very abundant.

Finally, it has already been argued that the slate-limestone contact is not a fault, but an unconformity. This indicates that the association of the breccia with the contact is not attributable to faulting and suggests that the breccia may be unconformity-related.

Sedimentary Depositional Origin

The suggestion that the Josephine Breccia is a sedimentary rock was made by McConnel and Anderson (1968). They say (p. 1476) that the rock mass of the entire Josephine Breccia must have been "formed in a rather shallow water environment . . . subject to periodically violent waves and to submarine slumps." In such an environment, carbonate reefs flourished and these were broken during violent storms, whereupon the broken reef detritus was carried by waves, currents, and gravity into the somewhat deeper basin areas where it came to rest in black dolomitic or limy or siliceous carbon-rich muds. In an attempt to explain the stratiform character and makeup of the Josephine the authors suggest (p. 1476, 1477) the following:

> Submarine slumping of larger masses of partly consolidated rocks also appears to have been common, creating particularly "thick" local turbidity currents that on settling formed local blanket-like very carbonaceous beds over the hummocky basin bottom . . . . Brecciation probably was further intensified by differential compaction and loss of water within the heterogeneous mass during diagenesis, resulting in fracturing and refracturing of blocks throughout the lithification process.

This author accepts McConnel and Anderson's reasons for believing that the sedimentary rocks were deposited in shallow water, but cannot accept the sedimentary and submarine slumping origin for the breccia. Although black, fine-grained dolomite and dark-gray to black jasperoid of the breccia matrix may be marine sediments, the evidence they give (p. 1478) for this—jasperoid fragments, blobs of jasperoid in the black, fine-grained dolomite matrix and the laminated dolomite—is only permissive, not diagnostic. Furthermore, as has already been emphasized, a much more "typical" matrix for the Josephine Breccia throughout its extent is a medium- to coarse-grained crystalline dolomite, which is by no means a marine sediment.

Sedimentary breccias generally display stratification, fair to good sorting of fragments that are grain supported, and very few or no vugs. The Josephine Breccia, however, has no stratification, no fragment sorting, little evidence for clastic grain support of fragments, and numerous vugs. The author, though intrigued by the suggestion, can find no evidence in support of a sedimentary origin for the Josephine Breccia.

Solution-Collapse Brecciation Origin

The removal of large volumes of soluble rocks like carbonates and evaporites by the dissolving action of moving waters, particularly meteoric waters, creates openings into which wall and roof fragments spall. Caverns, galleries, and other openings may fill rather slowly with such fragments or they may fill suddenly by collapse of the roof or walls, accompanied by slumping and fracturing of the rocks enclosing the openings. Such fragment accumulations are called solution-collapse breccias.

The Josephine Breccia is probably a solution-collapse breccia. A solution-collapse mechanism has been suggested by others as a subsidiary fragment-generating process, supplemental to tectonic brecciation. For example, Park and Cannon (1943, p. 53) write:

> The abundant stylolites in the upper parts of the Metaline Limestone (see pl. 8,A) indicate that appreciable removal through solution has taken place. Slumping of overlying beds, caused by this solution, may account for part of the brecciation, and it is possible that the brecciation has been accentuated by the dissolving action of mineralizing solutions.

and Dings and Whitebread (1965, p. 65) write:

> Locally, the movement of the hydrothermal solutions was probably through fairly permeable ground, as indicated by open and partly filled cavities and caves, and the brecciated character of much of the host rock. Solution collapse and dislodging of fragments by deformation are believed to have accompanied ore deposition.

Contrary to the views of these authors, with regard to the principal brecciation mechanism, the writer believes that the Josephine Breccia closely resembles typical solution-collapse breccias and has indeed formed by solution-collapse. In support of this contention, the typical characteristics of solution-collapse breccias are reviewed below. This is followed by a comparison of these characteristics with those of the Josephine Breccia. Finally, conclusions are drawn as to the origin of the Josephine Breccia.

Characteristics

Solution-collapse breccias may be found in any kind of rock that is soluble or is underlain by soluble rocks. The most common breccia hosts are limestone and dolomite, especially where these have been subjected to extensive karst development. They are quite soluble in meteoric waters, consequently breccias develop in these rocks by collapse of solution-generated openings. Breccias also develop in rocks above soluble carbonates, salt, gypsum, or anhydrite when solution removal of them leads to sagging and slumping of the upper rocks. Breccia masses formed by solution collapse may be coextensive with the soluble sedimentary rocks enclosing or lying below them; hence, they are often very extensive and stratabound. Their shapes range from cylindrical to arched to tabular, but for the most part, they are characteristically irregular branching bodies. Their shape and distribution may exhibit a control by joints or faults.

On a regional scale, they are blanketlike, generally conforming in a broad way with the bedding of the enclosing strata. Their lateral and upper borders usually are gradational, from breccia with disoriented fragments through breccia with fragments showing little rotation, through crackle breccia into slightly fractured to undeformed host rock. These borders may also be fault bounded. The bottom border is likely to be abrupt.

A rude stratification is present in some solution-collapse breccias. It is more likely to be apparent when the breccia is in well-bedded or strongly layered rocks.

Fragments in solution-collapse breccias are angular to subangular, providing they have not been corroded or replaced subsequent to brecciation. They show no sorting whatsoever. The lithology of the fragments of the breccia body is that of the rocks making up the roof or walls of the breccia body. It is quite common for breccia bodies of this kind in flat-lying sedimentary rocks to contain fragments of younger sedimentary rocks from much higher stratigraphic levels. This is one criterion that is useful in ruling out certain other means of breccia formation, like faulting, volcanic explosion, or sedimentation. In many breccias, such as fault breccias or sedimentary breccias, the fragments are grain supported; however, the fragments of solution-collapse breccias are self-supporting and the former interfragment space is filled or partially filled with later minerals, like calcite or quartz, that have been precipitated from solutions that moved through the very porous and permeable breccia mass. These later precipitates often form crystal cockades on the fragments.

The matrix of solution-collapse breccias may be clay or sand that has been carried into the breccia from the roof or walls, or it may be very fine-grained to very coarse-grained crystals of such minerals as calcite, dolomite, and quartz that were precipitated from solutions moving through the breccia.

Solution-collapse breccias are localized by the present erosion surface or by ancient erosion surfaces—unconformities. They also may be localized just above evaporite beds or just above those parts of the stratigraphic section that are known to carry evaporites in neighboring areas and from which, presumably, the evaporites have been dissolved.

A variation of solution-collapse breccia is breccia generated by spalling and collapse of openings created by the dissolving action of mineralizing hydrothermal fluids. Such mineralized breccias developed concomitantly with mineralization are called mineralization-stoping breccias. They possess about the same characteristics as solution-collapse breccias except that (1) they are developed in many kinds of rocks, even granite; (2) they are often localized in regions of volcanism or subvolcanic igneous intrusives; (3) their longest dimensions are much more likely to be more nearly vertical than horizontal; (4) they often show a strong localization by zones of fracturing and shearing; (5) they are more likely to be developed on a local than a regional scale; and (6) their matrix is gangue minerals, with or without ore minerals.

Comparison of the Characteristics

The great extent of the Josephine Breccia, its regional blanketlike form, its near conformability on a regional scale and discordance on a local scale, the carbonate nature of its host rocks, its gradational borders, and its position from a few feet to over 200 feet below a regional unconformity are all characteristics common to solution-collapse breccias. Likewise, the great range in size and unsorted nature of the angular to subangular fragments of adjacent (Metaline Limestone) and overlying (Ledbetter Slate or upper Josephine Breccia shale) strata are what is to be expected of solution-collapse breccia. The several kinds of breccia cement or matrix—black, fine-grained dolomite, jasperoid, and coarse crystalline dolomite or calcite—are compatible with a solution-collapse origin. In fact, the high degree of filling of much of the interfragment space by coarsely crystalline dolomite and quartz with excellent cockade texture is diagnostic of solution-collapse and mineralization-stoping origins, for only such origins would allow for the great amount of interfragment space into which the dolomite and quartz crystals grew. Additional support is provided by the many vugs, often lined with well-formed crystals of dolomite or quartz, or sometimes barite, galena, or sphalerite.

The possibility that the Josephine Breccia was formed by solution and collapse accompanying mineralization by hydrothermal fluid activity cannot be ruled out, but is believed to be a less satisfactory explanation than meteoric water solution-collapse because (1) the breccia seems not to show any localization by zones of fracturing or shearing that might have channelized mineralizing fluids, (2) it is inconceivable that the same fluids that created the cavern system by dissolving dolomite could also be responsible for the precipitation of dolomite to provide the breccia cement, and (3) the attitude and position of the Josephine Breccia is appropriate for dissolution by meteoric waters related to an overlying unconformity.

Conclusion

Though several characteristics of the Josephine Breccia can be accounted for by faulting or by sedimentation, an origin by solution and collapse accounts best for all aspects of the breccia—the distribution, size, and shape of the breccia mass, its gradational borders, the kinds of host rocks, the kind, size, angularity, and means of support of fragments, lack of fragment sorting, the nature of the breccia matrix, and the high incidence of voids or vugs. It is therefore believed to have formed by collapse of a cavern- or karst-system established in the Metaline Limestone, accompanying or following the dissolution of the carbonate rock by meteoric waters.

The conclusion that the Josephine Breccia is of solution-collapse origin is based on a large body of evidence. To go beyond this and suggest the time and conditions that may have led to the development of the karst and breccia is necessarily very speculative, because data are meager. Nonetheless, an attempt is made in the following section to reconstruct events or at least to suggest possibilities.

Unconformities, connected openings, and breccias.—To develop a system of caves and connected openings as extensive as the Josephine Breccia requires the movement of enormous volumes of water through the carbonate rocks. Either sea water or meteoric water could have provided the required volume of fluids, but only meteoric water would be sufficiently unsaturated in the mineral removed in solution. Any appeal to the mineralizing fluids as the dissolving agents is faced with the contradiction of a hydrothermal fluid depositing great volumes of dolomite in places from which it had just dissolved equal or larger volumes of dolomite.

An extensive system of connected openings may have developed during the Middle Cambrian to Middle Ordovician time interval, when uplift could have brought the rocks into the ground-water zone where dissolution of the carbonate rocks by meteoric waters resulted. Later subsidence brought about a marine transgression and an end to cavern development.

Another possibility is that the uplift just referred to did not allow the formation of very large caverns or sink holes but only a network of small connected openings. The limiting of the size of the openings may be attributable to a short duration of uplift or to a rather rapid uplift and active downcutting of the exposed rocks. This was followed by subsidence, deposition of Ordovician muds, their burial and lithification, followed by a second regional uplift with tilting during the middle or late Paleozoic. Erosion exposed the tilted homoclinal carbonate succession, and ground-water recharge areas were established in the more elevated and porous and permeable part of the carbonate section—the part that had been rendered somewhat porous and permeable following the first uplift. In this way, artesian conditions could have prevailed in a carbonate paleoaquifer immediately below the impervious Ordovician shales. In many respects, this model is like that proposed for the Kingsport and Mascot Formations in Tennessee (Harris, 1971). Meteoric water moving through this paleoaquifer was responsible for the increase in number and enlargement of connected openings, leading finally to solution-collapse and breccia formation. Later subsidence and marine transgression brought the processes to an end.

The suggestion that the region was twice uplifted and eroded calls for two unconformities, one of which is the Ledbetter Slate-Metaline Limestone contact. The liklihood of the existence of a second unconformity in the middle or upper Paleozoic rocks has been given some attention by previous authors. For example, Fyles (1959, p. 79) writes:

> Regional studies in the Kootenay arc suggest a mid-Paleozoic unconformity. The unconformity is obscured, however, by subsequent major deformation, which appears to have been that of the late Mesozoic orogeny.

Little (1960, p. 66, 67) identified a hiatus where Lower Jurassic rocks lie above Pennsylvanian(?) rocks in the Nelson Map-area, British Columbia. Dings and Whitebread (1965, p. 23) believe "it is possible that a marked erosional unconformity separates the Silurian and Devonian, and Ordovician rocks . . . ." Yates and others (1966, p. 49) on the basis of the presence of conglomerate in post-Devonian conglomerates of either Mississippian or Pennsylvanian age in the Metaline district, postulate a post-Devonian and pre-Permian "disturbance that need not be other than epeirogenic." And, still later, Yates (1970, p. 30) writes:

> Post-Mississippian sedimentary rocks . . . either were never deposited or, if deposited, were eroded from the area of the Metaline and Northport mining districts.

Support for the idea that the solution-collapse brecciation might be related to a post-Ordovician period of dissolving and brecciation of limestone by meteoric waters is found in the presence of black shale or argillite fragments in the Josephine Breccia at the Pend Oreille mine (Park and Cannon, 1943, p. 73; Dings and Whitebread, 1965, p. 93), the Z Canyon and Z Canyon Mutual mines (Park and Cannon, p. 75, 76), the Bailey property (Dings and Whitebread, p. 70), and the Iroquois, Galena Knob, and Admiral mines in Stevens County. These black shale and argillite fragments are presumed to be Ledbetter Slate. However, at the Neglected mine in Stevens County, no such presumption is necessary because the sulfide-bearing breccia has angular fragments of argillite containing graptolite fossils that identify the fragments as having come from the Ledbetter Slate. These fossiliferous fragments are at least 500 feet stratigraphically below the Metaline-Ledbetter contact on the Neglected mine property. The presence in the breccia of fragments of younger rocks at least 500 feet below their normal stratigraphic position, and the lack of any evidence for faulting, strongly support a solution-collapse origin for the breccia (Schuster, 1976).

Additional field and mine study of the stratigraphic section would be necessary to make a more convincing case for the existence of one or more post-Cambrian unconformities, but it seems to the author that either a post-Cambrian, pre-Ordovician unconformity or a post-Ordovician, pre-Permian unconformity, or both, must exist which played a very important role in the development of an extensive channel system, with accompanying breccia, in the Metaline Limestone just beneath the Ledbetter Slate.

ORE DEPOSITS

GENERAL

Production

There are 98 mining properties in Stevens County in which sphalerite and(or) galena are the principal sulfides. Their locations are shown on figure 5. These are mines and prospects that are valued primarily for their demonstrated or potential value in lead, or zinc, or silver. There are several other mines that have produced or are capable of producing small amounts of lead and zinc and considerable silver, but their principal value is in their content of copper and gold. They are not considered in this report.

The lead, zinc, and silver production of 59 of the 98 properties for which we have data is given in table 4. Of this 59, each of 13 has produced over 1 million pounds of combined lead and zinc. Since 1956, the only producing lead-zinc mines have been the Van Stone and Calhoun.

TABLE 4.—Production of lead, zinc, and silver from 59 properties in Stevens County, Washington[1/]

Mines and prospects	Lead (lbs)	Zinc (lbs)	Lead and zinc (lbs)	Silver (ozs)
A and C	9,484	17,111	26,595	31
Admiral	43,533	1,596,183	1,639,716	668
Advance	10,602	19,271	29,873	71
Aladdin	23,663	.....	23,663	429
Anderson	15,239	.....	15,239	225
Bechtol	249,230	.....	249,230	198
Big Chief	24,595	5,545	30,140	182
Black Rock	140,856	7,903,447	8,044,303	377
Bonanza	24,880,359	230,687	25,111,046	238,485
Bullion	8,253	.....	8,253	115
Burrus	3,155	.....	3,155	1,026
Calhoun	1,740,000	53,650,000	55,390,000	.....
Chewelah Eagle	88,693	.....	88,693	2,166
Chloride Queen	12,261	.....	12,261	1,569
Cleveland	2,700,000	551,170	3,251,170	98,745
Daisy	28,967	.....	28,967	13,978
Deep Creek	15,182,927	65,621,962	80,804,889	36,455
Double Eagle	3,089	.....	3,089	1,625
Electric Point	30,711,917	10,691	30,722,608	7,154
Farmer	15,183	23,624	38,807	71
Frisco Standard	5,973	.....	5,973	2,044
Galena Hill	8,254	.....	8,254	58
Galena Knob	5,900	.....	5,900	8
Gladstone	15,583,187	44,681	15,627,868	9,602
Great Western	434,072	936,524	1,370,596	125
Hi Cliff	9,456	8,140	17,596	81
Iroquois	28,602	97,450	126,052	95
Jackson	181	.....	181	1,318
Jay Gould	42,742	.....	42,742	2,502
Lakeview	2,389	.....	2,389	770
Last Chance	5,937,708	110,110	6,047,818	18,567
Lead King	4,755	.....	4,755	3
Lead Trust	455,945	224,363	680,308	1,507
Legal Tender	214,953	.....	214,953	122,211
Lucile	42,603	25,861	68,464	1,517

1/ No lead, zinc, or silver production data available on 39 properties of the 98 properties listed in figure 5.

TABLE 4.—Production of lead, zinc, and silver from 59 properties in Stevens County, Washington—Continued

Mines and prospects	Lead (lbs)	Zinc (lbs)	Lead and zinc (lbs)	Silver (ozs)
Magma	5,312	.....	5,312	16
Melrose	11,176	.....	11,176	2,973
Middleport	12,652	22,669	35,321	752
Minorca	249,000	.....	249,000	9,259
Morning	10,917	4,898	15,815	1,712
Myeera	8,715	.....	8,715	288
Neglected	7,979	.....	7,979	16
Nevada	1,390	.....	1,390	58
New Leadville	8,216	.....	8,216	16
Old Dominion	744,391	148,563	892,954	342,517
Orazada	7,374	.....	7,374	468
Providence	50,092	.....	50,092	87,442
Red Top	207,371	140,595	347,966	6,339
Santiago	5,385	57	5,442	141
Shoemaker	4,536	9,797	14,333	.....
Sierra Zinc	919,837	5,740,139	6,659,976	29,058
Silver Crown	5,674	.....	5,674	309
Silver Queen	14,148	.....	14,148	262,992
Silver Summit	2,523	.....	2,523	175
Silver Trail	15,553	20,371	35,924	2,916
Tenderfoot	.....	.....	.....	774
United Treasure	30,702	22	30,724	3,783
Van Stone	25,000,000	188,000,000	213,000,000	.....
Young America	939,719	771,629	1,711,348	69,893
Total	126,931,388	325,935,560	452,866,948	1,385,875

All zinc-lead deposits of Stevens County contain varying amounts of sphalerite and galena, and most contain pyrite. Some mines also contain such minerals as argentite, stephanite, boulangerite, stannite, etc., and consequently are silver producers. A ranking of 52 of the zinc-lead deposits for which we have silver production figures is provided by table 5. The ranking is according to the tenor of the ore expressed as ounces of silver per ton. The table also includes the principal minerals other than sphalerite and galena in each of the mines and prospects and the kinds of host rocks. The information on mineralogy was obtained mostly from Huntting (1956), which in turn was obtained almost entirely from macroscopic examination. Consequently the list of known mineral species is by no means exhaustive. There is no reason to question the presence of minerals that have been reported; however, it is very likely that more detailed study of the ores, especially under the microscope, would extend the list of mineral species somewhat.

According to table 5, the range in average silver content, as recorded from mine-production data over the life of each mine, is from practically nil to over 200 ounces per ton. Silver values of more than 1 ounce per ton are associated with quartz veins, most of which are in argillite. Of the 19 quartz veins carrying 10 ounces or more of silver per ton, five contain (in addition to sphalerite and galena) tetrahedrite and no chalcopyrite, three contain chalcopyrite and no tetrahedrite, and 11 contain both tetrahedrite and chalcopyrite. Deposits within the range 2.5 to 0.5 ounces silver per ton include quartz veins, sulfide veins (with or without quartz) and dolomite breccia deposits. None of the three quartz veins within this

TABLE 5.—Fifty-two mines and prospects of Stevens County, Washington, ranked by silver content

Property	Silver, (ozs/ton)	Mineralogy	Host Rocks		
Legal Tender	217	QTC	Argillite		
Jackson	189	QT	Argillite		
Providence	144	QTC	Argillite		
Minorca	103	Q C	Argillite,	limestone	
Silver Queen	98	QTC	Argillite,	limestone	
Morning	90	Q C			Schist
Old Dominion	84	QTC		Limestone	
Chloride Queen	53	QTC		Dolomite	
United Treasure	45	QT	Argillite		
Double Eagle	39	S	Argillite,	limestone	
Melrose	24	QT	Argillite		
Lakeview	19	QT	Argillite		
Myeera	14	QT	Argillite		
Orazada	13	QTC	Argillite,	limestone	
Burrus	13	Q C	Argillite		
Chewelah Eagle	12	QTC		Limestone	
Nevada	12	QTC		Limestone	
Jay Gould	11	QTC	Argillite		
Bullion	10	QTC	Argillite		
Silver Summit	10	QTC			Trachyte
Daisy	9	QTC	Argillite		
Silver Crown	9	?		Dolomite	
Middleport	8	QTC			Granite
Frisco Standard	8	QT	Argillite		
Young America	5	Q C		Limestone	
Lucile	5	QT		Limestone	
Magma	4	BD		Marble	
Cleveland	3.7	QT		Dolomite	
Silver Trail	3.4	Q C	Argillite		
Red Top	2.6	QT		Limestone	
Bonanza	2.3	S	Argillite		
Galena Hill	2.1	Q C			Schist
Neglected	1.8	Br		Limestone	
Aladdin	1.7	Q C	Phyllite,	limestone	

KEY: Q=quartz vein; T=tetrahedrite; C=chalcopyrite; S=sulfide vein; BD=banded dolomite; Br=breccia, ore minerals in matrix

DATA SOURCES: Fulkerson and Kingston (1958); Huntting (1956)

TABLE 5.—Fifty-two mines and prospects of Stevens County, Washington, ranked by silver content—Continued

Property	Silver, (ozs/ton)	Mineralogy	Host Rocks
Last Chance	1.6	S	Dolomite
Galena Knob	1.6	Br	Dolomite
Hi Cliff	1.5	Br	Limestone
Bechtol	1.1	S	Dolomite
Santiago	0.9	Q	Limestone
Big Chief	0.8	Br	Limestone
Lead King	0.6	Br	Dolomite
Gladstone	0.5	S	Dolomite
Sierra Zinc	0.5	BD	Dolomite
A and C	0.3	BD	Dolomite
Lead Trust	0.2	Br	Dolomite
Electric Point	0.14	S	Dolomite
Farmer	0.14	BD	Dolomite
Deep Creek	0.05	BD	Dolomite
Admiral	0.03	Br	Dolomite
Iroquois	0.03	Br	Dolomite
Black Rock	0.02	S	Dolomite
Shoemaker	0	S	Dolomite

range contain any tetrahedrite, though chalcopyrite is present in two of them. Values of 0.5 ounces or less, often very much less, are associated with three types of almost quartz-free zinc-lead deposits in carbonate rocks—sulfide veins, dolomite breccias, and banded marbles.

Classification

The zinc-lead deposits of Stevens County are well suited to a classification based on characteristics, like form and host lithology, that can be readily recognized by even the casual observer. Further refinement is based upon mineralogy and silver content. Such a classification is easy to use and it has, as we shall see, great practical value for exploration and mining purposes as well because it anticipates such important aspects of the deposits as their position, shape, extent, mineralogy, and grade or tenor. It has additional value in that the main classification groups have distinctive means of formation and probably unique ages. The classification, which is followed in this report, is as follows:

1. Quartz vein deposits, in rocks of various kinds and ages.
2. Sulfide veins.
    a. In noncarbonate rocks.
    b. In carbonate rocks of Metaline Limestone of Middle Cambrian age.
3. Concordant zinc-lead deposits in Josephine Breccia of the Metaline Limestone. This is the "Metaline Type" of Fyles (1966, p. 235).
4. Concordant zinc-lead deposits in breccia of the "Yellowhead horizon" of the Metaline Limestone.
5. Concordant metamorphosed zinc-lead deposits in banded limestone marble or dolomite marble of:

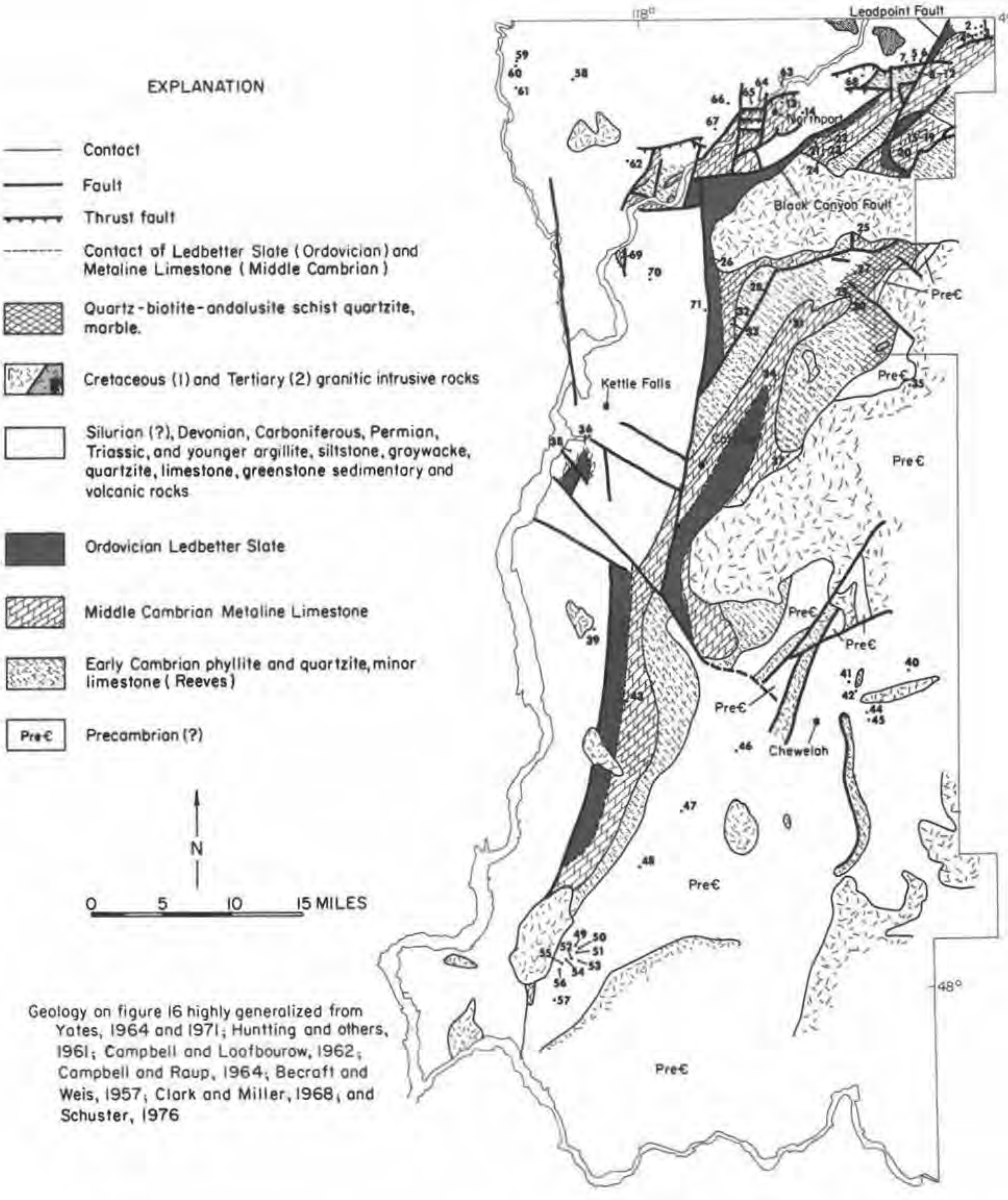

FIGURE 16.—Skeletonized geologic map of Stevens County, showing positions and mineral associations of lead-zinc vein deposits.

MINES AND PROSPECTS SHOWN ON FIGURE 16

T	1.	Frisco Standard
T	2.	United Treasure
T	3.	Myeerah
T=	4.	Keough
T=	5.	Lakeview
T=	6.	Ranch View
T=	7.	Jackson
T	8.	Evergreen
T	9.	Red Top
C	10.	Copper King
C	11.	Anaconda
C	12.	Lucile
?-	13.	Silver Crown
Sd	14.	Cast Steel
Sd	15.	Red Iron
Sd	16.	Wildcat
Sd	17.	Gladstone
Sd	18.	Electric Point
Sd	19.	Keystone
Sd	20.	Bechtol
Sd	21.	Scandia
Sc	22.	Black Rock
Sc	23.	Great Western
Sc	24.	Last Chance
C?	25.	Copper King
C	26.	Silver Trail
C=	27.	Morning
TC-	28.	Galena Farm
C-	29.	Burrus
C	30.	Aladdin
Sd	31.	Galena Knob
TC=	32.	Chloride Queen
Sd	33.	Tenderfoot
Sd	34.	Shoemaker
TC-	35.	Middleport
TC-	36.	Santiago
TC=	37.	Old Dominion
TC=	38.	Ark
TC-	39.	Daisy Tempest
TC-	40.	Winslow
TC-	41.	Jay Dee
TC-	42.	Chewelah Eagle
TC-	43.	Silver Summit
TC-	44.	Jay Gould
TC-	45.	Mullen
TC-	46.	Nevada
S=	47.	Double Eagle
T	48.	Cleveland
TC=	49.	Little Frank
TC=	50.	Legal Tender
TC=	51.	Deer Trail
TC=	52.	Brooks
TC=	53.	Hoodoo
TC=	54.	Silver Queen
TC=	55.	Saturday Night
TC=	56.	Aichan Bee
TC-	57.	Orazada
C	58.	Pomeroy
C?	59.	Perry
C?	60.	Rock Cut
C	61.	Galena Hill
C=	62.	Minorca
TC-	63.	Sunset
TC-	64.	Mountain View
TC=	65.	Providence
TC-	66.	Hubbard
TC-	67.	Bullion
T=	68.	Melrose
C	69.	Young America
Sc	70.	Bonanza
C	71.	Lucky Stone

S Sphalerite and(or) galena veins; minor quartz and carbonate

- c Concordant
- d Discordant

T Tetrahedrite-bearing quartz veins, with sphalerite and galena

C Chalcopyrite-bearing quartz veins, with sphalerite and galena

TC Tetrahedrite- and chalcopyrite-bearing quartz veins, with sphalerite and galena

= Silver, 15 to 200 ozs per ton

- Silver, >5 to <15 ozs per ton

? Possible sulfides in addition to sphalerite and galena

a. The upper limestone unit of the Metaline Limestone; that is, metamorphosed Class 3.
b. The middle dolomite unit of the Metaline Limestone; that is, metamorphosed Class 4.
c. The Reeves Limestone Member of the Maitlen Phyllite.

All members of Class 5 are of the "Salmo Type" of Fyles (1966, p. 235).

QUARTZ VEIN DEPOSITS

The distribution of lead- and zinc-bearing quartz vein deposits is shown in figure 16. They are distributed over the length and breadth of Stevens County in rocks ranging in age from Precambrian to Cretaceous. They seem to favor no particular strike or dip, though most dip at high angles. Some are concordant but most are discordant with respect to the attitude of the enclosing rock. About three-quarters of them are in argillite, phyllite, or schist; most of the remainder are in carbonate rocks, though several are in igneous rocks.

The quartz veins are dominantly quartz, with much lesser amounts of sphalerite and galena, and still lesser amounts of pyrite, chalcopyrite, and tetrahedrite. Some vein deposits contain somewhat less common minerals, such as boulangerite, stannite, stephanite, pyrargyrite, argentite, bornite, pyrrhotite, arsenopyrite, scheelite, siderite, dolomite, and calcite. The mineral constitution of most of the quartz vein deposits considered here was not determined by first-hand observations of the author, though he did confirm some of them by observing hand specimens. Most of the data were taken from previous publications, principally Huntting's report (1956). Very likely a thorough study with the aid of the microscope would provide a more complete mineral inventory, but for our purposes the present listing is adequate.

Although detailed study may suggest otherwise, present indications, arrived at on the basis of a review of published and unpublished literature describing the quartz vein deposits, are that they all formed at about the same time and under the same or very similar hydrothermal conditions. Since several of the deposits are in rocks of late Paleozoic age, several cut lamprophyre dikes and are cut by them, and at least one (Middleport mine) is in granite of Cretaceous age, all are probably relatively young, perhaps early Tertiary. In this and other respects they are very much like silver-bearing quartz veins of southeastern British Columbia (Fyles, 1967, p. 69).

All vein deposits whose locations are given on figure 16, and for which we have assay or production values, average more than 5 ounces of silver per ton, some very much more. Figure 16 also identifies the names and positions of the vein deposits, their host rocks, their major vein-forming minerals, and their range of silver content. Table 5 includes 30 quartz vein deposits for which we have production records (Fulkerson and Kingston, 1958, U.S. Bur. Mines, Inf. Circular 7872). The deposits are listed in order of their average silver content, expressed as ounces per ton. The table also identifies those quartz vein deposits that contain tetrahedrite or chalcopyrite, or both, in addition to the principal sulfides, sphalerite, and galena.

The quartz vein deposits account for about 75, 4.3, and 0.5 percent of all the silver, lead, and zinc, respectively, produced in Stevens County. That is, although their major contribution has been of silver, they have provided substantial amounts of lead as well. Because our concern in this report is largely with zinc-lead ores in carbonate rocks of Cambrian age, it is relevant to point out that at least five quartz vein deposits in carbonate rocks of Cambrian age have produced lead, zinc, and silver; two of these in particular, the Old Dominion and Young America mines, are responsible for approximately 30 percent of all the lead and 40 percent of all the silver produced from quartz vein deposits of all kinds in Stevens County. The five quartz vein deposits in Cambrian carbonate rocks and their production of lead, zinc, and silver are as follows:

Mine	Lead (pounds)	Zinc (pounds)	Silver (ounces)
Young America ...	939,719	771,629	68,893
Old Dominion ...	744,391	148,563	342,517
Red Top	207,371	140,595	6,339
Lucile	42,603	25,861	1,517
Chloride Queen...	12,261	...	1,569
Total	1,946,345	1,086,648	420,835

Other lead- and zinc-bearing quartz vein deposits in carbonate rocks of Cambrian age are the Ark, Galena Farm, Anaconda, Copper King, and Evergreen, bringing the total number of such deposits to ten. Of these, four (Old Dominion, Young America, Chloride Queen, and Ark) are in the Metaline Limestone, or its equivalent, of Middle Cambrian age. The other six are in the Reeves Limestone Member of the Maitlen Phyllite of Early Cambrian age. These ten deposits and their geologic settings are considered in detail in the section of this report entitled Mines and Prospects.

Most of the veins in the quartz vein deposits are only a few inches to a few feet wide, and only those very rich in silver would be likely to arouse any interest today. At any rate, production records suggest that their future production of lead would be small, at best, and their future contribution of zinc would be insignificant.

SULFIDE VEINS IN NONCARBONATE ROCKS

There are only two massive sulfide vein deposits in lead and zinc in noncarbonate rocks in Stevens County—the Double Eagle mine in the Chewelah district and the Bonanza mine in the Bossburg district (fig. 5). The contribution of the Double Eagle mine was very small (see table 3) and no further reference is made to this property. However, the Bonanza mine is appropriately named for it has produced (table 3) almost 25 million pounds of lead, a quarter million pounds of zinc, and 238,485 ounces of silver. That is, this one mine has produced almost one fifth of all the lead and one sixth of all the silver produced in Stevens County.

In view of the major contribution the Bonanza mine has made, a few words about it are appropriate here even though it is not in carbonate rocks and hence, strictly speaking, it does not fall within the scope of this study. The mine, inoperative since 1952, is in secs. 2 and 11, T. 37 N., R. 38 E., about 5 miles southeast of Bossburg. All of the workings have been inaccessible since 1955. The host rock is middle Paleozoic carbonaceous phyllite, argillite, and graphite schist. According to notes and maps of the Division of Geology and Earth Resources, the ore body was a zone of quartz-siderite-pyrite-galena mineralization within and conformable with highly foliated phyllite, beneath a hanging wall of graphitic schist and phyllite. The ore zone was at least 600 feet long on the 4th level, quite sinuous in plan, and its thickness ranged from a few inches to as much as 16 feet. Huntting (1956, p. 238) mentions a new ore body, discovered in 1950, that was 27 feet thick. The sinuous plan view of the ore is a reflection of the many contortions of the deposit. The longer, straighter portions strike about N. 45° W. and dip 25-55° NE. Along the shorter portions or "rolls" the strike ranges from east-west to north-south, and the dip may be as low as 15 degrees easterly. According to some descriptions, the ore zone graded laterally into the black phyllite and argillite, and in these marginal areas the proportion of pyrite and quartz was greater. The impression gained from the geologic map is of an ore horizon that has been folded and then dismembered by many faults striking north-northwest and dipping 50° to 66° E.

Previous authors (Bancroft, 1914; Weaver, 1920; Patty, 1921; and Jenkins, 1924) seemed to regard the deposit as a sulfide replacement of a shear zone. It may well be. However, in many respects it resembles a sedimentary sulfide deposit. Should it have a sedimentary origin, exploration for similar deposits in the area might well be justified.

SULFIDE VEINS IN CARBONATE ROCKS

Sulfide veins in carbonate rocks have yielded approximately 42 percent of the lead, 2.8 percent of the zinc, and 2.6 percent of the silver produced in Stevens County. The following figures gives the total production of lead and zinc and silver through 1956 for the 8 mines that have operated on sulfide veins in carbonate rocks.

Mine	Lead (pounds)	Zinc (pounds)	Silver (ounces)
Electric Point ..	30,711,917	10,691	7,154
Gladstone	15,583,187	44,681	9,602
Last Chance	5,937,708	110,110	18,567
Great Western ..	434,072	936,524	125
Bechtol	249,230	...	198
Black Rock	140,856	7,903,447	377
Galena Knob ...	5,900	...	8
Shoemaker	4,536	9,797	...
Total	53,067,406	9,015,250	36,031

Three prospects, Cast Steel, Scandia, and Tenderfoot, had no production reported through 1956. Production from these prospects since 1956 has not been significant.

A glance at the previous table emphasizes that the lion's share of the lead, zinc, and silver produced from sulfide veins in carbonate rocks has been from mines on Gladstone Mountain (Gladstone, Electric Point), the Black Rock mine, and the Last Chance mine, respectively. All sulfide veins contain relatively little silver; it is always less than 1.7 and may be as low as 0.02 ounces per ton.

All 11 mines and prospects are in dolomite of the Metaline Limestone although they show no preference for any particular stratigraphic position within that formation. All veins are along faults and in highly brecciated rock in and adjacent to fault zones. As a consequence, most are tabular and of regular strike and dip. In such cases the veins may have strike lengths as much as 650 feet (Great Western and Last Chance), and dip lengths of at least 800 feet (Shoemaker). Individual vein widths are generally a foot or two, though widths of as much as 4 feet are not uncommon and composite vein widths within a fault zone may be as much as 7 feet (Shoemaker, Scandia). These more or less tabular veins often have small offshoots or branches along subsidiary fractures. Where two or more mineralized fault zones intersect, fracturing, brecciation, and mineralization may be quite extensive. Ore shoots localized at such intersections tend to be ribbon- or pipe-shaped. The best examples are the many ore pipes on Gladstone Mountain, the most productive of which are in the Electric Point and Gladstone mines. Here, steeply dipping intersecting faults have been mineralized by galena at their intersections, giving rise to nearly vertical pipelike zones, which are circular to oval in plan view, ranging in maximum diameter from 30 to 150 feet and in vertical extent from 150 to 800 feet. These pipes branch downward into separate roots or taper downward and finally wedge out. Branches also extend laterally from the pipes along minor fractures. Similarly, galena is concentrated at fracture intersections in the Bechtol and Tenderfoot properties.

The sulfide veins are notable for their lack, or scarcity, of gangue. Most are massive sulfides diluted only by gouge and fragments of wall rock, though a little quartz (Galena Knob, Scandia, Tenderfoot, Great Western, Last Chance) or calcite (Scandia) may be present. "Red ground," consisting of hydrous iron oxides, clay, lead carbonate, lead sulfate, and dolomite particles, is the matrix for the masses of galena in the pipes on Gladstone Mountain. It is thought that the bulk of the iron in this was derived from the weathering and oxidation of siderite present in the primary ore. In some mines (Bechtol, Galena Knob, Gladstone, Electric Point, Cast Steel) the ore mineral is almost exclusively galena. In others (Great Western, Last Chance, Shoemaker) both galena and sphalerite are present. At the Black Rock mine the ore minerals were dominantly smithsonite (formed by the oxidation of sphalerite) and sphalerite.

Except for some dolomitization at the Scandia mine and silicification at the Great Western and Last Chance mines, there is no perceptible alteration of the wall rocks.

Metamorphism

Repeated movement on the sulfide-bearing faults has generated abundant fault breccia, gouge, sphalerite, mylonite (Shoemaker), gneissic galena (Shoemaker, Cast Steel, Gladstone), slickensided fault walls and fragments. Polished ore specimens from the Admiral, Advance, Black Rock, Gladstone, Great Western, Lead King, and Shoemaker mines were studied by means of the reflecting microscope, both before and after etching. This study revealed that galena and sphalerite tend to occur in two different grain sizes. The coarser one has galena grains as much as 0.80 mm long (Black Rock, Shoemaker) with curved cleavage pits; sphalerite grains are commonly from 1.0 to 2.0 mm across and are deformation twinned. Grains of the coarser size are likely to be somewhat elongate; this is especially true of the galena from the Gladstone mine which has a length: width ratio of about 5:1. Grains of the finer size include equiaxial grains of galena from the Black Rock and Shoemaker mines that average about 0.04 mm across, and equiaxial grains of sphalerite in ores of the Advance, Black Rock, and Shoemaker mines that range in width from 0.005 to 0.25 mm. The smaller grains of galena and sphalerite have well-developed granoblastic polygonal texture with many 120° triple junctions. In addition, the sphalerite has well-formed annealing twins.

These observations indicate that, following ore emplacement and repeated movement of the vein walls, the deformed galena and sphalerite were partially or completely recrystallized and annealed in at least the Admiral, Advance, Black Rock, Shoemaker, Great Western, and Lead King mines. In this respect, these ores resemble those of the concordant metamorphosed deposits in marble that are discussed later in this report. Both differ from some of the quartz veins deposits referred to earlier, like the Old Dominion mine, which on the basis of preliminary studies seem not to have undergone appreciable deformation or annealing since their emplacement.

Origin

The sulfide vein deposits in carbonate rocks are clearly younger than their host rocks, having been introduced into them along fractures. They lack the crustification, depositional banding, replacement, and other textures that are customarily associated with sulfides deposited from hydrothermal fluids. Some of them, especially the Bechtol, Electric Point, and Gladstone mines, probably had siderite accompanying the galena. Others, like Galena Knob, Great Western, Last Chance, and Scandia, have some gangue quartz or calcite. There is some silicification of the wall rocks at the Great Western and Last Chance mines. The presence of gangue and wall rock alteration is compatible with a hydrothermal origin. Possibly the absence of depositional textures referred to above can be attributed to destruction of the textures by the repeated fault deformation to which these veins were subjected.

On the other hand, sulfide veins at the Cast Steel, Tenderfoot, and Shoemaker properties seem not to have any gangue, and one cannot help but be impressed by the thoroughness with which galena fills every available fracture completely, even hairline cracks. In view of the recognized mobility of galena in the solid state (Stanton and Gorman, 1968) when subjected to deforming forces under only moderate temperature and confining pressure conditions, it is tempting to suppose that galena migrated to its present site during the deformation of earlier formed hydrothermal deposits. This suggestion is perhaps more appropriate to those sulfide vein deposits, like Galena Knob and Tenderfoot, which occur near concordant galena-bearing breccia deposits in carbonate rocks. In the Pend Oreille mine in Pend Oreille County, most galena is confined to the breccia matrix but occasionally it follows faults and fractures through any rock type, including typical Josephine Breccia matrix containing disseminated sphalerite, and in this form is clearly later than the sphalerite, according to McConnel and Anderson (1968, p. 1474). Also, Addie (1970) reports that occurrences in the Pend Oreille mine of calcite-quartz gash veins in the ore zone hanging wall directly above the ore sometimes carry sphalerite and galena near the ore.

Another interesting observation about the sulfide veins in carbonate rocks is that, with the exception of the Black Rock mine, they are dominantly galena-bearing rather than sphalerite-bearing. The large proportion of galena as compared to sphalerite can be observed in the field and is reflected by the production figures for the various deposits. They show that the lead to zinc ratio for the sulfide veins in carbonate rocks is about 14:1, whereas for quartz veins it is 6:1, and for the large concordant nonvein deposits in carbonate rocks it is 1:3. Even allowing for the fact that the zinc was not recovered from deposits during the early 1900's, differences in the ratios are surely significant.

From what has just been written about the scarcity of gangue, the known mobility of galena, the degree to which pure galena fills even the smallest fractures, the close areal association of galena veins with concordant galena-bearing deposits and the younger age of the veins, it seems likely that many such galena-rich veins are the products of mobilization of galena from the older galena-bearing concordant deposits. The degree to which such an origin might apply on the one hand and a hydrothermal origin unrelated to the concordant deposits on the other is difficult to assess, because textures generated by dynamic metamorphism and annealing recrystallization have overprinted and generally erased the earlier textures.

From the practical point of view it may not be very important to be able to say whether some or all of the sulfide vein deposits in carbonate rocks were brought to their present site in solution in hydrothermal fluids or in the solid state. Certainly they are epigenetic and localized by faults, fault breccias, and associated lesser fractures. New finds or extensions of known lodes can be expected to have sizes, shapes, regularity, continuity, mineralogy, and other characteristics like those already familiar to us. These and other features of all the known deposits of this kind in Stevens County are given in more detail for each deposit in the section entitled "Mines and Prospects in Carbonate Rocks."

CONCORDANT ZINC-LEAD DEPOSITS IN JOSEPHINE BRECCIA

Introduction

Almost all of the lead and zinc produced to date in Pend Oreille County has come from concordant deposits in Josephine Breccia of the Metaline Limestone, like those of the Pend Oreille mine. However, in Stevens County considerably less than 1 percent of all the lead and zinc produced has come from deposits of this kind. There are 17 such mines and prospects in Stevens County (fig. 6), only 9 of which have any record of production. These 9 and their production (Fulkerson and Kingston, 1955, USBM Info. Circ. 7872) figures are given in the following table:

TABLE 6.—Production from concordant lead-zinc deposits in Josephine Breccia, Stevens County, Washington

Mine	Lead (pounds)	Zinc (pounds)	Silver (ozs.)
Lead Trust	455,945	224,363	1,507
Admiral	43,533	1,596,183	668
Iroquois	28,602	97,450	95
Big Chief	24,595	5,545	182
Advance	10,602	19,271	71
Hi Cliff	9,456	8,140	81
Neglected	7,979	...	16
Galena Knob.....	5,900	...	8
Lead King	4,755	...	3
Total	591,367	1,950,952	2,631

The other mines and prospects for which there are no suitable production figures are A. Anderson, Chloride Queen, Cherry, Michigan Boy, New Leadville, Santiago, Scandia, and Tenderfoot. The A. Anderson, Cherry, Michigan Boy, New Leadville, and Santiago are little more than raw prospects, consequently their assignment to this class of deposits is only tentative.

Characteristics

The sulfide mineralization in this class of deposits is in a dolomite breccia referred to here as the Josephine Breccia. In addition, descriptions and illustrations of the breccia and its sulfide mineralization are given for individual mines and prospects in Stevens County in the section of the report entitled "Mines and Prospects in Carbonate Rocks." Therefore, in order to keep repetition to a minimum, only the outstanding characteristics of the Josephine Breccia and its associated mineralization are abbreviated below.

Summary

1. Size and shape: Known extent is over 25 miles; irregular blanketlike shape; thickness up to 200 feet.
2. Approximately conformable with enclosing strata, though locally discordant.
3. Position: Always within 200 feet of the overlying Ledbetter Slate.
4. Host rock is brecciated Metaline Limestone. It may be the upper limestone, middle dolomite, or the lower limestone unit of the Metaline Limestone.
5. Unsorted angular to subangular fragments of dolomite, black argillite, or chert cemented by dolomite, chert or jasperoid, quartz, sphalerite, galena, and

very little pyrite. Coarse crystalline dolomite is by far the most abundant mineral of the cement. It is generally much coarser grained and lighter in color than the dolomite of the fragments. It frequently displays excellent cockade texture on breccia fragment surfaces.

6. The breccia is essentially continuous but the degree of mineralization by sulfides ranges widely from practically nil to several percent.
7. Sulfides are confined to the cement (matrix) as disseminations or as depositional layers coating early-formed dolomite cement, partially or completely filling the remaining interfragment space. Where filling is incomplete, the vugs may be lined with rhombs of dolomite or euhedral crystals of quartz and(or) galena.
8. The silver content of the ore is always less than 2 ounces per ton and most is less than 1 ounce per ton.
9. Pyrite is present only rarely (for example, the Iroquois mine) and in amounts less than 1 percent. This is in striking contrast to the concordant lead-zinc deposits lower in the stratigraphic section (Yellowhead horizon).
10. Ore bodies are irregular, ranging in size from pods and lenses up to a few feet thick and a few tens of feet wide and long, to masses up to 100 feet thick and several hundred feet long.

Additionally, there are two aspects of the breccia in Stevens County worth recording—the intensity of brecciation and the ratio of galena to sphalerite. At the Lead King, Lead Trust, Big Chief (upper workings), Galena Knob, and Neglected properties, the brecciation seems to be more intense and more widespread than elsewhere. The mineralizing fluids seem also to have been more active here for it is in these deposits that we see some replacement of the breccia fragments and a much greater proportion of coarse white crystalline dolomite cement. Sulfide mineralization may include sphalerite (Lead Trust, Neglected) but galena is the dominant or exclusive sulfide. On the other hand, deposits like the Hi Cliff, Scandia, and Advance contain both sphalerite and galena and may be intermediate in degree of breccia development, although this is quite uncertain because of the relatively small amount of development done on the breccia zone on these properties.

The tendency for the deposits to be rich in one or the other, galena or sphalerite, is borne out to some extent by the mine production figures. The figures for the Admiral and Advance mines are anomalous because much of their production came from mineralized zones outside the Josephine Breccia.

The Josephine Breccia and its associated lead-zinc mineralization in Pend Oreille County possess all of the characteristics listed above for Stevens County, according to the reports by Park and Cannon (1943), Dings and Whitebread (1965), McConnel and Anderson (1968), and Addie (1970). Additional characteristics of the deposits in Pend Oreille County, to be expected but not yet recognized in deposits in Stevens County, are the following:

1. Most galena is confined to the breccia matrix but "occasionally it follows faults and fractures through . . . any rock type, including characteristic Josephine horizon breccia matrix containing disseminated sphalerite, and in this form is clearly later than the sphalerite" (McConnel and Anderson, 1968, p. 1474).
2. Fine-grained sphalerite is reported (Mc-

Connel and Anderson, 1968, p. 1473) to occur within the Josephine horizon in thin laminae and interlaminated with thin-bedded siliceous dolomite "intermingled with irregular breccia masses."

3. Some ore bodies are elongated in channellike shapes that pinch and swell, abruptly branch, change dip or plunge, coalesce irregularly with nearby channels and pods, and erratically develop bulges sometimes of major size above, below, or to either side of the main trend (McConnel and Anderson, 1968, p. 1471).

In a general way the ores follow bedding, but in detail they are crosscutting (Park and Cannon, 1943, p. 50).

Wall-Rock Alteration

Wall-rock alteration is relatively inconspicuous in these deposits in Stevens County. It consists of dolomitization, silicification, and calcitization.

Dolomitization

The upper limestone unit of the Metaline Limestone has been dolomitized at the Big Chief, Hi Cliff, Neglected, New Leadville, and Santiago mines. The product is a fine-grained, gray to dark-gray holocrystalline dolomite. Dolomitization is not confined to those parts of the upper limestone unit that are sulfide bearing or brecciated. It was not determined whether this first-generation dolomite was produced by early forerunners of the later mineralizing fluids or whether the early dolomitization and later mineralization are completely unrelated. The author prefers the second alternative and suggests that the early dolomitization was produced by evaporative reflux or widespread seepage refluxion (Adams and Rhodes, 1960) by hypersaline waters unrelated to the ore fluids. The younger coarser grained dolomite is the product of the ore-forming fluids. Younger coarse, white crystalline dolomite can often be found veining and replacing the gray, finer grained dolomite. Possibly the term "alteration" should be reserved for the substitution of the white, coarse-grained dolomite for the older gray, fine-grained dolomite. Alteration, so defined, is limited to the fragments and immediate borders of the breccia masses in Stevens County. However, it apparently is more pervasive in Pend Oreille County for Dings and Whitebread (1965, p. 53) write:

> At many places crystalline dolomite cuts, replaces or surrounds the older limestones and bedded dolomite of the Metaline, thus, clearly establishing the younger age for the crystalline dolomite. Moreover, crystalline dolomite locally follows, spreads out along, and in places obliterates fractures and faults of post-Cambrian age which offset the gray limestone and bedded dolomite.

It is worth emphasizing that there is a fundamental difference between the extent of dolomitization as viewed by Dings and Whitebread and by the author. The former emphasize the intensity and widespread nature of dolomitization by coarse crystalline dolomite because they regard the extensive ores and associated gangue as having formed by replacement (1965, p. 50). On the other hand, the author regards the ore deposits, including the great volumes of interfragment coarse crystalline dolomite, as filled deposits. Dolomite that has been emplaced by filling of spaces is not wall-rock alteration dolomite. Only replacement dolomite deserves that designation. On these terms, wall-rock dolomitization in these deposits must be regarded as slight.

Silicification

Silicification, with the formation of jasperoid, has taken place in the breccia fragments and breccia margins in a few places, especially in those parts of the breccia that have a microcrystalline quartz matrix (for example, the Pend Oreille mine). Outside the breccia masses, silicification is not pronounced.

Calcitization

Coarse-grained calcite, locally with cleavage surfaces several inches across, is common in mineralized areas. Some of it has filled spaces but some has no doubt formed by replacement and hence deserves to be included in "Wall-Rock Alteration."

Paragenesis of Breccia Ore

Sulfide-bearing breccia specimens from mines and prospects in both Pend Oreille and Stevens Counties were polished to aid in recognition of textural details in order to determine the sequence of mineralizing events following brecciation. It has already been pointed out that the fragments are sharp and angular, though in a few places (for example, the Lead Trust mine) they have irregular borders that grade into the coarse crystalline dolomite of the matrix. For all but these few exceptions, the coarse crystalline dolomite and(or) sulfides were deposited with cockade texture directly on the fragments. The cockade texture, as well as the vugs in the coarse crystalline dolomite lined with dolomite rhombs, quartz crystals, or galena crystals, testify to the deposition of gangue and ore minerals by filling open spaces between fragments.

In most breccias, coarse, white crystalline dolomite was the first mineral deposited on the fragments, followed by sphalerite and more coarse crystalline dolomite, with or without sphalerite and(or) galena and quartz. In a few places, sphalerite was deposited directly on the fragments, followed by the coarse crystalline dolomite with or without sphalerite and(or) galena. Where both sphalerite and galena are present, some of the sphalerite was deposited before the galena. Where the matrix is principally jasperoid, it is accompanied by finely disseminated sphalerite or sphalerite and galena. If galena is the only sulfide present, it is preceded by coarse crystalline dolomite and accompanied by quartz. In a very few places (such as Big Chief, upper workings) galena or galena and quartz may occupy all of the interfragment space.

From these observations it can be seen that the emplacement of coarse crystalline dolomite was essentially contemporaneous with the base metal sulfides. The similarity of the breccia constitution, whether it is developed in the lower part of the Metaline Limestone (a few hundred feet north of the Shoemaker, Cherry), the middle part (Iroquois, Lead King), or upper part (High Cliff), indicates that everywhere brecciation and mineralization operated in brittle rocks at some time following the lithification and dolomitization of the Metaline Limestone.

Metamorphism

The ores of the Josephine Breccia and their enclosing rocks were more or less metamorphosed during times of regional folding, faulting, and igneous intrusion. On the whole the degree of metamorphism is slight and can be recognized only through the study of polished sections of the ores under the reflecting microscope. Such a study was made of the ores of 6 (Admiral, Advance, Hi Cliff, Big Chief, Iroquois, and Scandia) of the 17 Josephine Breccia deposits. For comparison, the study also included specimens from the Grandview and Pend Oreille mines of Pend Oreille County.

The ores of the Grandview and Pend Oreille mines are essentially unmetamorphosed. Most sphalerite and galena occur as large crystals (up to 3.0 mm in diameter), showing only very slight development of deformation twins (sphalerite) or bending of cleavage surfaces (galena). Rarely, sulfide grains are much smaller (about 0.04 mm) and have polygonal shapes (galena) or annealing twins (sphalerite), which indicate (Stanton, 1964, 1972) that the sulfides must have been very slightly deformed and subsequently recrystallized, presumably during the thermal regime when the batholiths were emplaced.

The ores of the Admiral, Advance, Hi Cliff, and Big Chief properties of Stevens County are comparable in degree of metamorphism to those of the Metaline district. They tend to have somewhat better developed annealing twins and polygonal grains of galena, possibly indicating a slightly greater degree of metamorphism than the Metaline ores.

The ores of the Iroquois and Scandia mines in Stevens County are not quite as coarse grained (sphalerite 0.50-1.0 mm; galena 0.05-0.25 mm) as those described above. Some of the sphalerite has well-developed deformation twins, and both sphalerite and galena display equigranular (0.10-0.15 mm) polygonal texture with triple junctions. The higher degree of metamorphism implied by these textures is compatible with their location in completely overturned strata in contrast to the low degree of metamorphism of the Grandview, Pend Oreille, Advance, Hi Cliff, and Big Chief deposits, which are in rocks that are right side up.

Wherever stratiform zinc-lead deposits are found alongside granitic intrusives in Stevens County, they have been so strongly thermally metamorphosed as to have lost most of the characteristics by which we assign them to the Josephine or Yellowhead categories. Therefore, they are categorized as metamorphosed deposits and are treated at some length under "Concordant Metamorphosed Zinc-Lead Deposits in Banded Limestone and Dolomite Marbles." Strongly metamorphosed deposits that the author believes were originally of the Josephine Breccia type are the A and C, Howard, Maki, Plug, and Farmer.

Similar Strata-Bound Zinc-Lead Deposits

The Washington deposits have much in common with so-called Mississippi Valley-type deposits. Descriptions of many such deposits are reviewed by Brown (1967, 443 p.). They also bear resemblances to the zinc-lead deposits of east Tennessee, a review of which is given in Economic Geology, v. 66, no. 5, 1971. The Washington deposits are similar as well to strata-bound lead-zinc ores in carbonate rocks in western Canada, such as those of Pine Point, Northwest Territories, Monarch, and Kicking Horse deposits of British Columbia (Ney, 1954), and the recently developed Robb Lake deposits of northeastern British Columbia. The Robb Lake deposits in particular are remarkably similar to the Washington deposits. They are lead-zinc sulfide open-space fillings confined to "secondary breccias" within a dense gray dolostone (Middle Devonian), overlain by a black calcareous shale. The description of the deposits (Thompson, 1973, p. 19-20), which follows, could just as well be a description of the breccia ores of Washington.

> The breccias appear to be random, disconnected bodies which vary in form, size, and stratigraphic position within the Stone Formation. Internally they are generally composed of loosely packed, angular, dolostone fragments cemented by white, crystalline dolomite, but details of fabric are variable. Characteristically, sphalerite rims the dolostone fragments, whereas galena, which is much more rare, normally forms discrete grains within the dolo-

> mite matrix. Some of the breccia zones are roughly tabular in form and are broadly concordant with regional bedding; boundaries are irregular and often difficult to distinguish.

Thompson attributes the secondary dolomite and sphalerite-galena mineralization to open-space filling from circulating connate and(or) meteoric waters.

Origin

To be acceptable, any theory of origin should be able to account for (1) the lithologic, stratigraphic, and structural control of ore, and the channelways by which the mineralizing fluids reached the sites of mineral deposition; (2) the source of the metals; (3) the source of the sulfur; (4) the source of the mineralizing fluids; (5) the causes of deposition; (6) whether the ores are syngenetic, diagenetic, or epigenetic, and hence whether they have formed by sedimentation, filling, or replacement. Each of these is discussed in the following sections

Ore Control

The reason for the localization of the lead-zinc deposits in carbonate rocks within 200 feet of the overlying Ledbetter Slate has long been enigmatic. Dings and Whitebread (1965), though opting for some fracture control, are unsure of the principal controls, for they write (p. 66):

> The vast bulk of the ore . . . is in and adjoining irregularly shaped bodies of cemented dolomite breccia in which definite structures that might have controlled the emplacement of the ore are notably lacking.

Both Park and Cannon (1943, p. 53) and Dings and Whitebread (1965) interpret the breccias as tectonic (crush) breccias and so they believe the ore localization must have been controlled by major faults. On the other hand, McConnel and Anderson (1968) and Addie (1970) believe that the ores are sedimentary, having been formed syngenetically with the breccia, which they regard as sedimentary. Since all are agreed that the ore is localized by the breccia, the questions of the origin of the breccia and the origin of the ore are bound together. There is no need to review here the discussion on the nature and origin of the Josephine Breccia. The conclusion of that earlier discussion is that the breccia is a solution-collapse breccia formed by the spalling and collapse of paleokarst channels that were localized in the highest part of the Metaline Limestone. The "stratigraphic control" and "lithologic control" are attributed to the fact that the ore-bearing horizons are the first prominent sections of carbonate rocks beneath the unconformity and the overlying shales. The carbonates were both soluble (in meteoric water) and brittle, giving rise in turn to solution openings and brittle fractures yielding abundant angular fragments with high interfragment porosity and permeability. The structural control is the fracturing of the karsted rocks, under the force of gravity, that gave rise to the breccia. The resulting breccia provided the avenues for solution ingress and egress as well as the space for the deposition of ore and gangue minerals.

Source of Metals

The time-honored source for metals of hydrothermal mineral deposits has been magmas, through differentiation. The Kaniksu batholith of northeastern Washington and northern Idaho has been regarded as the parent of the Metaline ores by both Park and Cannon (1943, p. 53) and Dings and Whitebread (1965, p. 68). On the other hand, McConnel and Anderson (1968, p. 1477) believe the ores to be syngenetic or diagenetic in origin; presumably they view sea water as the source of the metals. Addie (1970, p. 78) prefers a syngenetic (sea-water source?) for zinc and a hydrothermal source (magma?) for lead.

In recent years there have been many suggested sources for the lead and zinc of strata-bound and stratiform deposits. One is that the base metals were enriched over the normal concentration in sea water during evaporation at the surface (Geldsetzer, 1973). Another proposed source is the metal adsorbed on clay minerals and other sedimentary particles or metals in detrital sulfides (Beales and Jackson, 1966) from which they were extracted by warm connate brines. Still another suggestion is that the metals were formerly lodged in small amounts in the crystal lattices of minerals of sediments and were released from those sites into the sea water or connate water during diagenesis. One such source of lead may be potash feldspar of arkosic sediments that interacted with sea water at temperatures below 200°C to give up its lead (Helgeson, 1967). Another intriguing idea (Roberts, 1973) is that the metals were released to sea water from Mg-calcite or aragonite as they were changed to dolomite during diagenesis. The dolomite precursor had incorporated the metals as it crystallized from sea water, which had been concentrated by evaporation in shallow restricted basins.

For all theories that propose the concentration of metals in sea water or marine sediments, the ultimate source must have been volcanism or erosion of continental rocks. The latter source is the one preferred by many authors for the base metal mineralization in the Canadian Western Cordillera, of which the deposits of Pend Oreille and Stevens County are the southern extension. Billingsley and Locke (1941) and Sinclair (1964) suggest that the Purcell (Precambrian) strata may have been the immediate source of the lead and zinc. Gabrielse (1969, p. 28) suggested that:

> During the Early Cambrian and Late Proterozoic large volumes of cratonal Precambrian crystalline rocks were eroded. This resulted in the last great contribution of clastic sedimentary rocks to the Cordilleran geosyncline from the craton. Perhaps these sediments contained the metals that were later remobilized and concentrated to produce the base-metal deposits mainly in the Lower Cambrian rocks.

Sangster (1973) reiterated this view and reported that the latest isotopic and lithologic evidence supports it.

These and other suggestions make for interesting speculation but, in fact, the sources of the metals remain conjectural. The situation today is not greatly different from when Fyles (1966, p. 233) summarized it as follows:

> Present knowledge permits us to conclude only that the early sedimentary history may have been the beginning of a cycle of migration and localization of lead and zinc into the highly concentrated zones which constitute ore bodies.

Source of Sulfur

For magmatic hydrothermal deposits it has been traditional to call on the magma for sulfur, as well as for metals and mineralizing fluids. For some deposits it has been suggested (Knight, 1957) that metal-bearing fluids reacted with pyrite of wall rocks, substituting the guest metal for the host metal (iron). That is, iron sulfide of the wall rocks provided the sulfur. In recent years, increasing numbers of North American geologists have questioned the wisdom of assigning the full responsibility to magmas for the heat, fluids, metals, sulfur, and gangue of hydrothermal mineral deposits. The trend has been to share the view of European geologists who have long assigned a large role to sedimentation in the formation of sulfide deposits in sedimentary rocks. Consequently, much more attention is now being given to the likelihood that organic matter directly or indirectly provided the sulfur. By far the most popular proposed sulfur donor is hydrogen sulfide. The hydrogen sulfide is thought to have been generated by anaerobic bacteria in the presence of sea water sulfate or connate water sulfate and organic material under anaerobic conditions. The suggestion is attractive because anaerobic bacteria are ubiquitous in subaqueous reducing environments where organic matter is preserved and because sea water and(or) connate water provide an inexhaustible supply of sulfate.

The sulfur isotope (^{34}S and ^{32}S) ratios for 22 sulfide specimens of zinc and lead ores of northeastern Washington are incompatible with a deep-seated magmatic source for the sulfur. However, they are entirely compatible with a source in sulfate waters (sea water, connate water, evaporite solutions), with anaerobic bacterial reduction of sulfate to H_2S. The metal sulfides retained the sulfur isotope ratio of the H_2S with which the metal-bearing fluids reacted to precipate the metal sulfides. The sulfur isotope analytical data and a discussion of their significance is given in Appendix A.

Supply of Mineralizing Fluid

Mineralizing waters conceivably can be magmatic, metamorphic, connate, sea water, or meteoric water, or some combination of these. As has been pointed out in the preceding section, the popular trend in hypothesizing on the origin of hydrothermal metal sulfide deposits in recent years has been away from magmas, with a consequent devaluation of the fluid, metal, and sulfur contribution formerly assigned to them. This trend has been accentuated by the recognition that fluid inclusions in the ore and gangue minerals of many hydrothermal deposits generally are sodium-calcium-chloride brines, many of which have very high salinity. An excellent review of studies of fluid inclusions from Mississippi Valley-type ore deposits is given by Roedder (1967). He concludes that for these deposits an origin by sedimentary-syngenetic, volcanic exhalative, simple magmatic hydrothermal, and meteoric circulation processes seem to be precluded by the inclusion data; deposition from modified, deep-circulation, heated connate brines is compatible with these data, and is considered to be a satisfactory working hypothesis (Roedder, 1967, p. 349). Although fluid inclusions are abundant in sphalerite from northeastern Washington, their composition has not been determined. In view of the practically universal presence of sodium, calcium, and chloride ion in fluid inclusions from minerals the world over, there is every reason to believe that those from Washington are no different.

Another source of hypersaline brine is the sodium-calcium-potassium-chloride brine which is expelled by compaction of coastal plain (sabkha) sediments (carbonates and evaporites). Such brines can dissolve small amounts of lead and zinc from carbonate rocks through which they pass. They might then migrate to a fluid trap either to react immediately with hydrogen sulfide or await its arrival (Bush, 1970). Alternatively, sea water undergoing evaporation under restricted shallow basin or sabkha conditions would become more saline and metal-rich and denser. Its Mg/Ca ratio would increase as aragonite and gypsum precipitate. Such a brine is capable of moving downward in response to gravity, through porous carbonate rocks, dolomitizing them. Such refluxing brines would be warm and metal-bearing; that is, they would qualify as hydrothermal mineralizing fluids (Geldsetzer, 1973).

Hot brines of a composition approximated by fluid inclusions are known to be good solvents for zinc and lead (Helgeson, 1964; Barnes and Czamanske, 1967) in which the metals are transported as soluble chloride complexes at moderate temperatures.. Even at temperatures as low as 100°C, fluids with compositions compatible with fluid inclusion data—slightly acid, chloride-rich brine with a fairly low sulfate content—are quite capable of transporting and depositing sufficient lead, zinc, and sulfur to form an ore body (Anderson, 1973).

Causes of Deposition

If the mineralizing fluid is a brine of the kind just referred to, then precipitation of lead sulfide and zinc sulfide may be induced by cooling, neutralization, dilution, or by an increase in the amount of reduced sulfur. The source of reduced sulfur is generally thought to be the sulfate of sea water or connate water, which is reduced to sulfide by methane, by organic matter, or by anaerobic bacteria. The last is the reducing agent most often proposed.

One of the earliest and most imaginative models for lead-zinc transport and deposition in carbonate rocks is that of Beales and Jackson (1966). This model calls for the unwatering of shales by compaction during basin evolution. These connate waters escape from the basin shales through the permeable "plumbing system" provided by carbonate rocks. The hypersaline basinal waters, carrying the metals as soluble chloride complexes, precipitated their metal sulfides in the carbonate rocks where they mixed with carbonate formational waters rich in hydrogen sulfide.

Precipitation of galena and sphalerite from brines carrying soluble metal chloride complexes by the addition of sulfide ion is also part of a model proposed by Geldsetzer (1973). However, this model differs greatly from that of Beales and Jackson in the direction of flow and the source of the metal of the circulating brine. The brine of the Geldsetzer model, rather than deriving its metal from the shales and moving up toward the basin margin, derives its metals by evaporation-concentration of sea water in shallow restricted marine environments. This brine, because of its higher density, flows downward through porous and permeable karsted and brecciated limestones. The precipitation of aragonite and gypsum from the surface brine during evaporation resulted in an increase in its Mg/Ca ratio, which led to the dolomitization of the limestone breccia and breccia cement with which it came in contact. The brine also carried metals, organic matter, and a normal population of bacteria, including sulfate-reducing bacteria. These, together with a continuous supply of gypsum formed during dolomitization, resulted in a small but continuous generation of sulfide ions, which combined with the chloride complexes of lead, zinc, and iron to precipitate galena, sphalerite, and pyrite.

Syngenesis, Diagenesis, Filling, and Replacement

During more than 50 years since Bancroft's report (1914) on the ore deposits of northeastern Washington, authors writing about these ore deposits have classified them as epigenetic replacement deposits. Some of the proponents of this point of view are Bancroft (1914), Weaver (1920), Patty (1921), Park and Cannon (1943), Mills (1954), Dings and Whitebread (1965), and Weissenborn (1966). Jenkins (1924) considered the deposits in Stevens and Pend Oreille Counties to be epigenetic, formed both by filling and replacement. Park and Cannon (p. 50) and Dings and Whitebread (p. 69), though recognizing that there was unquestionably some open-cavity deposition of ore, considered the amount to be subordinate to that of replacement.

The first contradiction of the epigenetic replacement origin was published by McConnel and Anderson (1968). They argued for a syngenetic sedimentary origin for the breccia ores of the Metaline district. Later, Addie (1970) partially endorsed their hypothesis by suggesting that sedimentary syngenetic pyrite was replaced by sphalerite during diagenesis, although he ascribed the galena to "much later" (that is, epigenetic) hydrothermal solutions.

A review of the observations and opinions of these various authors, as well as those of the writer, particularly having to do with the Josephine Breccia and the ore it contains, has been given in foregoing parts of this text. These observations conform to criteria for an epigenetic origin, as listed by Snyder (1967), as follows:

1. Mineralization of post-lithification structures, such as solution collapse structures.
2. Extensive open-space filling, vein, breccia, or bedding.
3. Marked changes in height, width, and tenor of ore that cannot be related to sedimentary or diagenetic features or environments.
4. District-wide lack of close control of mineralization by specific sedimentary environments.
5. Presence of J-type lead.
6. Distribution of mineralization relative to tectonic structures.

The last two criteria, strictly speaking, are not directly applicable to the northeastern Washington ores because the lead isotopic composition of the latter are as yet undetermined and the ores show no relation to major faults or fold axes. However, lead-zinc ores in carbonate rocks just north of the Washington districts are known to be of J-type (Sinclair, 1966), and the host breccia of the Washington ores is believed to be a solution- or karst-collapse breccia beneath an unconformity, a "tectonic structure."

It is concluded that the breccia ores are epigenetic and have formed by filling of breccia interstices. In most deposits the role played by replacement processes is inconsequential.

The length of time that elapsed between formation of the breccia and its mineralization by sulfides is not known. However, the author has reason to believe that the ores were introduced prior to folding and prior to emplacement of the Cretaceous granitic batholiths. This is contrary to the view, held by many, that the ores are related to the batholiths. Belief in the pre-batholith age of the sulfide mineralization is based upon the recognition that batholiths have metamorphosed the ores where they are in contact and even intrude them. This evidence is considered in more detail in a later section of this report.

Finally, reference should be made to the scattered irregular streaks and patches and small veins of coarse-grained quartz, calcite, sphalerite, and galena that are to be found (McConnel and Anderson, 1968, p. 1474; Addie, 1970, p. 77) both within and outside the breccia. Also, small veins of galena, with or without quartz, are found infrequently cutting breccia and nonbrecciated carbonate rocks. Their total contribution to lead-zinc production is very small. They are clearly epigenetic, younger than the breccia ore, and have probably been produced by mobilization of the older sulfides during post-breccia ore metamorphism.

Summary

Although we have many facts about the sulfide ores in the Josephine Breccia, there are many gaps in our knowledge and much room for speculation. However, when speculation takes the form of a model against which observations and ideas can be tested, it serves a very useful purpose. Ideally each subsequent model approaches nearer to the "truth." Even if a particular model is itself not closer to the "truth," its statement is likely to lead to comparisons and contradictions that in turn generate new models that ultimately lead to a better understanding. With this in mind, the following series of events relating to the formation of these ore deposits is proposed:

1. Following the deposition of the Metaline Limestone there was uplift, probably accompanied by mild flexing of the strata, and exposure of the carbonate rocks to erosion. Relief on this erosion surface was low but erosion was active enough in places to remove the upper limestone unit, and in other places to remove both the upper and middle units. During this time the near-surface carbonate rocks were rendered porous and permeable by virtue of the many connected pores and larger openings generated by the solvent activity of meteoric waters.
2. The region subsided and great thicknesses of carbonaceous shale were deposited on the old erosion surface (unconformity) during Ordovician time.
3. A second regional uplift during middle or late Paleozoic time was accompanied by tilting of the strata. Erosion exposed the tilted homoclinal carbonate succession, and ground-water recharge areas were established in the more elevated and permeable parts of the carbonate section—the part that had been rendered somewhat porous and permeable during the first uplift. That is, artesian conditions were established in the Metaline Limestone beneath the Ledbetter strata. Meteoric waters moving through this paleoaquifer increased the number and size of the solution openings, leading finally to collapse and breccia formation. Subsidence and marine transgression brought this phase to an end.
4. At the time of the marine transgression, evaporative conditions were established in shallow restricted marine basins; the dense hypersaline brines formed in them flowed down through the limestone paleoaquifer, displacing its contained waters and dolomitizing the breccia fragments and limestone walls by a seepage refluxion process.
5. Subsequently, hydrothermal metal-bearing brines, either from compacting basinal sediments seaward or from evaporating hypersaline waters shoreward, circulated through the breccia depositing sphalerite, galena, coarse crystalline dolomite and other gangue minerals by filling interfragment spaces.
6. Sometime between Early Triassic and Late Jurassic time the strata and their enclosed ores were uplifted, and gently to intensely folded and faulted. In the intensely folded regions tectonites were developed in both rocks and ores.
7. In Late Jurassic to Cretaceous time, granitic magmas were emplaced cutting across and disrupting both sedimentary rocks and ores. The high thermal regime caused thermal metamorphism of the rocks and ores, resulting in partial to complete recrystallization and annealing of the deformed rock, gangue, and ore minerals.

Except for a small amount of later faulting and final uplift and erosion that led to their exposure today, this brought to a close the events that had any material affect on the lead-zinc ore deposits.

CONCORDANT ZINC-LEAD DEPOSITS IN BRECCIA OF YELLOWHEAD HORIZON

Introduction

As mentioned previously, the Yellowhead horizon of the Metaline Limestone is a zone in the middle dolomite unit, anywhere from 500 to 1,200 feet below the top of the formation. Typically this horizon is a breccia mineralized with abundant pyrite, sphalerite, a little galena, coarse crystalline dolomite, and often very fine-grained quartz or jasperoid. The horizon derives its name from the Yellowhead mine, Pend Oreille County, the geology of which has been described in detail by Morton (1974). Some of the outstanding textural characteristics of the ores of the Yellowhead mine are given in table 7. Other deposits of similar kind in Pend Oreille County are the Flusey, Lucky Strike, Riverside, and Lakeview prospects.

Origin of Breccia Host and Ore

Sulfides in all these deposits are in the matrix of a dolomite breccia, which in most respects—distribution, form, gradational borders, unsorted angular fragments, sparry dolomite matrix, and other features—is very much like the Josephine Breccia and other solution-collapse breccias. The most obvious differences between the Yellowhead breccia and the Josephine Breccia are their stratigraphic positions and the universal presence of abundant pyrite in the former. Everything points to the Yellowhead breccia being a solution-collapse breccia but as yet no unconformity or former evaporite horizon to which brecciation might have been related have been identified within the Metaline Limestone. Therefore, the reason for the localization of the breccia within the middle dolomite unit of the Metaline Limestone is not understood.

Like the Josephine Breccia, the breccia of the Yellowhead horizon was porous and permeable so that later warm metal-bearing fluids circulated through it, depositing the dolomite matrix and the sulfides. The mineralizing fluids, which circulated through the Josephine and Yellowhead breccias, were much alike and may even have come from the same source.

Calhoun Mine

The only representative of this class in Stevens County is the Calhoun mine, the third largest producer of combined zinc and lead in Stevens County, after the Van Stone and Deep Creek mines. The sulfide mineralization at the Calhoun mine has been only moderately affected by regional metamorphism and not at all affected by thermal metamorphism. In this respect, the ores of both the Yellowhead and Calhoun mines differ greatly from their strongly metamorphosed equivalents, such as the Deep Creek and Van Stone mines. The metamorphosed ores of the Yellowhead horizon are described elsewhere in this report.

An account of the geology of the Calhoun mine has been prepared for this report (see under "Mines and Prospects") by James Browne, geologist, Day Mines, Wallace, Idaho, formerly geologist at the Calhoun mine. The similarities between the ores of the Calhoun mine and other deposits of the Yellowhead horizon in Pend Oreille County are quite striking and include the following: (1) the position within the middle dolomite unit of the Metaline Limestone, (2) the localization of sulfides in the matrix of a dolomite breccia, (3) the sparry dolomite breccia matrix and associated pyrite, sphalerite, and galena, and (4) the many ore mineral textures indicative of filling—

botryoids, colloform banding, nodular pyrite, and others. In fact, except for stratigraphic position, the ores of the Calhoun and other mines of the Yellowhead horizon are very similar to those of the Iroquois mine (see "Mines and Prospects").

Though the ores of the Calhoun mine share characteristics with other deposits, they have several characteristics that seem to be unique and somewhat puzzling. These include the following: (1) the platy nature of most of the breccia fragments and their strong parallelism, giving rise to the prominent planar fabric characteristic of the host rock (fig. 17), (2) the overall discordant attitude of this planarity or layering with respect to the attitude of the host rock zone as a whole and with respect to bedding in both the footwall and hanging wall, (3) the draping of host rock layering over irregular breccia blocks (fig. 18), (4) the elongate ribbonlike or rodlike shapes of the ore shoots and their gentle plunge to the southwest, and (5) the sheetlike extensions of host rock breccia into the hanging wall.

FIGURE 17.—Host rock dolomite breccia of Calhoun mine, showing typical elongate dolomite fragments in slightly coarser grained dolomite matrix. Parallel arrangement of elongate fragments gives rock a platy character or rough foliation. Note that the foliation in the matrix at point of white arrow parallels the overall platy fabric and does not conform to the border of the large subjacent dolomite fragment. This strongly suggests that the platy fabric is metamorphic, not sedimentary or diagenetic. Scale is in inches.

FIGURE 18.—Strongly developed planar fabric in dolomite breccia of the host rock zone, Calhoun mine. The draping of this layering over the convex side of the large dolomite fragment is interpreted as being metamorphic in origin rather than diagenetic (differential compaction). Sulfides are confined to the cement or matrix. Scale is in inches.

An Alternative Origin

The ores of the Calhoun mine are considered by Browne (see "Mines and Prospects") to have formed by filling of spaces between breccia fragments, with minor replacement of breccia cement. The host-rock breccia he believes to be a sedimentary breccia produced by compaction and slumping of coarse clastics accumulated on the steep front of a carbonate reef. According to this theory, the strong planar fabric of the host rock zone is a depositional feature; that is, bedding. However, the reef front breccia theory raises many questions, not the least of which are (1) the lack of reef structures in the middle dolomite of the Metaline Limestone here or elsewhere, (2) the striking and complete lack of sorting of fragments, (3) the highly platy and elongate shape of most of the fragments, and (4) the concentration of ore mineralization into long, narrow, gently plunging ore shoots within steeply inclined breccia.

An alternative theory is that the breccia of the Calhoun mine is a solution-collapse breccia like that of the Iroquois mine in Stevens County and many mines in Pend Oreille County. However, unlike the deposits in Pend Oreille County, the rocks of the Calhoun mine and in the surrounding district have been folded at least twice and have been completely overturned at the Calhoun mine. Thus, it is argued here that the pronounced layering and banding of the host rock zone and the greatly elongated and parallel orientation of breccia fragments are the result of regional metamorphism. The planar fabric probably is an axial surface foliation developed at the time the strata were folded.

The following observations and explanations are compatible with this theory:

1. Many of the breccia fragments have length:thickness ratios of as much as 10:1. Some are lenticular and many are fusiform, rod shaped, and ribbon shaped (fig. 17); shapes commonly assumed by cobbles and fragments in regionally metamorphosed rocks.
2. The attitude of the planar fabric of the host rock with respect to the attitude of the hanging-wall stratification is compatible with the fabric being axial surface foliation in the overturned strata. Furthermore, the intersection of the foliation with the bedding plunges about 10° SW., parallel to the plunge of fold axes in the Leadpoint area.
3. The direction and plunge of the ore shoots are parallel to the intersection of the foliation (planar fabric) of the host-rock zone and bedding of the hanging wall. Parallelism between ore mineral concentrations and metamorphic lineation is a widely recognized phenomenon in metamorphosed ore deposits.
4. The ores of the Calhoun mine, though retaining many of the primary depositional textures, have other textures (see table 7) that are metamorphic in origin.
5. The fact that foliation is only weakly developed or lacking in the footwall and hanging-wall rocks is because the rocks of the footwall and hanging wall, though they display some color banding, are remarkably homogeneous in chemical composition, mineral composition, and texture. They are not of a kind to develop an obvious foliation during regional metamorphism. However, the rocks of the host-rock zone, composed as they are of carbonate rock fragments of a great variety of shapes and sizes, would have responded readily to dynamic stresses by rotation, cataclasis, solution, and redeposition, resulting in the pronounced fragment elongation and par-

allelism that gives the rock its distinctive appearance. The somewhat gradational nature of the footwall-host rock contact, in which the brecciation of the host rock is often seen to extend into the footwall rocks, may be attributed to the slightly and irregularly brecciated nature of parts of the footwall rocks adjacent to the host-rock zone.

6. Draping of host rock "bedding" over the larger angular fragments of hanging-wall rock (fig. 18) was brought about by plastic flow during deformation, rather than by differential compaction of carbonate sediments.

It is the author's contention that the sulfide ores of the Calhoun mine, like many others in northeastern Washington and southeastern British Columbia, were already in place in the carbonate breccias at the time of regional folding and metamorphism. The ores were deformed along with their host rocks. Some of the sulfides may have been mobilized differentially, but not sufficiently to move them out of the breccia matrix where they were initially emplaced. The Calhoun ores and rocks probably represent a stage of metamorphism of Yellowhead mineralization between two extremes. Thus, the ores of the Yellowhead mine would represent the unmetamorphosed end member and the ores of the Deep Creek mine the strongly metamorphosed end member. Possibly the foliation and layering at the Deep Creek mine is the end result of regional and thermal metamorphism of a mineralized solution-collapse breccia (fig. 19), where the sulfides are concentrated in streaks and bands not far removed from their original interfragment positions. The ores and breccia of the Calhoun mine were regionally but not thermally metamorphosed, and hence both sulfides and breccia have retained enough of their original textures and patterns of distribution as to appear quite different from the rocks and ores of both the Yellowhead and Deep Creek mines.

FIGURE 19.—Prominent banding or layering of zinc ore of Deep Creek mine. Light-gray and gray bands are dolomite. Dark-gray to black streaks and bands, as at arrow tips, are sphalerite and pyrite. Scale in inches.

Exploration

Ores of this kind, like many others in this part of Washington, are localized in dolomite breccias within the middle dolomite unit of the Metaline Limestone. The presence of abundant pyrite or its oxidation products, with or without base-metal sulfides, always deserves further attention. The localization of sulfides within the matrix of a dolomite breccia confirms the identification and leads to a concentration of effort on the breccia and its extensions. If, like the Calhoun, the breccia is composed of elongate parallel fragments giving the breccia body a distinct foliation, it may be expected that base-metal concentrations or ore shoots will lie within the plane of the foliation and will plunge in a direction and at an angle equal to (1) the plunge of the intersection of the foliation and bedding, (2) the plunge of the most obvious (second stage?) folds in the area, and (3) the direction of elongation of the fragments.

CONCORDANT METAMORPHOSED ZINC-LEAD DEPOSITS IN BANDED LIMESTONE AND DOLOMITE MARBLES

Introduction

Unlike the mines of Pend Oreille County in which production has come from relatively unmetamorphosed ores, several of the most important zinc-lead mines in Stevens County have host rocks and ores that have been intensely metamorphosed, both by regional and thermal metamorphism. There are no production figures for 8 of the 14 deposits in this class in Stevens County. These are Howard, Maki and Dosser, Plug, Chollet, New England, Longshot, Lucile, and Red Top. The first six of these are essentially prospects and may have had no production. The last two, Lucile and Red Top, have produced lead and zinc but no distinction has been made between production which came from the metamorphosed concordant parts of the deposits and that which came from quartz veins. The six important mines that have produced zinc and lead from metamorphosed ores are shown here, along with their production.

	Lead (lbs)	Zinc (lbs)	Silver (ozs)
A and C	9,484	17,111	31
Farmer	15,183	23,624	71
Subtotal	24,667	40,735	102
Deep Creek...	15,182,927	65,621,962	36,455
Van Stone	25,000,000	188,000,000	......
Magma.......	5,312	....	......
Subtotal	40,188,239	253,621,962	36,455
Sierra Zinc ...	919,837	5,740,139	29,058
Total	41,132,743	259,402,836	65,615

Characteristics

These deposits are found near the borders of the granitic plutons (see fig. 5) in dolomite marble or calcitic marble that is highly banded, white, gray, and dark gray, medium- to coarse-grained, and complexly folded. These marbles are regionally and contact metamorphosed: (1) upper limestone unit of the Metaline Limestone (A and C, Howard, Farmer, Plug, Dosser and Maki mines); (2) middle dolomite unit of the Metaline Limestone (Deep Creek, Van Stone, Magma, Chollet, and New England mines); and (3) the Reeves Limestone Member of the Maitlen Phyllite (Sierra Zinc, Longshot, Lucile, and Red Top mines).

The bands or metamorphic rock layers vary from a fraction of an inch to a few feet in thickness, and from a few feet to a few tens of feet in length. In some places they have remarkably regular strikes and dips, whereas in other places, for example at the Sierra Zinc and Van Stone mines, they curve, bifurcate, or have strongly convolute foldlike forms. Where in a given area they are convolute, the various convolutions have the same plunge throughout the area, and this plunge is parallel to the plunge of folds in beds. In some areas, as at the Van Stone mine and the bottom level of the Deep Creek mine, the marble is very siliceous and tremolitic. Tremolitic marble and tremolite-sulfide intergrowths are well displayed at the A and C, Howard, Farmer, Deep Creek, Van Stone, and New England mines. The tremolitic and(or) siliceous parts of the marble have a configuration like that of the bands of the marble (Van Stone mine).

Where the host rocks have been regionally metamorphosed but not very strongly contact metamorphosed (Maki and Dosser, New England, Deep Creek), the carbonate grains are elongate and parallel. The direction of elongation tends to lie within the plane of the banding. That is, the rock is a tectonite. Where contact metamorphism has been more intense, the constituent grains, including the base metal sulfides, are about equigranular with polygonal shapes (under the microscope) and well-formed triple junctions where three polygonal grains meet.

Ore Deposits

The sulfide (sphalerite, galena, with or without pyrite, and pyrrhotite) mineralization in the banded marble occurs as disseminated grains, streaks, lenticles, rods, elongate clusters, lenses, and veinlike masses arranged with their long or tabular dimensions in the plane of the banding. Individual sulfide grain clusters or lenses or veinlike masses may have a foldlike shape or distribution pattern (fig. 20). The scale of the sulfide lenses and masses is comparable to that of the bands in the marble; that is, they vary from a fraction of an inch to a few feet in thickness, and from a few inches to several tens of feet in length. Where the parallel lenticles, clusters, and lenses of base metal sulfides are separated by equal or greater thicknesses of barren marble, the grade of the ore is low. Where the clusters, lenses, and masses are large, closely spaced, and relatively continuous the grade is high. In some mines (for example, Deep Creek), the larger tabular masses of sphalerite are as much as 5 feet thick and several tens of feet long. Most often the individual sulfide masses or lenses are much smaller than this, but where they are sufficiently numerous and closely spaced they may constitute ore bodies as much as 300 feet thick and over 1,000 feet long (Van

FIGURE 20.—Foldlike patterns exhibited by sphalerite(s) in light-gray, coarse-grained dolomite(d) of host rock zone, Calhoun mine.

Stone mine). Ore bodies make up only a small part of the entire mineralized zone and their boundaries are "assay walls." Occasionally the sulfide masses and the ore bodies of which they are a part have shapes that resemble the hinge areas of folds. That is, they are horseshoe-shaped (Deep Creek mine) like the hinge of a fold, with limbs of ore thinning as they extend away from the hinge area. These limbs, as well as other more or less tabular ore bodies, may die out by branching and becoming very ragged, or by a gradual wedging out of the mass, or by a gradual increase in the Fe:Zn ratio. On the bottom level of the Deep Creek mine, not only was the sphalerite content less than on other levels, but the host became very siliceous and highly refractory, thereby raising the mining costs and the grade of sulfide mineralization that could be considered as ore. Ore bodies may plunge very gently, as at the Van Stone mine, or very steeply to vertically, as at the Deep Creek mine. It is thought that the plunge of the ore shoots is parallel and related to the folds in the enclosing strata. The ores show no localization by faults. Although faults are very common in the Deep Creek and Van Stone mines, they brecciate and displace the ores and are clearly younger than the ore.

In the ore zones, the most abundant sulfide is sphalerite. It is black to brown to light brown or yellow in color. In many places the dark brown to black sphalerite grains or grain clusters have pale yellow rims. This type of sphalerite is generally found closely associated with pyrrhotite (Farmer, Van Stone). The explanation for this association may be that the pyrrhotite was formed by sulfidization of iron in the black (iron-rich?) sphalerite. The source of the sulfur and the heat energy that favors such a reaction may have been the granitic intrusives. In support of this theory is the recognition that the pale yellow sphalerite has better polygonal texture than does the black sphalerite. Probably the heat accompanying the intrusion promoted the recrystallization and grain growth of the sphalerite, generating the polygonal textures diagnostic of annealing.

Galena may be found in small amounts enclosed in pyrite masses as thin scalloped layers parallel to depositional banding or growth zones of pyrite and adjacent sphalerite. Such depositional textures are preserved only in galena enclosed in pyrite that has buttressed the galena from the ravages of regional metamorphism. In a very few deposits, galena occurs in aggregates of elongate grains where the ratio of length to width is as much as 5:1. These elongate grains are about parallel to the metamorphic banding, suggesting that their orientation can be credited to regional metamorphism. Where late faulting has caused cataclasis of pyrite, galena is found as a matrix for the pyrite fragments. Apparently under the conditions of regional metamorphism, galena is very mobile and migrates by solid flow to areas of lower pressure.

The susceptibility to solid flow exhibited by galena is well known (for example, see Gill, 1969, McDonald, 1970, and Salmon, Clark, and Kelly, 1974). It is to be expected that during the deformation of mixed sulfides, galena will move more readily than sphalerite and sphalerite will move more readily than pyrite. Due to their different susceptibility to mobilization, one would expect that mixed sulfides, under appropriate temperature and pressure conditions, would be separated in space into their mineral components. Although it is recognized that galena can be mobilized, there is no agreement as to the distance it may travel. The author has observed that pure galena fills even the smallest fractures subsidiary to galena-rich veins (Cast Steel mine); and (McConnel and Anderson, 1968, p. 1474) remark that:

> . . . galena follows faults and fractures through any rock type including typical Josephine Horizon breccia matrix containing disseminated sphalerite, and in this form is clearly later than the sphalerite.

Furthermore, with regard to the mobility of galena, it is interesting to note that for Stevens County zinc-lead ores the ratio of lead:zinc in the concordant nonvein deposits in carbonate rocks is 1:3, whereas the ratio of lead:zinc in massive sulfide veins in the same carbonate rocks is 15:1. Is this a reflection of the mobility of galena? Are the galena veins the result of metamorphic differentiation and differential mobilization of galena? The answers to these questions are yet to be found.

The mineral that is the best indicator of the character of the deposits before they were deformed is pyrite. It is relatively scarce in the A and C, Howard, Farmer, Plug, and Maki mines because prior to metamorphism these deposits were of the Josephine Breccia type which characteristically contain very little pyrite. However, in the Yellowhead and Sierra Zinc types, in the metamorphosed middle dolomite unit of the Metaline Limestone and in the Reeves Limestone, respectively, pyrite is abundant both before and after metamorphism. In fact, it is the high pyrite content of the ore at the type Yellowhead mine in Pend Oreille County that gives the ore the yellow color implicit in its name. In these deposits, pyrite is the most widespread of all sulfides, generally extending far beyond the zinc-lead rich sections in all directions.

Pyrite, even when subjected to stress under conditions of very high confining pressure and temperature, is much more likely to resist deformation or behave in a brittle manner and to break than it is to deform plastically. As a result, in a mixed sulfide aggregate subjected to metamorphism, primary textures in coexisting sphalerite and galena are destroyed but primary textures in pyrite may be preserved. Such texture preservation is well shown by pyrite from several deposits in Stevens County. Typical primary textures observed in polished sections of ores from metamorphosed deposits include the following:

1. Thin fine-grained pyrite layers interlaminated with equally thin layers of dolomite and sphalerite, often scalloped.
2. Pyrite crystal aggregates enclosing curving linear arrays of sphalerite and(or) galena blebs, probably representing a more metamorphosed stage of 1 (figs. 21, 22, 23, 25, 26).
3. Hemispherical shells composed of pyrite columnals with their long axes oriented radially (fig. 24); sometimes blebs of sphalerite are distributed radially also.
4. Crusts of mixed granular and columnar pyrite crystals with well-formed crystal faces on their distal ends and well-developed growth zones (visible after etching) parallel to the crystal faces (figs. 24, 26).

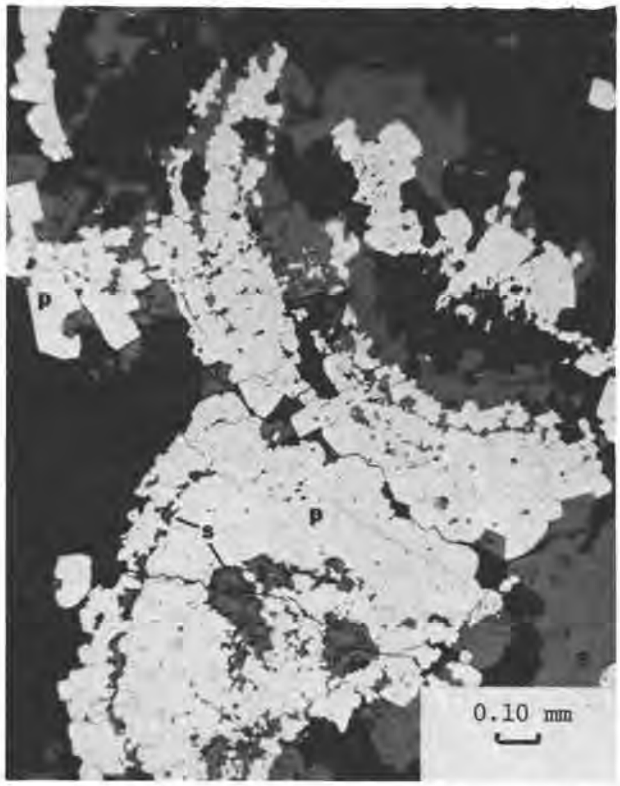

FIGURE 21.—Polished section of ore from Calhoun mine, showing botryoidal aggregates of pyrite(p) crystals surrounded by and enclosing sphalerite(s) in irregular linear arrays paralleling botryoidal structure of pyrite. Outside the pyrite crystal aggregates are a few larger euhedral pyrite metablasts. Host dolomite appears black in reflected light.

5. Relatively coarse euhedral pyrite crystals enclosing sphalerite-galena linear arrays that are parallel to pyrite faces (fig. 27).

The similarity of these textures to those in the pyrite of the Yellowhead mine (Morton, 1974), the Calhoun mine (Browne, see "Mines and Prospects"), and some of the nodular pyrite from the Salmo district (Mills, 1974) is quite striking. The textures are indicative of a primary hydrothermal deposition at low to moderate temperatures and shallow depths by

FIGURE 22.—Exceedingly fine-grained intergrown and interlayered pyrite(p) and sphalerite(s) surrounded by very much coarser grained granular pyrite (upper right quadrant). Very coarse pyrite porphyroblasts (lower left) and dolomite (black). The fine-grained, banded texture is a relic of original depositional texture. Equigranular and porphyroblastic textures in pyrite are products of metamorphism. Polished section of Calhoun mine ore.

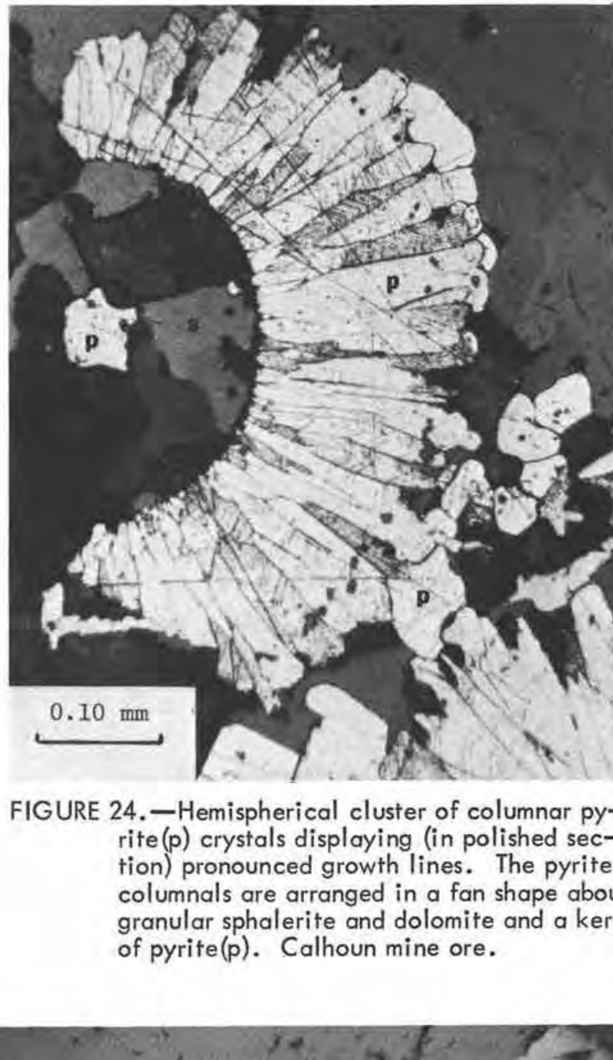

FIGURE 24.—Hemispherical cluster of columnar pyrite(p) crystals displaying (in polished section) pronounced growth lines. The pyrite columnals are arranged in a fan shape about granular sphalerite and dolomite and a kernel of pyrite(p). Calhoun mine ore.

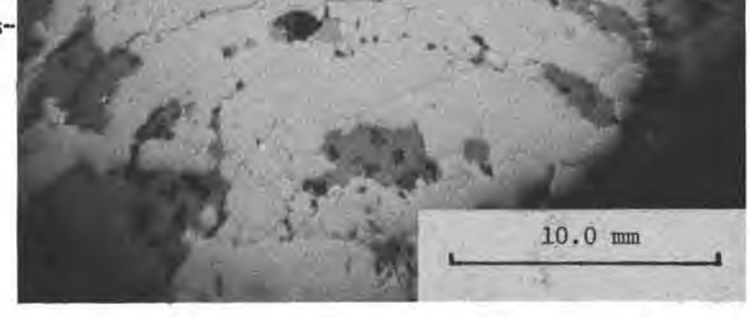

FIGURE 23.—Polished section of sphalerite(s) and pyrite(p) ore from Van Stone mine. The discontinuous parallel arrays of sphalerite are relics of the original depositional layering of the sulfides. This relic "fragment" of pyrite-sphalerite is surrounded by coarser grained equigranular sphalerite.

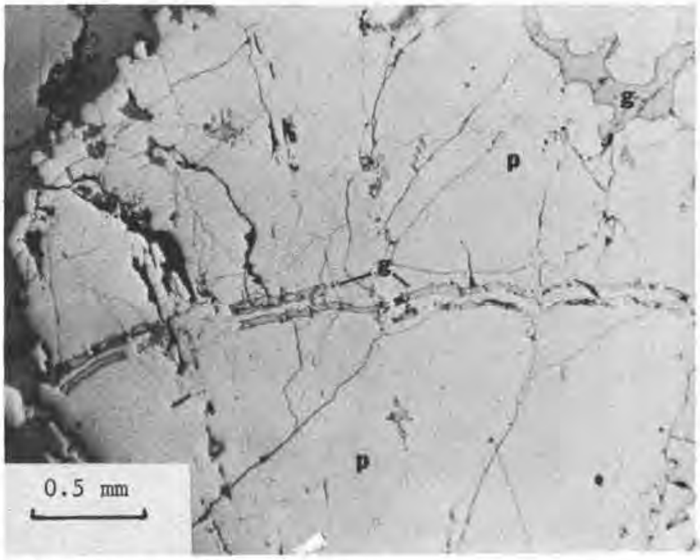

FIGURE 25.—Polished section of coarsely crystalline pyrite(p), enclosing twin scalloped layers of galena(g). The coarsely crystalline nature of the pyrite and the relation of the twin galena layers to growth zones in the pyrite are brought out by etching and are illustrated in figure 26. Van Stone mine ore. Photo by Tom Neitzel.

FIGURE 26.—Polished and etched section described in figure 25. Etching brings the coarse-grain size and tapered columnar form of the pyrite, growth zones in the pyrite, and the parallelism of the galena layers (at arrow tips, galena destroyed by pyrite etchant) with the growth zones of pyrite. This demonstrates that the galena bands are not veins but are layers deposited on pyrite crystals during some intermediate growth stage. Van Stone mine ore. Photo by Tom Neitzel.

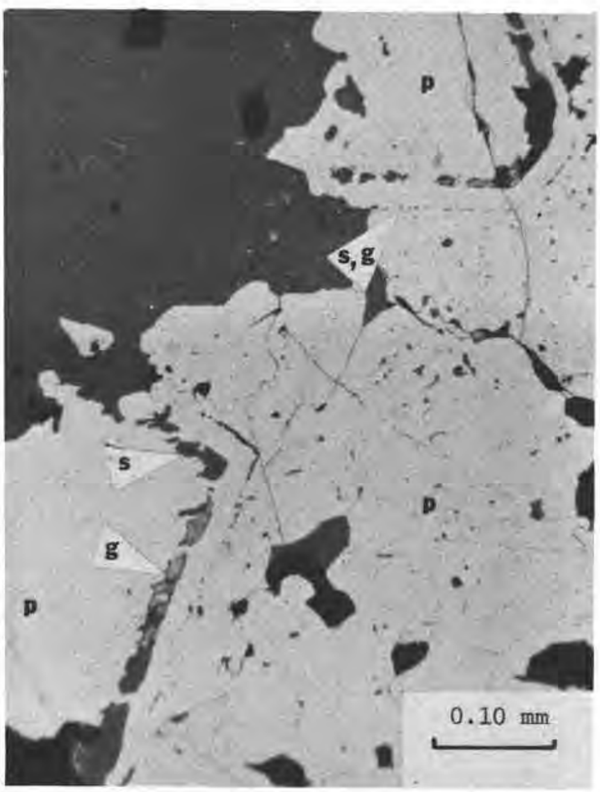

FIGURE 27.—Polished section of sphalerite (upper left) and pyrite(p) of two kinds. One pyrite contains many scattered small inclusions of sphalerite and dolomite, giving pyrite a faintly speckled appearance. The other kind of pyrite (lower left and upper right) takes a better polish, is much coarser grained, and markedly euhedral. It contains inclusions of sphalerite(s) and galena(g) and dolomite (black), not randomly scattered through the crystal, but highly organized into somewhat discontinuous layers parallel to crystal faces. Calhoun mine ore.

space filling, not by replacement. They are compatible with a primary origin by deposition in the interfragment space of a breccia.

Metamorphism

As indicated above, the ores of this class were quite different formerly from what they are today. Initially they probably resembled the ore types we find today in the Josephine Breccia (Pend Oreille mine) and in the breccia of the Yellowhead horizon (Calhoun mine). Since their formation as hydrothermal breccia-filling deposits, they have been metamorphosed and have assumed a different aspect. That the ores were deformed during regional metamorphism and partially or completely recrystallized and annealed during later heating by intrusive activity is indicated by the following summary of characteristics of the metamorphosed ores:

1. Sulfide aggregates occur as streaks, lenses, and bands about parallel to the foliation or banding of the enclosing metamorphic rocks.
2. Many of the sulfide masses and ore bodies are elongate in a direction parallel to metamorphic lineation.
3. Some sulfide masses are fold-shaped, with thicker crests or troughs than limbs; hinge areas plunge parallel to lineation and fold axes of the metamorphic host rocks.
4. Galena, sphalerite, and some pyrite grains often have lengths several times their widths, and their long dimensions are approximately parallel to the longest dimension of the carbonate grains of the host.
5. Sphalerite commonly displays deformation twins (figs. 28, 29) and some of these are bent.
6. Bending of galena cleavage planes is observed in galena-bearing ores that have been only slightly metamorphosed.
7. Galena often tends to be concentrated in dilatant zones, such as cataclastic pyrite breccia, fold hinges, and small fractures in ores and host rocks.
8. Annealing twins are common in sphalerite (figs. 30, 31).
9. Granoblastic polygonal texture, with well-formed 120° triple junction points, is

FIGURE 28.—Chalcopyrite(cp) concentrated along deformation twin lamellae in sphalerite. Undeformed sphalerite from the Sierra Zinc mine seldom displays chalcopyrite; therefore it is thought that the chalcopyrite is an exsolution product, the unmixing having been triggered by deformation of the solvent sphalerite. Textures brought out by polishing and etching of zinc ore from Sierra Zinc mine.

common and well developed in galena (figs. 31, 32), sphalerite (fig. 30), pyrrhotite, and very rarely in pyrite. This texture is common in the carbonates and quartz of the enclosing rocks also.

10. Where galena is the minor phase in sphalerite-galena aggregates, the galena occurs as triangular or cuspate patches in polished sections, clearly localized along sphalerite grain boundaries.
11. Where sphalerite is the minor phase in galena-sphalerite aggregates, the sphalerite occurs as small blebs along galena grain boundaries or as spherical masses within the galena.
12. Masses of small granoblastic-textured and annealing twinned sphalerite grains often invade or enclose ragged relics of coarser grained deformation-twinned sphalerite (fig. 29).
13. Minerals of high form energy, like pyrite and tremolite, occur as distinctive porphyroblasts in many of the ores (fig. 33).
14. Sphalerite near intrusives may have a rim of lighter color than its core and is often associated closely with pyrrhotite.

FIGURE 29.—Polished and etched section of zinc-lead ore from Cast Steel mine. Medium-grained granoblastic sphalerite, some of it displaying prominent annealing twins, surrounds two ragged remnants of large polysynthetic deformation twinned crystals of sphalerite. In the lower quarter of the photo is granoblastic polygonal galena(g), a product of annealing and grain growth, as in the granoblastic sphalerite.

FIGURE 30.—Polished and etched section of zinc ore from Van Stone mine, showing well-formed annealing twins in coarse-grained, granoblastic polygonal sphalerite, the grain boundaries of which are often seen to meet at triple junction points (arrow tip) with approximately 120-degree angles.

Possibly this can be attributed to sulfidization of iron in the marginal parts of the sphalerite grains and its incorporation in pyrrhotite.

The first seven of the above characteristics are indicative of regional metamorphism. The last seven are indicative of recrystallization and annealing during subsequent contact metamorphism.

Other relevant characteristics of these deposits are as follows: (1) gangue minerals and metamorphic rock minerals are one and the same, (2) some sulfide ore zones have very ragged borders, (3) sulfide masses lack feeder channels, and (4) there is a notable lack of reliable replacement criteria.

The 18 characteristics above are incompatible with an origin by selective hydrothermal replacement of metamorphic rocks. Rather, the characteristics are indicative of metamorphism of sulfide bodies together with their enclosing host rocks.

Further evidence in support of the idea that ore deposits of this class were derived by metamorphism of deposits of the types described earlier is provided by table 7. The table is designed to show the steps in the progression from relatively unmetamorphosed concordant zinc-lead deposits of the Yellowhead type, through the regionally metamorphosed, to the contact metamorphosed equivalents. The data have been obtained by reflecting microscope study of polished

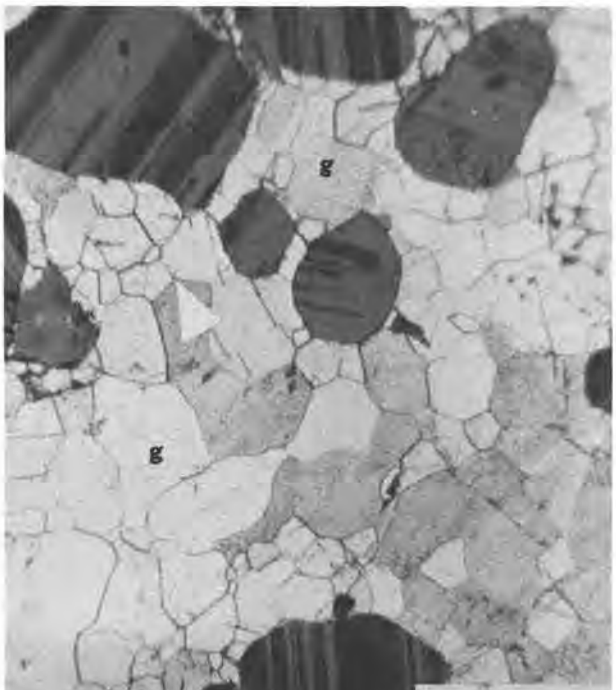

FIGURE 31.—Polished and etched section of lead-zinc ore from Deep Creek mine, showing (1) typical round or oval shape of sphalerite(s) when surrounded by galena, (2) annealing twins in sphalerite, (3) soap bubble or granoblastic polygonal texture in galena(g) and (4) distinct near 120-degree triple junction points in galena (as at arrow point). All these features are diagnostic of sulfide annealing and grain growth during thermal metamorphism following an earlier regional deformation.

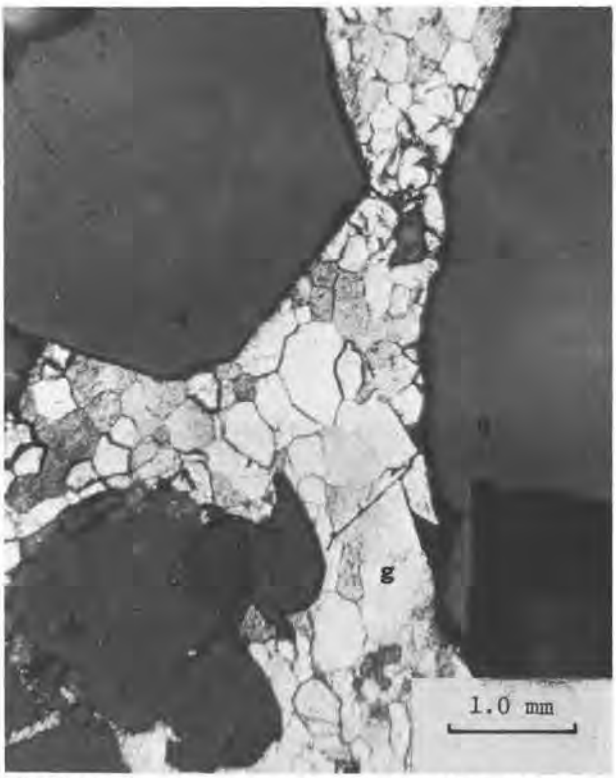

FIGURE 32.—Polished and etched section of lead-zinc ore from Sierra Zinc mine, displaying pronounced granoblastic polygonal texture in galena(g) between quartz crystals(q).

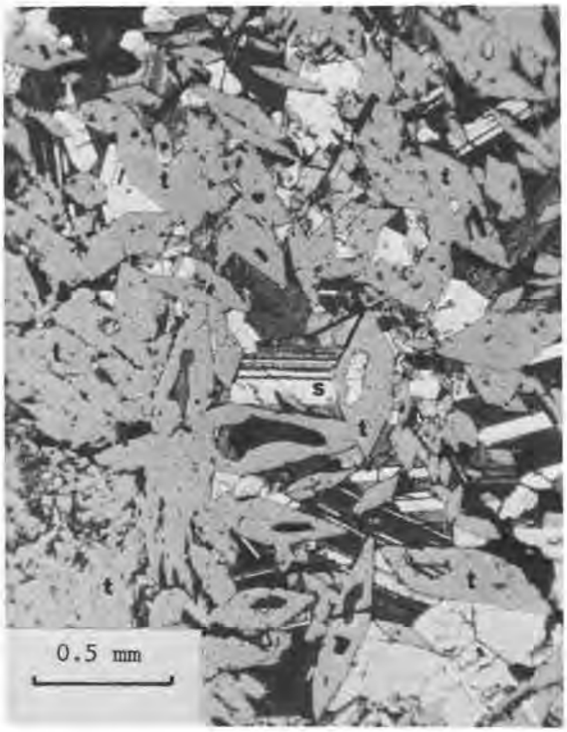

FIGURE 33.—Polished and etched section of zinc ore from Van Stone mine, showing intergrowth of annealing twinned sphalerite(s) and euhedral tremolite(t). Photo by Tom Neitzel.

and etched sections of the ores from the Yellowhead, Calhoun, Deep Creek, and Van Stone mines, all of which are in the middle dolomite unit of the Metaline Limestone or its metamorphosed equivalent. Attention is directed especially to the presence or absence of primary depositional textures, grain size, grain shape, grain boundary relations, and twinning.

From table 7, we can see that the outstanding textural characteristic of the unmetamorphosed deposits is the fine grain size (less than 100 microns) of all minerals, and also the many examples of textures characteristic of primary sulfide deposition and growth. After slight regional metamorphism, some of the sphalerite and galena are coarser and strained. There are no annealing textures. Pyrite has not been affected and hence it preserves all depositional textures.

With advanced regional metamorphism and slight contact metamorphism, the galena has been mobilized so that it is concentrated between pyrite grains and fragments. Some galena shows pronounced strain and some has recrystallized into finer grained aggregates. Sphalerite has coarsened greatly and tends to be elongate in the plane of metamorphic banding. Deformation twins are common. Some sphalerite has been annealed by recrystallization and grain growth so that it exhibits good granoblastic polygonal texture with 120° triple junctions. All primary textures in galena and sphalerite have been destroyed, except for a few inclusions of these minerals in masses of pyrite. Pyrite tends to be elongate, with grains strung out in the plane of metamorphic banding. Locally, masses of pyrite have preserved some of the depositional and growth textures of included galena and sphalerite, as well as those of the pyrite itself.

With intense contact metamorphism, both galena and sphalerite become more or less equigranular, with planar grain boundaries and many 120° triple junctions. Sphalerite exhibits well-developed annealing twins. There is no trace of primary depositional or regional metamorphic textures in either galena or sphalerite. Exceptionally, larger masses of pyrite may include elongate patches of galena and sphalerite disposed in such a way as to suggest that they are relicts of primary depositional layers. Grain size of galena and sphalerite is larger than in the less intensely thermally metamorphosed ores. Pyrite may have preserved some of its primary depositional banding and growth zones. Individual coarse euhedral pyrite porphyroblasts are common. Some pyrite masses are composed of nearly equigranular crystals, which display polygonal boundaries in polished sections and even have a few 120° triple junctions.

Thus, table 7 documents some of the steps in the progression from relatively unmetamorphosed zinc-

TABLE 7.—Textures in pyrite, sphalerite, and galena from the Yellowhead, Calhoun, Deep Creek, and Van Stone mines

	Yellowhead mine	Calhoun mine	Deep Creek mine	Van Stone mine
PYRITE				
Grain size (microns).....	2-1800, most <50	5-250, most <100	30-500	50-900
Grain shape..............		Blocky crystals as much as 600x700	Columnar crystals to 500	Columnar crystals 50x500 to 100x1000
Grain arrangement.......	Mosaic	Mosaic	Mosaic	Mosaic
Pyrite-pyrite interfaces	Irregular, interlocking	Irregular, interlocking, some porphyroblastic	Irregular to subplanar to polygonal; porphyroblastic	Irregular to smoothly curving to polygonal; porphyroblastic
Primary depositional textures	1. Many pyrite nodules, 500-1000 microns diameter, with radiating crystals of pyrite around core of dolomite or sphalerite. 2. Good crystal growth zones. 3. Botryoidal, thinly laminated, and interlaminated with sphalerite, galena, and dolomite. 4. Cockade on breccia clasts.		1. Disjointed partial nodules and bands of columnar crystals alternating with bands of granular pyrite. 2. Relic bands of sphalerite, galena, and dolomite preserved in pyrite masses. 3. Growth zones in coarse pyrite.	
Deformation textures	A few fractured pyrite nodules	Incomplete fractured pyrite nodules	Remnants of pyrite nodules in groundmass of sphalerite and dolomite	
Annealing textures	None	None	Some polygonal grains	Common granoblastic polygonal texture with 120° triple junction points
SPHALERITE				
Grain size (microns) and shape	8-2000	50-200	100-500 annealed; to 1000x3000 deformed	20-300, most 50, all annealed, polygonal
Grain arrangement......	Mosaic	Mosaic		
Sphalerite-sphalerite interfaces	Irregular, interlocking	Irregular, interlocking	Interlocking to smooth to planar with 120° triple junction points	Planar, with 120° triple junction points
Primary depositional textures	1. Colloform bands and thin laminae of sulfides and dolomite. 2. Botryoids and cockade. 3. Growth zones. 4. Primary twins.	Some preservation of concentric thin-layered sphalerite, galena and dolomite	No primary textures remain except for a rude banding of sulfides within masses of pyrite.	

Continued

TABLE 7.—Textures in pyrite, sphalerite, and galena from the Yellowhead, Calhoun, Deep Creek, and Van Stone mines—Continued

	Yellowhead mine	Calhoun mine	Deep Creek mine	Van Stone mine
SPHALERITE—Continued				
Deformation textures	A few bent primary twins; scarce deformation twins	Numerous deformation twins	Deformation twins in coarse elongate crystals	None
Annealing textures	Rare annealing twins	Some annealing twins	1. Very numerous annealing twins and well developed granoblastic polygonal texture with 120° triple junction points. 2. Single sphalerite grains may enclose subspherical blebs of galena. 3. Grain boundaries may host cuspate and forked galena. 4. Intergrowths with porphyroblasts of tremolite and diopside.	
GALENA				
Grain size (microns) and shape	10-10000, most <50	500-800	70-400 equigranular to polygonal	500x500 to 500x900, nonpolygonal; 30-300, polygonal
Grain arrangement	Mosaic	Mosaic		
Galena-galena interfaces	Irregular, interlocking	Irregular, interlocking	Some irregular, most smoothly curving or planar with 120° triple junction points	Planar, with 120° triple junction points
Primary depositional textures	1. Thin colloform layers interlaminated with sphalerite, pyrite, and dolomite. 2. Colloform bands enclosed within and parallel to growth zones in pyrite.	Thin colloform layers interlaminated with sphalerite, pyrite, and dolomite	Rare preservation of colloform layers within pyrite masses where layers parallel depositional banding and growth zones of pyrite crystals	
Deformation textures	A few broken and lightly flexed layers, with sphalerite and dolomite; no single grain deformation recognized		None	None
Annealing textures	No distinctive annealing textures, with exception of slight development of subgrains		1. Very well developed granoblastic and polygonal texture, with 120° triple junction points. 2. Minor sphalerite along grain boundaries or as subspherical blebs entirely enclosed by galena	

lead deposits of the Yellowhead type, through their regionally and thermally metamorphosed equivalents. The deposits as they exist today owe their aspect more to the imprint of metamorphism than to their initial mode of deposition.

Origin

The concordant metamorphosed zinc-lead deposits are products of an early hydrothermal deposition, followed by regional and contact metamorphism. The ores of the A and C, Howard, Farmer, Maki, and Plug prospects initially were much like the unmetamorphosed, nonpyritic ores in the Josephine Breccia of the upper limestone unit of the Metaline Limestone. The ores of the Deep Creek, New England, Van Stone, Chollet, and Magma mines initially were probably like the relatively unmetamorphosed pyritic ores of the Yellowhead horizon of the middle dolomite unit of the Metaline Limestone in Pend Oreille County (for example, the Yellowhead mine) or of the slightly metamorphosed pyritic ores of the Calhoun mine, Stevens County. The concordant ore deposits of the Sierra Zinc, Longshot, Lucile, and Red Top mines are like those at the Reeves MacDonald mine, British Columbia (Fyles and Hewlett, 1959) in their stratigraphic position (Maitlen Phyllite) and degree of metamorphism. No unmetamorphosed equivalents of these deposits are known. Presumably, they would be like those of the Josephine Breccia or the breccias of the Yellowhead horizon.

The breccia hosts for both the pyritic and nonpyritic ores probably are solution-collapse breccias. They served as channel ways for widespread circulation of mineralizing fluids at relatively shallow depths. The source and movement of the fluids, the metals, and the sulfur have been discussed previously (see "Origin of Lead-zinc Deposits in the Josephine Breccia").

The nature of the initial or primary sulfide deposition of the metamorphosed ores has been determined by (1) comparing their geology and mineralogy with those of the unmetamorphosed ores of the Josephine Breccia and of the Yellowhead horizon of Pend Oreille County, and (2) the recognition in polished section of original deposition and growth textures that have been preserved despite metamorphism. Primary deposition is older than Jurassic and may be as old as Cambrian.

During Triassic or Jurassic time the rocks and their ores were subjected to one or more periods of regional metamorphism, during which they were folded and given a metamorphic fabric. Solution, redeposition, recrystallization, and plastic flow of the carbonates and sulfides gave rise to metamorphic banding and lineation and a migration of galena into dilatant zones. Formerly tabular deposits were intensely folded and rendered lenticular and streaky as rocks and ores were squeezed and transposed. At this stage both rocks and ores could properly be called tectonites. Primary depositional textures were partially or completely erased.

In Late Jurassic and Cretaceous time the region was intruded by batholiths of granodiorite and quartz monzonite. Whether the ore deposits were in contact with the intrusives or merely in the general area of intrusive activity, they were contact metamorphosed to some degree. This metamorphism involved recrystallization and grain growth of the rocks and ores, greatly changing the textures generated during the earlier regional metamorphism. These new textures include granoblastic polygonal texture and 120° triple junctions in carbonates, quartz, and sulfides, annealing twinning in sphalerite, concentration of minor minerals along grain boundaries of major minerals in mineral aggregates, and porphyroblasts of pyrite and tremolite. Where thermal metamorphism was moderate, it only partially erased textures developed earlier in the base-metal sulfides and had no effect on pyrite. Where it was strong, it erased textures developed during regional metamorphism. However, even when contact metamorphism was intense, the gross aspects (banding, lineation, lenticularity) developed during regional metamorphism were preserved.

Similar Deposits and Earlier Views

Deposits very similar to the Washington State deposits exist at the Reeves MacDonald mine and at the Jersey, H. B., Aspen, and Jackpot mines of the Salmo district of British Columbia, due north of the Metaline district of Washington. All of the Canadian deposits are in metamorphosed Reeves Limestone (Fyles, 1967, p. 66-67). Although most authors have considered the Reeves MacDonald and Salmo ores to be due to the hydrothermal replacement of carbonate rocks, Muraro (1966) was the first to suggest that the Salmo ores had undergone post-depositional metamorphism; he suggested that before metamorphism they probably resembled the relatively unmetamorphosed lead-zinc ores of the Metaline district or what are referred to in this report as the ores of the Josephine Breccia.

MacDonald (1970, p. 55-64) has provided us with abundant, convincing evidence in support of Muraro's contention that the Salmo ores are metamorphosed. As early as 1968, Cox (1968, p. 1515) questioned the prevailing hydrothermal replacement hypothesis for the origin of the Van Stone deposit and similar deposits in Washington. His reservations are expressed as follows:

> The Kaniksu batholith itself is unmineralized, at least as far as we have been able to determine. There is almost no development of typical marbles and contact metamorphic effects preceding mineralization in any of the principal mines of northeast Washington and southern Canada. There is a strong suggestion in some areas that metamorphic minerals have developed either contemporaneously with or subsequent to the formation of mineral deposits. While it has generally been accepted that mineralization was later than the Late Cretaceous-early Tertiary batholiths, such as the Kaniksu, there seems to be no real evidence that this is the case. The deposits in places show amazing conformity to folding as though the deposit itself may have been folded. This is especially true at the Van Stone mine and in the Jersey and Reeves mines in British Columbia. It has been suggested that this general belt originally contained deposits of the Mississippi Valley type and that the present shape and distribution and location of these deposits is due to later reworking during the period of Late Cretaceous-early Tertiary mountain building and igneous intrusion.

In his study of the Van Stone mine, Neitzel (1972) found abundant evidence that the sulfide ores are older than the folding and igneous intrusion. In 1970, the author (see A and C mine) found streaky sphalerite and galena mineralization in limestone marble at the A and C mine where the sulfide mineralization is truncated by a barren granite dike, an offshoot of the Spirit pluton.

That is, the present report confirms for all such deposits of Stevens County what has been suggested or demonstrated for the Van Stone mine and for related deposits in the Kootenay Arc of southeastern British Columbia—the sulfides were emplaced prior to the principal regional deformation and long before the emplacement of the Kaniksu and related batholiths.

Ore Exploitation and Metamorphism

In relation to the exploitation of metamorphosed ores of this class, significant effects of intense regional and contact metamorphism are as follows:

1. Single tabular or blanketlike ores change to multiple separate smaller tabular or lenticular deposits.
2. Borders of individual ore-bearing areas

change from highly irregular to more regular borders.

3. Dips change from flat or gentle to moderate, steep, or vertical; ore shoots change from nonplunging or gently plunging to moderate or steep plunging, parallel to the plunge of lineation and fold axes in the enclosing strata.
4. There is short-distance migration of galena from galena-sphalerite-pyrite aggregates.
5. The susceptibility of the ores to mineral dressing is improved by increasing their grain size and friability.

MINES AND PROSPECTS IN CARBONATE ROCKS

A AND C MINE

The A and C mine is on the south fork of Bruce Creek in the NE¼ sec. 3, T. 37 N., R. 39 E. and the SW¼ sec. 34, T. 38 N., R. 39 E., only a few hundred yards from the county road between Echo and Onion Creek. According to Huntting (1956), workings consist of a 220-foot adit, a 110-foot adit, a shaft, and an open cut. None of the underground workings were open at the time of the author's visit.

Weaver (1920, p. 241, 242) describes the deposit as follows:

> The ore deposits consist of a mineralized zone trending nearly east and west along the contact between the Clugston limestone on the south and the granite on the north. The ores are in the limestone and about 6 feet south of the granite contact. They consist of chalcopyrite, sphalerite, and pyrite replacing the limestone along a zone varying from 2 to 12 feet in width. The limestone has been greatly silicified and the amount of mineralization varies and in places gradually disappears so that it is not possible to determine where the vein ceases to become ore and passes into the country rock.

The only accessible working in 1970 was an open cut about 30 feet long in which medium-gray banded limestone marble is in contact with granite. The limestone marble is part of the upper unit of the Metaline Limestone. In the trench it is quite tremolitic and is mineralized over a width of about 10 feet, with dark-brown to black sphalerite and fine-grained galena in streaks and irregular masses several inches across. Pyrite and pyrrhotite are present also, but no chalcopyrite was found, though its presence was mentioned by Weaver. The mineralized zone strikes east and west and appears to have a very steep dip.

Of particular interest is the discovery that the streaky sulfide mineralization is truncated by a barren granite dike with chilled margins and carrying no base-metal sulfides. The granite must be younger than the base-metal mineralization. Molybdenite was found on joint surfaces in tremolitic limestone marble on the mine dump and disseminated in granite bedrock. Molybdenite is found in quartz veins and aplite dikes at several localities in this general area (Todd, 1973). It is related to the granite pluton and is much younger than the base-metal mineralization.

About 1 mile east of the A and C workings is a small trench exposing granite in contact with dolomite mineralized with plates, rods, and lenticles of black sphalerite. The sphalerite bodies give the rock a pronounced lineation. The granite contact is at a high angle to this lineation and the granite is devoid of base-metal mineralization. As at the A and C mine, the base-metal mineralization is pre-granite. The lineation in the dolomite is almost certainly metamorphic in origin but there is no field evidence to indicate whether the form of the sphalerite is attributable to metamorphism or whether it was inherited during metasomatism.

ADMIRAL CONSOLIDATED

The Admiral Consolidated workings are in the SW¼ sec. 36, T. 40 N., R. 41 E., about 1¼ miles north of Leadpoint. Total production from 1902-1956 was 43,533 pounds of lead, 1,596,183 pounds of zinc, and 668 ounces of silver.

Lower Workings

The lower workings consist of roughly Y-shaped connected tunnels (fig. 34) totaling about 460 lineal feet, driven in white, light-gray, and dark-gray limestone of the upper limestone unit of the Metaline Limestone. For about 60 feet of this length the limestone is slightly dolomitic and mineralized with disseminated sphalerite over a maximum width of 8 feet. This zone strikes approximately N. 20° W. and dips 68°-75° W., probably about parallel to bedding in the limestone. It has been stoped for a length of 150

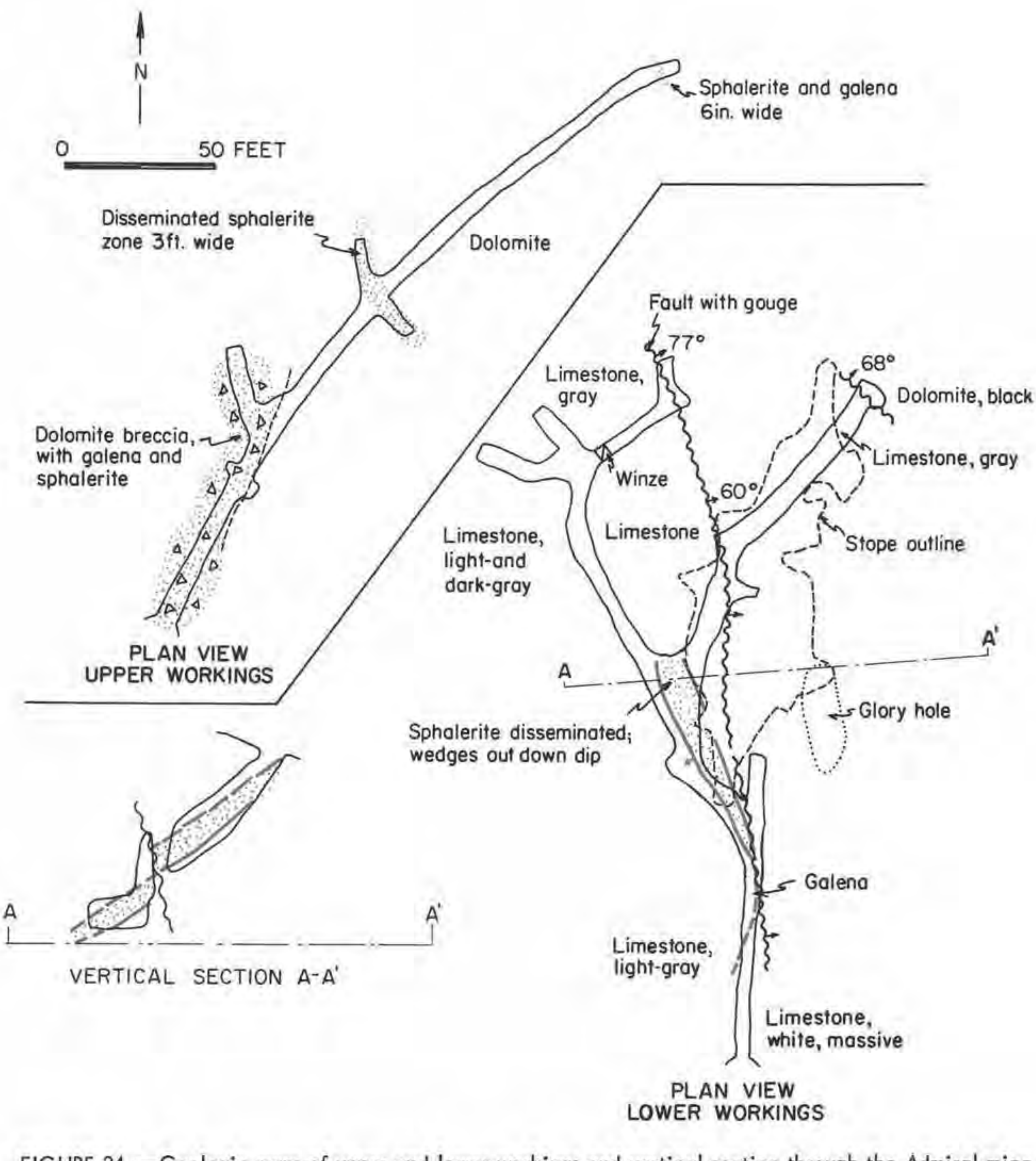

FIGURE 34.—Geologic maps of upper and lower workings and vertical section through the Admiral mine (SW¼ sec. 36, T. 40 N., R. 41 E.), Stevens County.

feet above the level extending through to surface, about 75 feet up dip from the tunnel floor.

Upper Workings

The portal of the upper workings is about 500 feet northeast of the portal of the lower workings, and approximately 120 feet higher in elevation. The upper adit was driven for 260 feet, with two short crosscuts 80 to 130 feet from the portal. From the portal to the first crosscut, the rock is a slightly siliceous gray dolomite breccia consisting of fragments of dolomite, chert, and black argillite in a light-gray dolomite matrix. Most fragments are rimmed with light-gray to white coarsely crystalline dolomite. Masses of clear coarsely crystalline calcite occur sporadically throughout the breccia. Galena and sphalerite are found in the coarser dolomite matrix between the fragments. The best grade is estimated to be about 10 percent combined lead and zinc over a width of 4 feet. The breccia zone is not exposed beyond 80 feet from the portal and is presumed to have passed into the northwest wall. A minor amount of disseminated sphalerite is to be found in massive dolomite in the second crosscut and near the face of the main tunnel.

The most appropriate place in which to do further work seems to be the northward extension of the breccia zone exposed in the upper workings.

ADVANCE MINE

The Advance mine is in the SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 18, T. 39 N., R. 41 E., about 3 miles northeast of the Deep Creek mine. Production has been 10,602 pounds of lead, 19,271 pounds of zinc, and 71 ounces of silver.

According to Huntting (1956) underground workings consisted of a shaft, three adits, drifts, crosscuts, and raises totaling about 2,621 feet. He describes the deposit as follows:

> Low-dipping mineralized zone in limestone with interbedded slate exposed underground averages 10 feet wide and is 200 feet long. Surface trenching shows length of 4,000 feet.

The limestone appears to be the uppermost part of the upper limestone unit of the Metaline Limestone, just beneath the Ledbetter Slate. Dump rock is light-gray banded limestone and dark-gray highly silicified limestone with quartz stringers. The silicified limestone contains sphalerite and galena.

The occurrence of essentially pyrite-free zinc-lead mineralization in silicified or jasperoidal limestone just beneath overlying Ledbetter Slate bears a strong resemblance to the ores of the Josephine Breccia of Pend Oreille County. Therefore, it is assumed that the Advance mine mineralization is an extension of that horizon.

A. ANDERSON PROSPECT

The A. Anderson prospect is in the NE$\frac{1}{4}$ sec. 3, T. 39 N., R. 41 E. It was not examined by the author but is reported (Huntting, 1956, p. 375) to be a sphalerite-galena "replacement deposit" in limestone near the black slate (Ordovician Ledbetter) contact.

ARK MINE

The Ark property is in the NW$\frac{1}{4}$ sec. 11, T. 35 N., R. 37 E., 2 miles south of the mouth of the Colville River at Lake Roosevelt. The mine has been idle for many years and the old workings are completely inaccessible. Production was sporadic between 1915 and 1942, probably totaling less than 3,000 tons. Values were in lead, silver, zinc, and copper.

Rocks in and about the mine are quartz-biotite-andalusite schist, hornblende schist, mica schist, and limestone marble, possibly belonging to the Maitlen Phyllite; some, if not all, of the limestone, may belong to the Metaline Limestone. The schists are highly foliated and the limestone is thin banded. Foliation and banding are parallel to each other (N. 65° E., 70°-80° NW.) and approximately parallel to bedding. Tightly appressed parasitic folds are common; they all plunge about 40° to the southwest.

According to notes prepared by geologists of the Division of Geology in 1938, the workings consisted of a main tunnel driven in a southeast direction in an attempt to cut a large quartz vein exposed 250 feet above the camp. The vein ranged in width from 2 to 25 feet and was found along the contact of shale (phyllite?) and limestone dipping about 45° SW. The tunnel "failed to catch up" with the vein. A raise was driven 815 feet from the portal, and at 150 feet above the level a drift was driven N. 2° W. until it cut the vein 70 feet from the raise. From there a drift was driven on the vein for 120 feet, 100 feet of which had been stoped up 50 feet (vertical component). The vein attitude here was N. 50° W., 40° SW., though dips varied. Thickness ranged from 4 to 30 feet and contained inclusions of shale. Walls were polished to a mirror finish, and a brittle surface from one to two inches thick covered the shale and limestone. No gouge was present. The vein consisted of white glassy to dead-white friable quartz, carrying galena, tetrahedrite, sphalerite, and pyrite. The ore as a whole showed no preference for either wall but seemed to be scattered at random throughout the vein.

Any further exploration should concentrate on the extension of the marble-schist contact. In view of the regular and pronounced plunge to the southwest exhibited by parasitic folds and lineation, there is a good likelihood that sulfide ore shoots plunge similarly. This may explain why the mineralization is confined to the very west end of the lower level rather than directly down dip from the upper level. Possibly the extension of the upper level mineralization lies southwest of the lower level drift face.

BECHTOL MINE

The principal workings of the Bechtol mine are in the SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 23, T. 39 N., R. 41 E., one-quarter mile east of the north end of Deep Lake (fig. 35). The mine has been worked intermittently since it was located in 1896. Recorded production is 249,230 pounds of lead and 198 ounces of silver.

Surface and underground workings, faults, and mineralized zones are shown on figure 36. The host rocks are described by Campbell (1949) as light-gray cherty dolomite striking from due north to N. 30° W. and dipping vertically. Yates (1964) mapped them as intraformational breccia above the middle unit of the Metaline Limestone. They are cut by faults of diverse orientation, though most strike either northeasterly with northwest dips or northwesterly with northeast dips. Dips on most faults are between 50 and 90 degrees.

Campbell (1949) describes the ore zones as follows:

> The main ore body lies along a fault which strikes N. 45° E. and dips 45° NW. near the surface, but flattens to almost horizontal at the bottom of the incline which follows it down dip. The ore is irregularly distributed in the limonitic gouge which almost universally marks the fault. . . . The dimensions of that part of the fault known to be mineralized, irrespective of lead content, are 100 by 150 by 6 feet, but the mineralized block undoubtedly extends beyond this. . . . The lead ore consists of lumps of coarse galena as much as a foot in diameter, imbedded in earthy and crusted limonite. Most of the lumps are

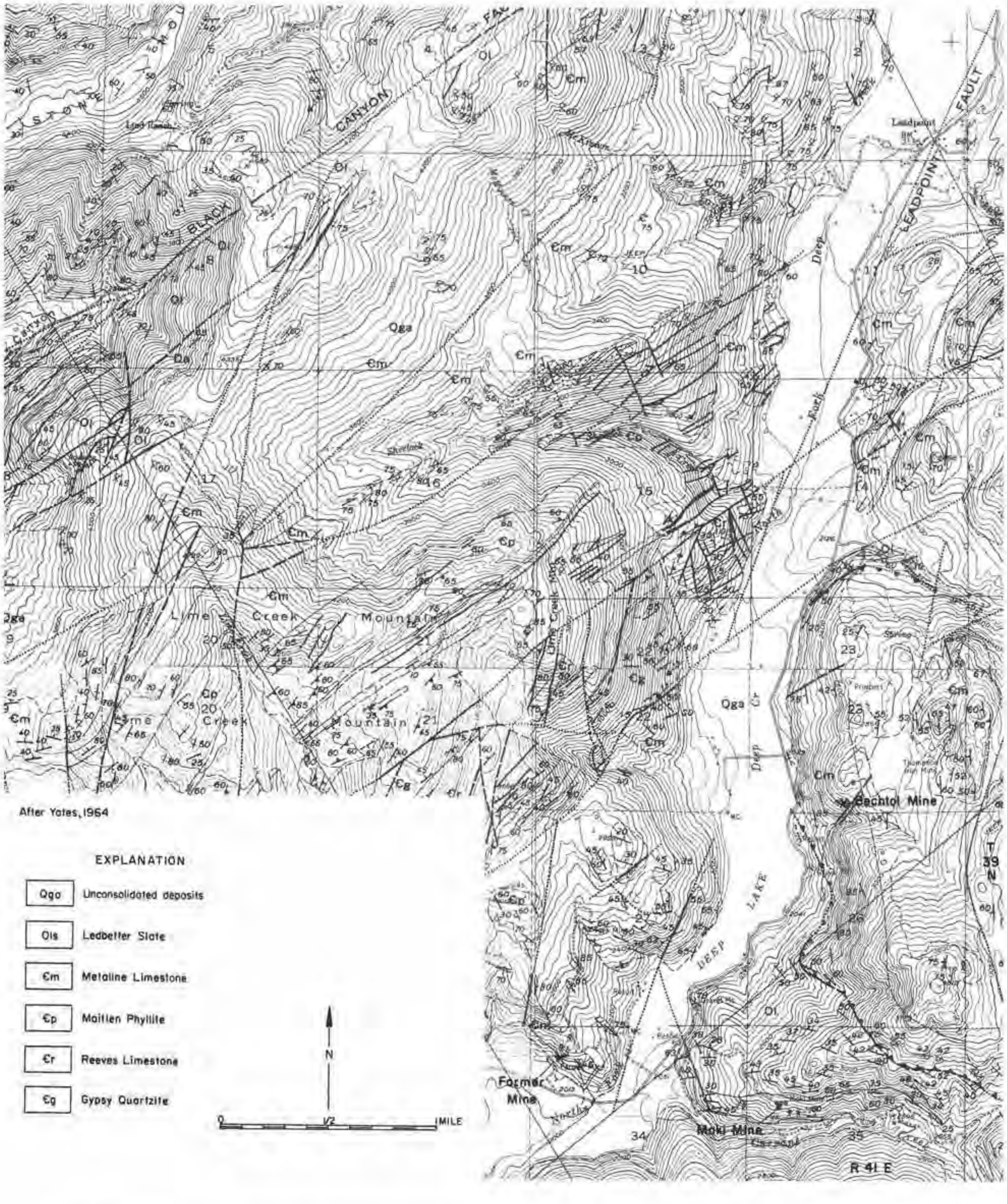

FIGURE 35.—Geologic map of area between Deep Lake and Leadpoint, showing location of Farmer, Maki, Bechtol, and Calhoun mines.

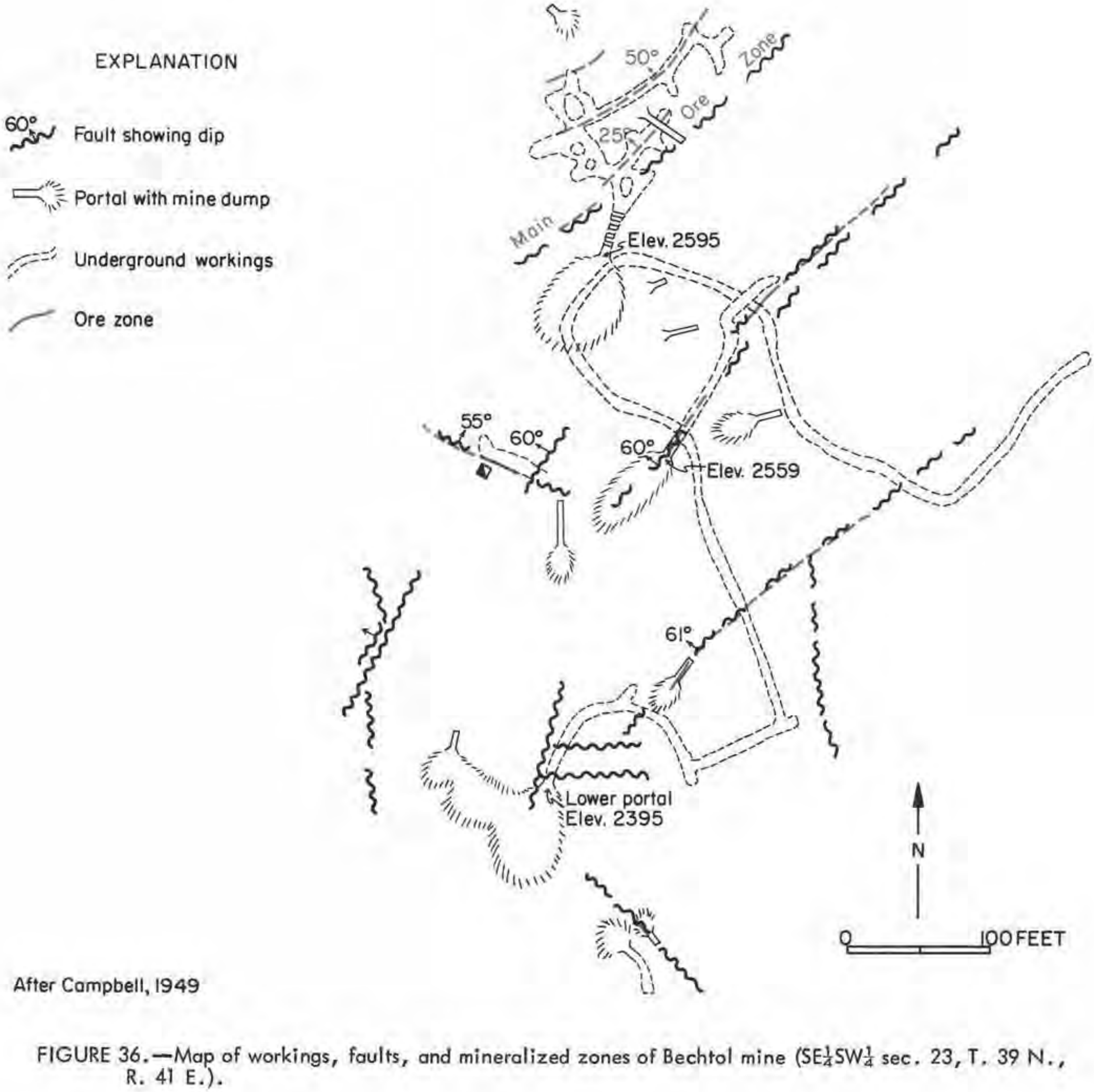

FIGURE 36.—Map of workings, faults, and mineralized zones of Bechtol mine ($SE\frac{1}{4}SW\frac{1}{4}$ sec. 23, T. 39 N., R. 41 E.).

> coated with 1/16- to 1/8-inch selvages of very thin-banded, dark-gray anglesite which is in turn overlain by a layer of cerussite needles.

The underground workings were inaccessible in 1967. However, mineralized branches of the "main ore body" can be seen where the workings have caved through to surface. A smooth fault wall striking N. 45° W. and dipping 63° NE. has up to 8 inches of rust-colored dolomite adhering to it, with veins of galena, up to 4 inches thick, parallel to the fault wall.

The principal primary minerals throughout the Bechtol workings are siderite and galena (Campbell, 1949, p. 1). The low silver content (about 73 percent lead and 1.2 ounces silver per ton) of the lead-rich ore, the absence of zinc, the siderite gangue, and the sulfide localization along brecciated fault zones are characteristics shared by the Bechtol mine and many mines and prospects on Gladstone Mountain.

BIG CHIEF MINE

The Big Chief mine is in the SW¼ sec. 14, and NW¼ sec. 23, T. 37 N., R. 39 E., on Comstock Mountain, between the south and middle forks of Clugston Creek. Production has been 220 tons of ore containing 182 ounces of silver, 139 pounds of copper, 24,595 pounds of lead, and 5,545 pounds of zinc.

The most extensive underground workings are those of the main adits on the north slope of Comstock Mountain, in SW¼ sec. 14, the portals of which are at an elevation of 3,020 and 3,450 feet. Although they are no longer accessible, they were examined by Division of Mines and Geology geologists in 1953. The upper adit was driven for 535 feet in a direction S. 62° E. The first 100 feet is in black argillite of the Ledbetter Slate. The next 28 feet exposes intensely deformed and broken argillite of a nearly vertical fault zone, striking within a few degrees of north. The remainder (approximately 400 feet) of the tunnel is all light-gray and dark-gray dolomite, except for a 2-foot-wide tetrahedrite-bearing quartz vein, striking N. 35° E., dipping 65° NW., about 435 feet from the portal, and a few feet beyond this, a basic igneous dike 8 feet wide striking N. 72° E., dipping 65° NW. One hundred and ninety feet from the portal, a branch tunnel has been driven for about 215 feet, first in a south then in a southwest direction, for the first 50 feet on a narrow gouge zone striking north and dipping 75° E. As the tunnel changed its direction to more nearly southwest, it continued in dolomite, with several minor faults, until it intersected the contact with the Ledbetter Slate about 130 feet from the main tunnel. From here to the face the rock is black argillite, dipping steeply to the southeast. Except for the tetrahedrite of the quartz vein referred to above, no ore minerals were seen.

A lower adit (portal elevation 3,020 feet) is reported to have a total length of 2,370 feet. For the first 800 feet from the portal, it bears S. 60° E., then S. 83° E. for 300 feet, then N. 84° E. for 940 feet to a face. Thirty-five feet back of the face, a side tunnel heads off to the south, then to the southeast for a total length of 330 feet.

The first 1,000 feet of the lower adit is in black argillite of the Ledbetter Slate. The next 340 feet is in the Metaline Limestone carbonate rock, cut by a few thin seams of quartz containing a little pyrite. A prominent sphalerite-bearing vein up to 1 foot wide, striking N. 05° W. and dipping 40° E., marks the beginning (1,340 feet from the portal) of highly banded gray and black carbonate rock that extends to 1,650 feet. From here to the face at 2,040 feet, the rock is dolomite and dolomite breccia. The branch tunnel, extending for 330 feet southeasterly from near the face, is also in dolomite breccia and dolomite, striking N. 50° E., and dipping 30° W., with a sphalerite-bearing zone about 15 feet wide at the start of the branch tunnel. The footwall (west) side of this zone is marked by pyrite and sphalerite in a zone 6 inches wide, striking N. 07° W., dipping 70° E. Presumably, the mineralization at this stratigraphic level, about 1,100 feet below the Ledbetter-Metaline contact, corresponds to the pyrite- and sphalerite-bearing Yellowhead horizon of the middle dolomite unit of the Metaline Limestone. Apparently none of the sulfide exposures were stoped.

About one-quarter mile south of the principal adits, high on the south slope of Comstock Mountain, in E$\frac{1}{2}$NW$\frac{1}{4}$ sec. 23, T. 37 N., R. 39 E., are several old cuts, a 25-foot vertical shaft, and a 260-foot adit, referred to as the Meyer adit. Weaver (1920, p. 239) refers to a vertical 50-foot shaft at an elevation of 4,200 feet, from the bottom of which a drift was driven an unknown distance to the west. Ore from these workings was said to have averaged 14 percent lead. The workings were inaccessible even then. The Meyer adit portal is at 4,035 feet in elevation, and the tunnel has been driven straight for 260 feet in a direction N. 24° E. The rock is all banded black or drak-gray and light-gray dolomite and dolomite breccia. No sphalerite is reported but galena is present as small disseminated irregular lumps or masses and as veinlets or seams, especially in the coarse-grained "bleached sandy sideritic dolomite" at 8, 38, 142, 178, and 186 feet from the portal. Similarly, in the several open cuts and trenches, sphalerite is seldom reported but galena is widespread as blebs and small seams scattered through the dolomite, especially with the "sideritic dolomite."

In 1968, the author examined these old cuts and recent bulldozer cuts on the south slope of Comstock Mountain. Most of the rock exposures are light-gray dolomite, probably of the middle dolomite unit of the Metaline Limestone, containing quartz nodules and short irregular quartz veins seldom more than a few inches long. Upon close examination, much of the rock appears to be brecciated, with thin quartz seams between the breccia fragments. Elsewhere, the rock is a breccia of fine-grained dolomite fragments in a matrix of coarse-grained dolomite. The matrix is generally lighter in color than the fragments and commonly is accompanied by galena and quartz. Such galena fills the space between breccia fragments. Consequently, masses of it are highly irregular in shape, seldom more than a couple of inches wide, frequently attached to other interfragment galena masses by thin veins or seams, forming a galena network. In the breccia, the galena is always between dolomite fragments, never in them. The accompanying coarse-grained dolomite of the matrix is probably what has been referred to as "sandy sideritic dolomite."

Previous workers frequently mentioned the highly erratic distribution of the galena. For example, Weaver (1920, p. 237-239) described the deposits as lenslike in form and highly variable in size, with galena occurring "in seams, in small pockets, and in nodules." He emphasized that these nodules are "widely scattered through the limestone and do not appear to exist in the form of well-defined continuous veins."

Neither previous workers nor the author were able to gain much of an idea about the distribution pattern of the breccia. The time allotted to this study was too short for this. Most earlier authors implied a relationship between the breccia and faulting. However, there are many faults without breccia and a great deal of breccia far removed from and unrelated to faults. An origin by solution-collapse is one that seems best to fit the breccia characteristics.

The most western exposure of galena-bearing dolomite breccia at the Big Chief mine is within 150 feet of the projected position of the contact between the dolomite breccia and the black argillite of the Ledbetter Slate. This contact strikes almost due north,

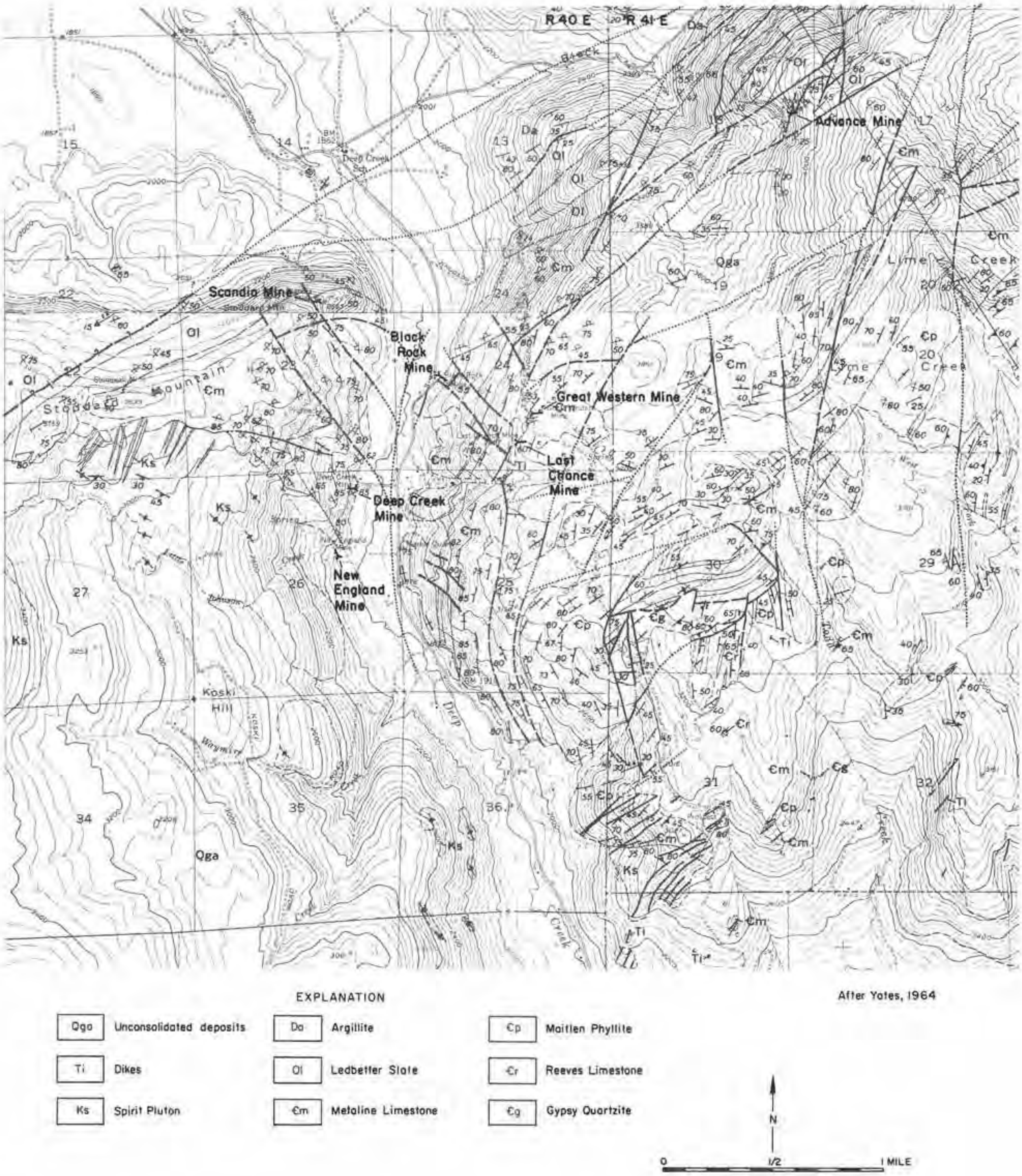

FIGURE 37.—Geologic map of area that includes the Scandia, Deep Creek, New England, Black Rock, Great Western, Last Chance, and Advance mines.

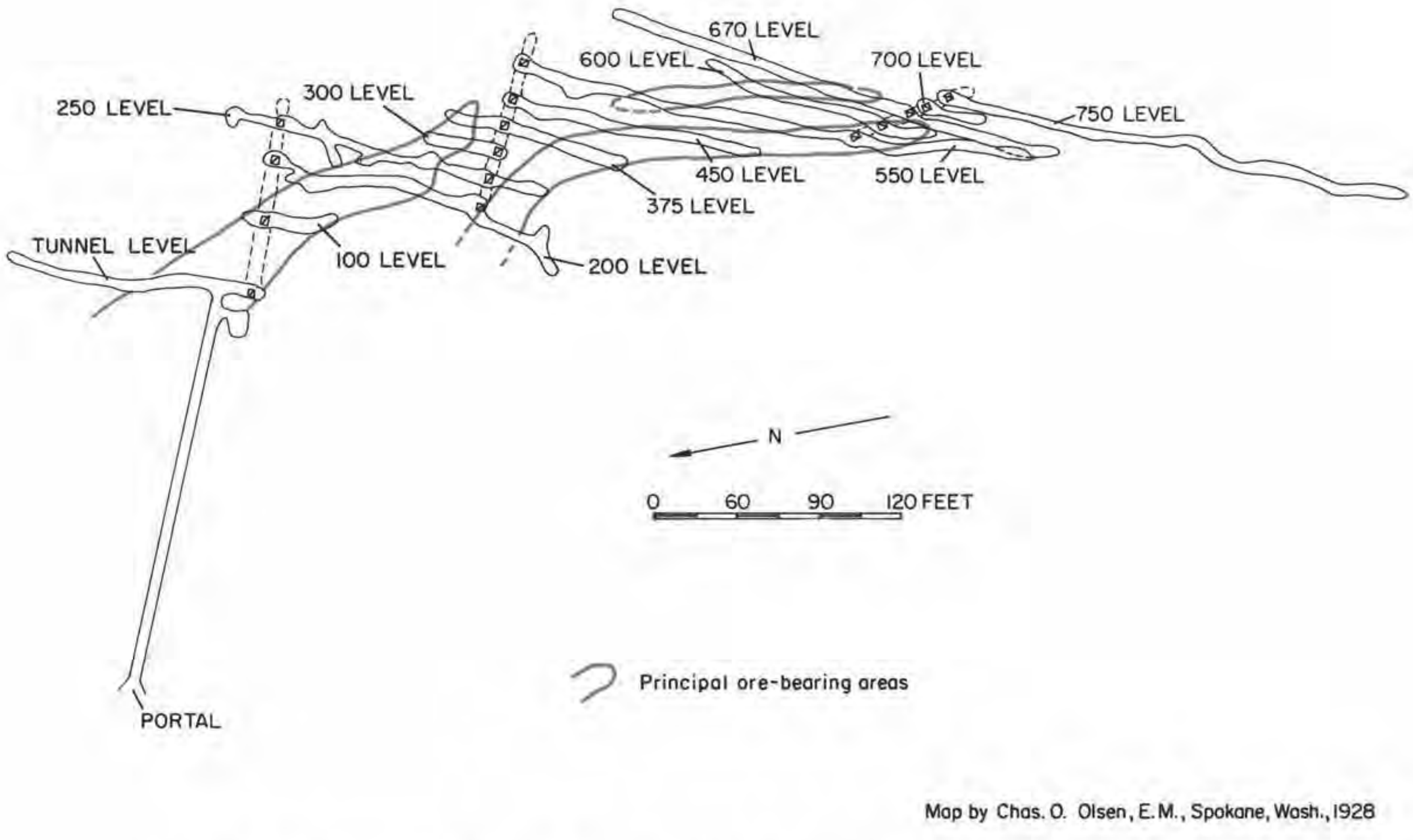

FIGURE 38.—Composite level plan, Black Rock mine, showing limits of principal ore-bearing areas.

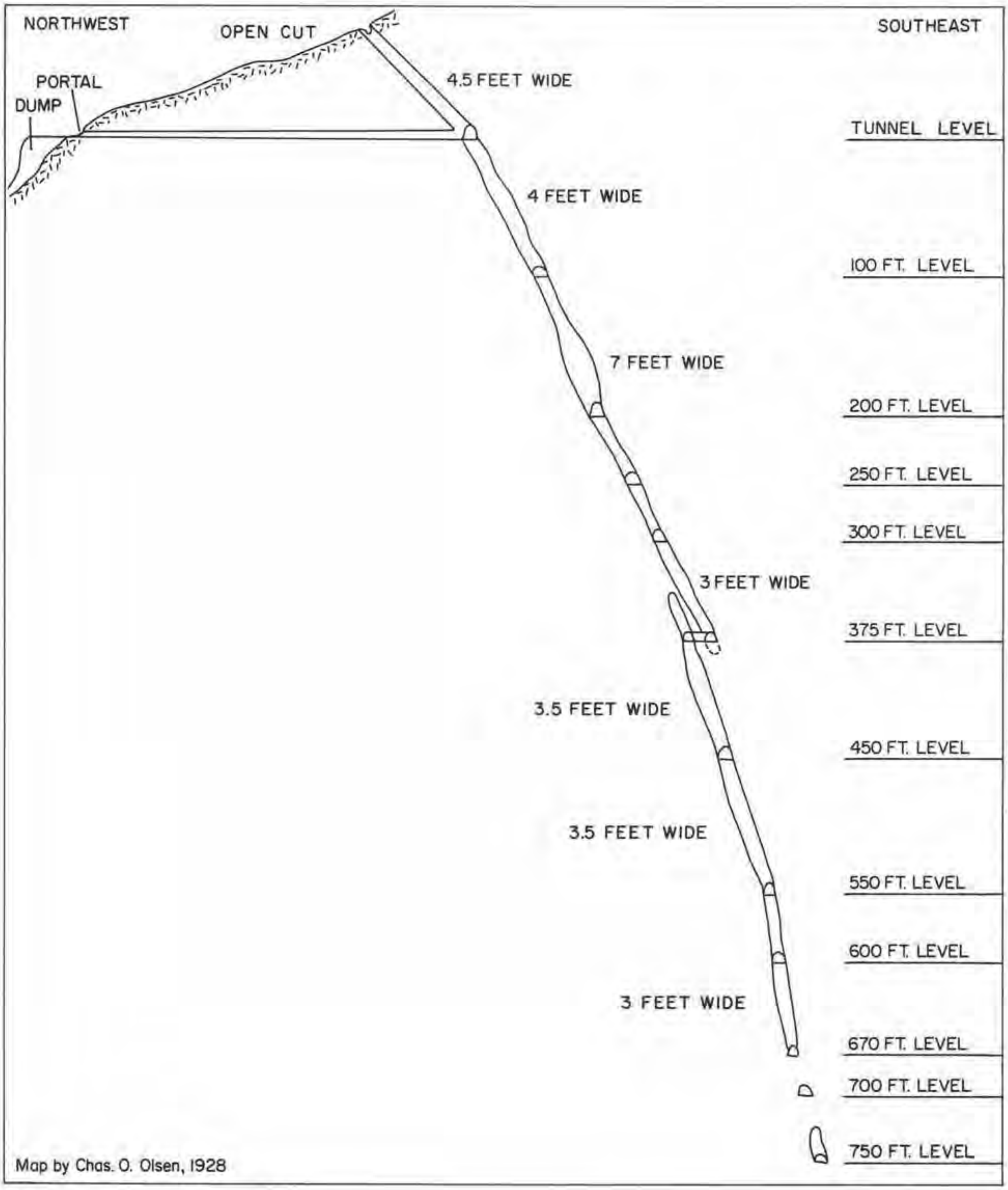

FIGURE 39.—Vertical cross section, Black Rock mine.

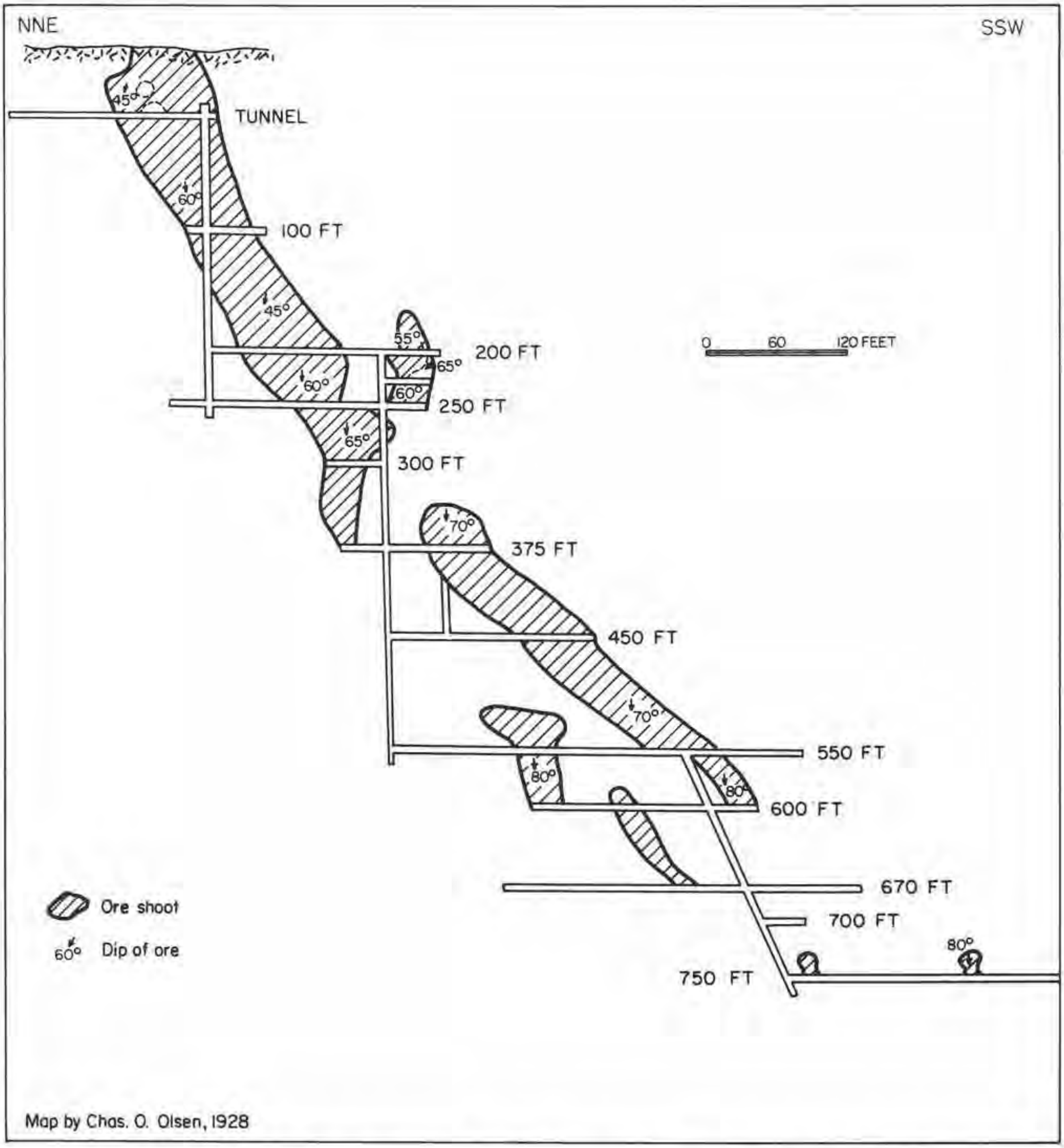

FIGURE 40.—Vertical longitudinal section, Black Rock mine, showing principal ore-bearing areas.

EXPLANATION

Geology by James Browne and Gerald Carr

		Ti	Lamprophyre dikes	———	Contact
Metaline Limestone	Upper limestone unit	Cmu	Gray limestone	———	Fault
	Middle dolomite unit	Cmm / Cmml	Gray dolomite, with dark, mottled dolomite; Cmml-Limestone within unit	68	Ore zone showing dip
				62	Strike and dip of beds
	Lower limestone unit	Cml	Dark argillaceous limestone	54	Overturned bed

Pit or shaft · Breccia · Trench · Short adit · Underground workings · Mine dump

FIGURE 41.—Geologic outcrop map of area of Black Rock, Last Chance, and Great Western mines.

and judging from its trace in rugged terrain, must have a rather steep dip. One shallow digging about on the contact exposes a slightly iron-stained, porous breccia composed of black argillite fragments in a fine-grained matrix. The presence of this breccia and the fact that the dolomite here is part of the middle dolomite unit of the Metaline Limestone, rather than the upper limestone unit, indicates that the contact between the slate and dolomite is either a fault or an unconformity.

BLACK ROCK MINE

The workings of the Black Rock mine, now inaccessible, are in NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 24, T. 39 N., R. 40 E., 3,300 feet northeast of the shaft collar of the Deep Creek mine (fig. 37). The original discovery of the ore was in 1920. Production amounted to 140,856 pounds of lead, 7,903,447 pounds of zinc, and 377 ounces of silver.

According to C. O. Olsen (private report, 1928) the deposit was worked on 12 levels between the surface and the bottom level, a vertical depth of 825 feet. The strike of the vein throughout the mine is N. 23° E. Between surface and the 300-foot level the ore shoot dipped 64° SE., plunged 52° to S. 20° E., and raked approximately 64° southerly in the plane of the vein. From the 375-foot to the 600-foot level, the ore shoot dipped 75° SE., plunged 42° to S. 10° W., and raked approximately 42° southerly in the plane of the vein.

Jenkins (1924, p. 107-109) provides the following information about the deposits in the early years of its operation when the mine was only 250 feet deep:

> The ore was found at the surface as smithsonite, occurring on a fault which had a decided drag on its hanging wall. . . . a fault plane lies on the footwall side of the body, striking S. 25° W. dipping 64° to the southeast. This fault lies in the plane of the dipping beds on its east side, but the beds in the tunnel west of the fault dip in an opposite direction. . . . the ore body is largely confined to the sheared and brecciated zone between these faults.

The plan, vertical section, and longitudinal section (figs. 38, 39, and 40) illustrate the position, attitude, thickness, and extent of the ore body. The plan of the workings has been transferred to the geologic map prepared by James Browne and Gerald Carr (fig. 41) so as to show the mine in its geologic setting and in its position with respect to the Last Chance and Great Western mines.

It appears that the smithsonite-sphalerite mineralization was localized along a fault zone, striking about parallel to the enclosing dolomite of the middle unit of the Metaline Limestone (Yates, 1964). However, not all faulting was premineral, for Jenkins mentions (1924, p. 109) collecting "a good specimen of brecciated sphalerite." There seems no reason to doubt that the mineralization is epigenetic. The primary sphalerite was intensely oxidized to smithsonite.

GEOLOGY OF THE CALHOUN MINE

by

James Browne

The Calhoun mine, located 36 miles north of Colville and 1 mile northwest of Leadpoint on the Deep Lake county road (fig. 35), is referred to in older reports as the Anderson prospect. Andy Anderson, a long-time resident of Leadpoint, discovered mineralization there in 1910 and explored it with shallow pits and trenches. During World War II, the U.S. Bureau of Mines drilled several holes as part of the Defense Minerals Program. Goldfields Consolidated Corp. later acquired the property, mined by open-pit method the area prospected by Anderson, drilled out a portion of the ore body adjacent to the pit, and initiated mechanized development. American Zinc Co. resumed exploration and development in 1963 and entered into production in 1966. The mine closed in 1968 because of depressed metal prices and diminishing ore reserves after extraction of nearly a million tons of ore.

The host rock of the Calhoun ore is part of the middle member of the Metaline Limestone. Composed almost entirely of dolomite, this member contains only a few limy patches, which in this area do not appear to be restricted to any particular stratigraphic horizon. Structurally, the Metaline Limestone, together with the Gypsy Quartzite, the Maitlen Phyllite, and the Ledbetter Slate, make up part of the north limb of an overturned anticline, with formations striking N. 50° E. to N. 60° E., and dipping 50° to 90° SE. (Yates, 1964).

That part of the Metaline Limestone from which almost all mine production has come is a silicified dark-gray dolomite breccia and is referred to here as the host rock zone. It lies beneath a hanging wall of gray to dark-gray, unsilicified dolomite and above a footwall of light-gray to gray, silicified to unsilicified dolomite (fig. 42). The contacts of the host rock zone with the hanging-wall and footwall rocks strike N. 50° E. to N. 60° E. and dip from 50° to 80° SE.

The hanging-wall rocks are irregularly interbedded, fine-grained, gray and dark-gray mottled dolomite. On some weathered surfaces, the dark mottled dolomite displays closely packed oolites and pisolites. In a few places, the gray dolomite exhibits stromatolitelike crinkled banding, but only rarely, the vast bulk of it being massive and featureless. Small patches and stringers of chert and quartz are scattered sparingly in both rock types. Fine to coarse "zebra"

FIGURE 42.—Vertical northwest-southeast cross section through upper open pit, Calhoun mine.

banding (thin, alternating light- and dark-gray crystalline dolomite bands), mainly associated with dark-gray mottled dolomite, parallels the bedding. Hanging-wall strata invariably strike N. 50° E. to N. 60° E.

Hanging wall-type dolomite is also found deep within the footwall in both surface exposures and in diamond drill holes far below the typical footwall dolomite. In a few diamond drill holes, no typical footwall dolomite was found below the host rock zone. In these, the rocks both above and below the host rock zone are of the kind most often found only in the hanging wall.

Footwall dolomite most commonly is light-gray to gray in color, though dark-gray, tan or pink varieties are found locally. It is fine- to very fine-grained and varies from unsilicified to highly silicified. Silicification generally takes the form of small, irregularly shaped blebs and stringers of quartz; less commonly, the silicified rock is banded or massive. In places, the dolomite contains small irregular areas of poorly defined breccia thought to be sedimentary in origin because of the faint sandy (clastic) appearance of the matrix.

Host Rock Zone

The characteristic rock of the host rock zone is a dolomite breccia in which many or most of the breccia fragments are highly elongate, lenticular, or platy, and roughly parallel, giving the rock a strongly banded or layered (light-gray and dark-gray) appearance (fig. 17). Brecciation and banding often extend for a few feet into the footwall so that the footwall-host rock contact is very irregular and the footwall rock is gradational into the host rock (ore) zone. The matrix of the host rock breccia is composed of small fragments and sandy to silty clastic-appearing material, which has been replaced(?) by coarse-grained white dolomite in many places. Replacement of the larger, platy, silicified fragments by coarse white dolomite is also suggested by the scalloped margins of the fragments where in contact with the dolomite.

The layering of the host rock zone strikes about N. 68° W. and dips from 5° to 20° S-SW. at a high angle to the bedding of the dolomite in the hanging wall and to the strike and dip of the host rock zone itself. In some places the banding dips at more than 20°, and locally it is inclined at a low angle to the northwest.

In many places the host rock extends up to 20 feet into the hanging wall as sheetlike projections or thick lenses, while still retaining the comparatively flat dip characteristic of the layering in the main host rock zone. These sheetlike projections are composed of what appears to be finely bedded clastic dolomite, with some finely divided carbonaceous material along the bedding surfaces.

The host rock zone also contains blocks and fragments of hanging wall dolomite (fig. 18) embedded in irregularly layered host rock on or near the hanging wall-host rock contact. In a few stopes where the host rock zone is narrow, included fragments of hanging wall dolomite occur across the entire zone.

Minor folds resembling drag folds were found in many places in the south and southeast portions of the mine. Host rock in this area is almost exclusively banded, light to dark-gray, silicified dolomite. Because these folds, which are highly contorted in places, are not normally expressed in the overlying or underlying bands, it is thought that they represent penecontemporaneous slump folding. Sulfides are especially abundant in these fold zones.

Mineralization and Ore

Sphalerite and galena are the only commercially valuable minerals in the mine. Minor amounts of cadmium and silver were recovered from the zinc and lead concentrates. Mill heads over the life of the mine averaged less than 4 percent combined lead and zinc.

Mineralization is distributed erratically throughout the host rock zone. Large volumes of host rock contain only scattered low-grade zinc mineralization, whereas in other areas the mineralization occurs as numerous small, high-grade concentrations with much interstitial low-grade material.

Ore bodies are elongate in the direction of the regional strike (S. 50° W. to S. 60° W.) and plunge from 5° to 20° SW. Irregular in outline, they vary up to 80 feet wide, 80 feet high, and 650 feet long. An average ore body may be 35 to 45 feet wide, 20 to 30 feet high, and 300 to 350 feet long.

Fine- to medium-grained, yellow to orange, reddish-brown and dark-brown sphalerite, accompanied by pyrite, quartz, and white, medium- to coarse-grained dolomite, is by far the dominant ore mineral. It occurs as fracture and breccia fillings in and replacing silicified dolomite in the host rock zone. Galena is widespread but in very minor quantities, except in a few areas. Pyrite is found in close association with sphalerite and in amounts about equal to sphalerite overall, though the ratio of pyrite to sphalerite varies widely from place to place. For example, some of the stoped areas that were richest in lead and zinc contained relatively small amounts of pyrite. Concentrically banded, very fine-grained pyrite occurs in many places in the ore zone, in some instances giving the impression of having existed as crusts before being broken up prior to or during the introduction of sphalerite and galena.

The best quality and quantity of ore is to be found in the breccia. Generally the sulfides are confined to the matrix between the breccia fragments, appearing to have filled interfragmental openings, though some replacement of the white to light-gray, coarsely crystalline dolomite matrix has taken place. In a few places the sulfides seem to have partially replaced the breccia fragments as well. Near the footwall of the host rock zone, the fragments are more highly silicified and the matrix may be entirely very fine-grained quartz or jasperoid, with sphalerite grains, clusters, lenticles, and "veins" ramifying through the matrix between the fragments.

A number of ore occurrences are known from only slightly brecciated, lightly fractured, banded or massive silicified dolomite within the host rock zone, presumably replacing the dolomite.

Most of the ore is found within the main host rock breccia zone. However, one small stope was entirely in hanging wall rock and elsewhere a modest amount of mineralized hanging wall dolomite was mined adjacent to and as extensions of the main stoping areas. Most mineralization within the hanging wall is closely associated with zebra rock and coarse-grained, white to light-gray crystalline dolomite in dark mottled dolomite.

Mineralization within the footwall normally consists of fine- to very fine-grained, light-gray sphalerite filling spaces between breccia fragments and replacing slightly banded dolomite, breccia matrix, and less often, breccia fragments. Purple fluorite is often found in the footwall near the contact with the host rock, and it may extend into the host rock zone for a few feet. Galena rarely occurs within the footwall.

No thorough microscopic study and determination of paragenesis was made, but from the examination of hand specimens and a few thin sections and from general observations underground, it seems that quartz, white dolomite, and pyrite (possibly in that order) were deposited before sphalerite and galena. Minor quantities of quartz cement post-ore fractures and fault gouge.

Faults and Dikes

A large number of post-ore faults and dikes are exposed in the workings of the Calhoun mine. Most strike northerly and dip steeply east or west. Only a few faults exhibit appreciable displacement, the greatest being about 80 feet. Displacement is mostly dip-slip.

Dikes overshadow faults both in number and in importance. In relation to the mining operations, the faults were only a minor nuisance, but the dikes were a major source of dilution in many stoping areas. Few dikes were thick enough or closely spaced enough to justify mining them separately for waste or leaving them as pillars.

The dikes probably are lamprophyres. They range from very fine-grained to relatively coarse-grained, from biotitic (with minor augite, hornblende, and olivine in places) where fresh, to chloritic where altered. Highly altered dikes contain considerable serpentine and secondary carbonate. Dikes vary in color from greenish-black, to dark green, to pale green, depending on the extent of alteration. In a dike containing both altered and unaltered phases, the alteration was generally most intense along the contacts. Even though they have a wide textural and compositional range, the dikes are thought to have a common source.

Contact effects in the dolomite and ore adjacent to dikes include serpentinization, bleaching, dedolomitization, conversion of pyrite to pyrrhotite, and recrystallization of sphalerite. Sphalerite in the contact zone may be either coarser grained than normal, in which case it assumes a reddish-brown color, or finer grained and of a very pale straw color. Some dikes produce no contact effects, whereas others, mainly the coarser grained unaltered dikes, may have contact effects extending 6 to 8 feet into the adjacent rocks. Contact effects are normally present along both contacts of a dike. The most intense contact alteration effects were observed along a dike in the southwestern part of the mine. This particular dike was a medium-grained biotitic type, which contained subangular and rounded fragments and blocks of different rock types, mainly light-colored quartzite, but also granite, schist, dark quartzite, dolomite, quartz, and gneiss. The fragments generally have smooth surfaces with rounded corners and edges, probably the result of abrasion and assimilation.

Origin of Host Rock Zone

When considering the possible origin of the host rock zone, two questions arise: (1) to what can we attribute the pronounced layering of the host rock zone and the parallel orientation of platy and elongate fragments, and (2) why is the layering discordant with respect to the layering or bedding of the hanging-wall dolomite and with respect to the regional attitude of rock formations?

The author suggests that an answer to both of these questions is forthcoming if we assume that the layering in both footwall and hanging-wall rocks is bedding. Recognizing that the rocks of the mine area are on the limb of an overturned fold and hence may be upside down, the attitude of the bedding (layering) at the time of deposition of the strata can be determined easily with the aid of a stereonet by rotating the hanging-wall rocks from their present attitude (dip approximately 60° SE.) about 120 degrees to their original horizontal position below the host rock. Such an operation indicates that the bedding (layering) of the host rocks, if it existed at the time of deposition of the enclosing strata, had a dip of 51° in a direction N. 35° W. Such a steep bedding inclination could have been obtained if the relatively fine-grained clastic material with included hanging-wall rock fragments were deposited on the steep flank of a bioherm (the hanging wall), from which they were derived by wave erosion. Partial cementation of the flank sediments was followed by down-slope slumping of the steep flank sediments or by compaction.

According to the literature on present-day reefs and fossil reefs, stratification in sediments flanking reefs may differ in attitude as much as 90° from stratification in the reef. Possibly, the host rock zone represents a disconformity, a time during which sea level remained relatively static in relation to the reefs, in the midst of an otherwise lengthy period of slow sea-floor subsidence. This would have fostered the accumulation of debris in much greater quantities than would have been generated under conditions of subsidence, where the reef-building organisms would be striving just to maintain their position in or near the intertidal zone, the zone of maximum growth.

As noted earlier in the text, fragments and blocks of the hanging wall are commonly found in the host rock near its contact with the hanging wall. In contrast to the platy host rock breccia fragments, the hanging-wall blocks are irregular in shape and the host rock bedding drapes over them conspicuously (fig. 18). Banding in these hanging-wall blocks ranges from rotated to essentially parallel to the bedding of the main hanging-wall rocks (fig. 43), the latter case being more common. If we assume that these blocks represent material broken from the reef that fell into the sediment that was later to become host rock, then the great majority of the blocks should be rotated from their original attitude, which they are not. That they are not may indicate that they fell or slid only a short distance, and by being embedded in the sediment they were prevented from rotating or overturning.

Silicification of the fragments and clastic matrix was accomplished later by ground water or hydrothermal solutions moving through the permeable reef front breccia.

While this "reef theory" does not satisfactorily explain all characteristics and peculiarities of the host rock zone and its relationships to the hanging wall and footwall, other theories[1] have their shortcomings too. It is to be hoped that future efforts to extend and explore the host rock zone will turn up evidence more conclusive than what is available at present, or that future workers will discover clues which have been overlooked.

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[1] For quite a different interpretation of the nature and origin of the Calhoun host rock breccia, see "Calhoun Mine, an Alternative Origin."

1. Platy breccia of silicified to highly silicified, light-gray (extremely silicified) to black dolomite. Few fragments light-gray and gray unsilicified dolomite. Banding common in silicified fragments, parallel to lineation of fragments. Matrix of white, coarse-grained dolomite and small grit-size fragments of silicified material. Matrix partly replaced by fine-grained to coarse-grained pyrite, fine-grained, massive sphalerite and a little fine-grained, patchy galena.
2. Interbedded, dark mottled dolomite and gray to light-gray dense dolomite. Some coarse-grained, white dolomite as wavy banding and zebra banding. Bedding as shown, strike S.58° W., dip 79°-80° SE.
3. Fragments of gray dolomite in dark dolomite matrix.
4. Dark-gray to black bedding, with small included platy fragments. Little fine pyrite and sphalerite.
5. Light-gray dolomite, bedded as shown.
6. Platy to blocky breccia of unsilicified to slightly silicified, gray and dark-gray to black dolomite fragments. Mineralized matrix as on opposite wall. Many dark block fragments are partly silicified and suggest dark mottled dolomite. Banding (bedding?) generally parallel to length of fragments or blocks.
7. Highly mineralized.
8. Black silicified dolomite; few flat stringers of sphalerite interfinger with platy breccia to east.
9. Typical silicified and mineralized platy breccia.
10. Highly silicified dark fragments in matrix of fine sphalerite-quartzite mixture. Looks like Metaline ore.
11. Typical silicified and mineralized platy breccia. Grades into blocking and platy breccia about 6in. from face.

LEGEND

Hanging wall - massive and fragmental

Host rock - breccia and matrix

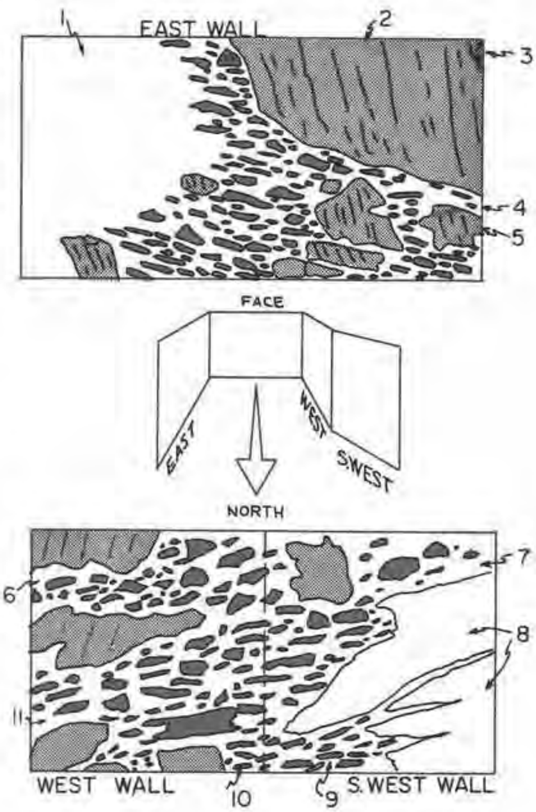

FIGURE 43.—Geology of parts of walls of U5L cutout, Calhoun mine, showing and describing relations between ore host breccia and hanging-wall dolomite.

CARBO PROSPECT

The Carbo prospect is in the NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 25, T. 39 N., R. 42 E., almost 2 miles east of Deep Lake. Campbell (1945) described the ore as an aggregate of cavernous lenses of smithsonite-rich dolomite up to 12 by 35 feet in exposed cross section, elongated parallel to the bedding of low-dipping white dolomite of the Metaline Limestone. Most lenses are a few inches thick and a few feet long. The dip extension of the mineralization is concealed. The largest lens assayed 20.5 percent oxidized zinc.

Yates (1964) mapped the host rock as intraformational breccia above the middle dolomite unit of the Metaline Limestone. A visit to the prospect in 1967 confirmed the highly brecciated character of the host rock, the presence of smithsonite in the rubble of the trenches, and the total lack of sulfides.

It is very unlikely that the prospect has any economic value. Nevertheless, it is of considerable interest because of its geologic setting in the intraformational breccia and its conformable character.

CAST STEEL MINE

The workings of the Cast Steel mine are in the SW$\frac{1}{4}$ sec. 3, T. 39 N., R. 40 E., about 200 feet east and 50 feet below the Northport-Spirit road. They consist of vertical and inclined shafts, both caved, and a tunnel driven for 70 feet in a S. 67° W. direction on a mineralized fault zone (fig. 44). The same zone crops out on the hillside 75 feet and 150 feet east of the portal of the tunnel. It strikes N. 67° E.

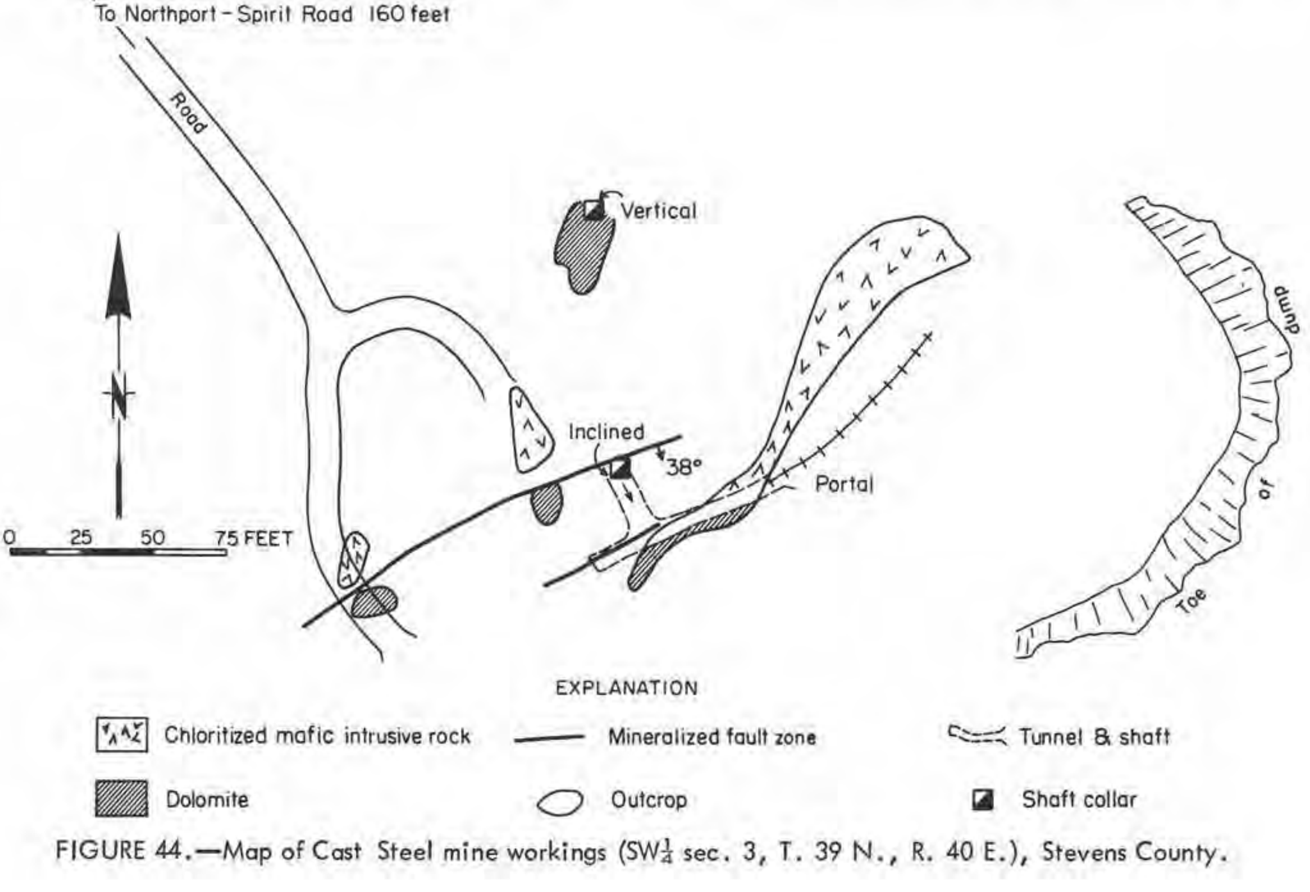

FIGURE 44.—Map of Cast Steel mine workings (SW$\frac{1}{4}$ sec. 3, T. 39 N., R. 40 E.), Stevens County.

and dips 38° SE. between chloritized mafic igneous intrusive rock in the footwall and gray dolomite in the hanging wall. The dolomite is probably the middle unit of the Metaline Limestone. The age of the intrusive is not known, but must be either Jurassic or Tertiary in age, according to the geologic map of the Deep Creek area (Yates, 1964).

Both the dolomite and the intrusive rock are intensely fractured for a few inches adjacent to the fault and the fractures are filled with galena and a little sphalerite. Some fractures, a fraction of an inch wide, subsidiary to the main fault zone, extend for as much as 2 feet into the intrusive and into the dolomite. Much of the galena is gneissic or "steely," indicating that it has been deformed during faulting.

Polished and etched sections of the ores, when examined under the reflecting microscope, reveal abundant deformation textures (bent cleavage surfaces, deformation twins in sphalerite, fractured pyrite) and annealing textures (equigranular galena) indicating that the sulfides had been subjected to considerable deformation and subsequent partial annealing after their emplacement.

CHERRY PROSPECT

The Cherry Prospect is in the NE¼ sec. 8 and NW¼ sec. 9, T. 36 N., R. 40 E. Four adits, totaling 483 feet of workings, are on the steep, west bank of Joe Creek where they expose gray, dark-gray, and black limestone, dolomite, and crackle breccia of both limestone and dolomite, of the lower unit of the Metaline Limestone. Bedding strikes are northeasterly and dips are moderate to the northwest.

The lowermost adit, approximate elevation 2,490 feet, bears N. 71° W. for 183 feet. Except for a small lamprophyry dike in the face of the tunnel, the rock is all dark-gray to black dolomite and dolomite crackle breccia. No sulfides were found. About 200 feet above the lowermost adit, an adit has been driven for about 50 feet in a direction N. 30° E. It exposes argillaceous limestone and dark-gray dolomite cut by calcite-filled minor faults. A little sphalerite was found beneath a small fault in the west wall. The main adit, approximate elevation 2,780 feet, has been driven in a direction S. 75° W. for 130 feet in black limestone and limestone crackle breccia, thence in a direction S. 20° E. for 90 feet in dark-gray to black dolomite and dolomite crackle breccia. No sulfides were found in the limestone but a small amount of disseminated sphalerite is to be found in dolomite and dolomite breccia near both the west and south faces. The uppermost workings, at approximately 2,830 feet in elevation, consist of a 30-foot adit driven due west along a small north-dipping fault in brecciated black limestone and dolomite. The rock below the fault is highly brecciated and weakly mineralized, with white calcite, quartz, and sphalerite over a tunnel length of about 6 feet.

The Cherry prospect appears to have little to recommend it. It can be said to be characterized by the presence of minor sphalerite in dolomite breccia of the lower unit of the Metaline Limestone, and by the absence of other sulfide minerals, such as galena and pyrite.

CHOLLET PROSPECT

The Chollet prospect, in the NE¼ sec. 1, T. 37 N., R. 39 E., is on a north-facing slope, between 3,000 and 4,000 feet in elevation, about 5 miles west of the Van Stone mine. Glacial deposits cover about 90 percent of the surface. According to Cox and Hollister (1955), the rock section is complexly folded Maitlen Phyllite, Metaline Limestone, and Ledbetter Slate, striking N. 10° E. to N. 50° E., with steep dips to the north. The Metaline Limestone appears to be about 4,000 feet thick here, including a lower unit on the east consisting of 1,000 feet of interbedded limestone and silty argillite, a middle unit 1,500 feet thick of fine-grained white, gray, and black dolomite, and an upper unit to the west, 1,500 feet thick, of massive, gray limestone grading upward into argillaceous limestone and slate, locally capped by jasperoidal dolomite. Farther to the west is black argillite of the Ledbetter Slate.

Geochemical soil sampling and analysis by American Smelting and Refining Co. identified five zinc anomalies, one of which was more than 2,000 feet long and 800 feet wide. Due to the lack of outcrop, the anomaly was explored by extensive trenching (about 2,000 lineal feet), most of which did not reach bedrock, and by diamond drilling. Bedrock mineralization was found to be largely oxidized. The unoxidized mineralization consisted of pyrite and dark-brown sphalerite "replacing" fine-grained dolomite along bedding and small fractures. Despite the great extent of the soil anomaly, the exploration work proved disappointing and no further work has been done.

According to Cox and Hollister (1955), the primary sulfide mineralization is in the middle dolomite unit of the Metaline Limestone, about 2,700 feet stratigraphically below the overlying Ledbetter Slate. The kind and position of the sulfide mineralization resembles that of the Yellowhead horizon.

CHLORIDE QUEEN

The Chloride Queen mine is in the E½ sec. 23, T. 37 N., R. 39 E., on the south side of Comstock Mountain, along the south fork of Clugston Creek. Production from 1902-1956 was 35 tons of ore carrying 1,569 ounces of silver, 19 pounds of copper, and 12,261 pounds of lead. Underground workings are on three levels: a lower level at approximately 3,250 feet elevation totals 2,655 feet of tunnels; an upper level at 3,420 elevation has 240 feet of tunnels; and an intermediate level at 3,350 feet elevation has 860 feet of tunnels. In addition, there are several shafts, raises and stopes (fig. 45).

The upper and intermediate levels and part of the lower level are mostly drifts on a faulted and brecciated zone in silicified dolomite. The faults are accompanied and paralleled by quartz veins and stringers up to several inches wide mineralized with tetrahedrite, sphalerite, galena, and some pyrite. The mineralized zone strikes N. 65° W. and dips 60°-90° NE., and is up to 15 feet wide; all or most of the production was from this zone.

A second and different type of mineralization is exposed in the lower adit, beginning about 900 feet from the portal and continuing erratically almost to the face, 1,850 feet from the portal. This mineralization is weak, consisting of sphalerite and galena, with very little pyrite, as tiny stringers and irregular masses up to a few inches across in dolomite breccia. The same kind of mineralization is exposed in surface cuts on the top of the hill above the underground workings. Jenkins (1924, p. 114) described the lead deposit on top of the hill as "galena occurring in bunches branching out in tiny stringers in brecciated gray dolomitic limestone." Brief descriptions of this deposit prepared by other geologists suggest strongly that the nature of the lead-zinc mineralization here is identical to that on the south workings of the Big Chief mine which, in turn, is very much like the sulfide mineralization at the Lead King and Lead Trust mines on Gladstone Mountain. The dolomite breccia host and its galena and sphalerite, unlike the breccia of the tetrahedrite-quartz zone on the upper levels, seem not to bear any relation to faults, slips, or other structural features generated by movement and crushing.

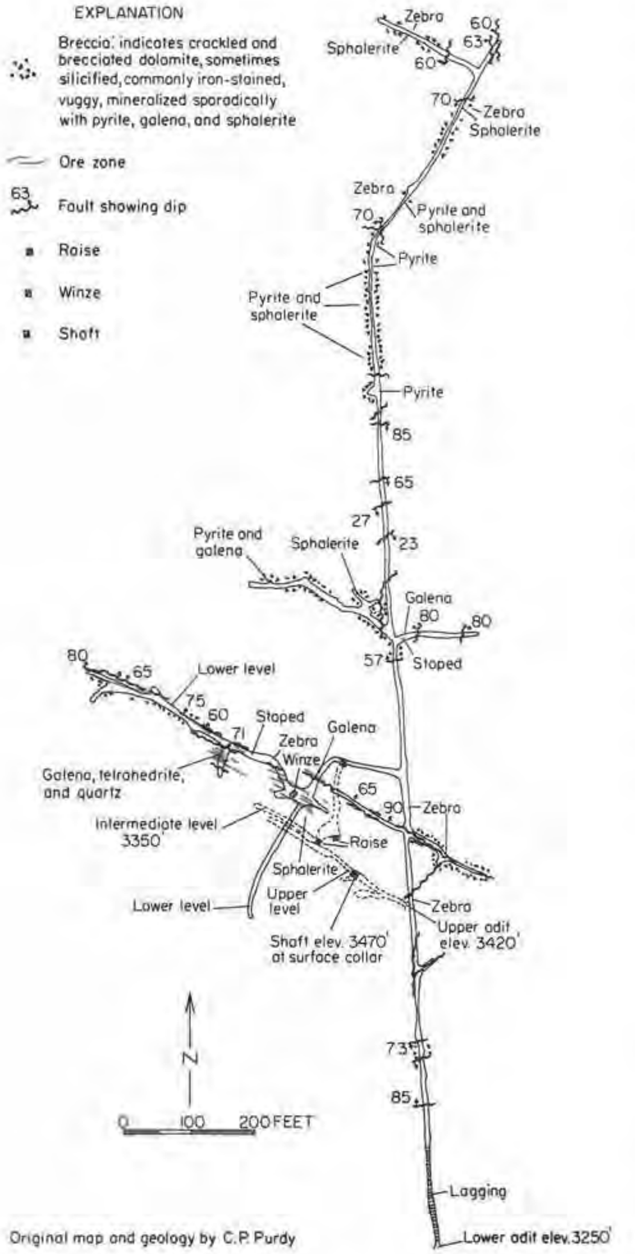

FIGURE 45.—Plan of lower, intermediate, and upper levels, Chloride Queen mine. Geology shown only for lower level. All rock, except where noted, is massive, fine- to medium-grained, light-gray, gray, and dark-gray dolomite. Dark-gray dolomite is commonly white-mottled. Highly banded parts are marked "zebra."

In short, there are two different kinds and ages of mineral deposits in the mine. One is sphalerite and galena, accompanied by a few subhedral or euhedral quartz crystals, in the matrix of a dolomite breccia. It does not appear to be structurally controlled. The other is a fracture zone mineralized with quartz, tetrahedrite, sphalerite, and galena and carrying, on the average, 45 ounces of silver per ton. It is believed to be younger, possibly very much younger, than the lead-zinc mineralization in dolomite breccia.

Presumably, the quartz-tetrahedrite-galena-sphalerite mineralized zone has been sufficiently well explored and mined on the present mine levels that no further expenditure there is advisable. However, in view of the persistence of the vein underground, some drilling for down-dip extensions of the ore body may be worthwhile. In addition, because of the great areal extent of the galena-sphalerite mineralization in dolomite breccia on Comstock Mountain, it is probable that large tonnages of this kind of mineralized ground may exist. Careful mapping and drilling would be required to explore this possibility.

DEEP CREEK MINE

The Deep Creek mine is on the west bank of Deep Creek in NE$\frac{1}{4}$ sec. 26, and SE$\frac{1}{4}$ sec. 23, T. 39 N., R. 40 E. It operated continuously from 1944 to 1956 and is reported (Fulkerson and Kingston, 1958) to have produced 15,182,927 pounds of lead, 65,621,962 pounds of zinc, 24,085 pounds of copper, and 36,455 ounces of silver. The mine is now (1974) idle and stripped of all underground and surface equipment and facilities except for a couple of dilapidated buildings. The workings are filled with water to within a few feet of the collar of the shaft.

An inclined shaft extends from the collar (elevation 1,877 feet above mean sea level) in a direction S. 18° W., at an average inclination of 64°, to the deepest (1,125 feet above mean sea level) of the 9 working levels, the 850-foot level. Almost all mine workings are beneath the water-saturated sands and gravels of the Deep Creek valley in carbonate rocks that are laced with post-ore faults and water courses. Consequently, high-pressure water was a continual problem during mining, necessitating extensive grouting ahead of exploration and development headings and large water-pump capacity.

Host rock for all ore mineralization is dolomite or dolomite marble of the middle unit of the Metaline Limestone that has been complexly folded into a synformal anticline plunging 80° to 90° ESE. to SE. (fig. 37). That is, the rocks have been tightly folded into a very steeply inclined troughlike form, concave to the east in map view, with the ore-bearing middle dolomite unit surrounded to the northwest and southwest by the underlying, but younger, limestone of the upper unit of the Metaline Limestone. This complex structure has been recognized by mapping the contacts of the middle and upper units and to a much lesser degree by observing bedding attitudes.

In 1953, the author, while in the employ of the mine owners and operators, Goldfield Consolidated Mines Co. of San Francisco, mapped the geology of all accessible mine openings on the 100-, 200-, 250-, 350-, 450-, 550-, 650-, and 850-foot levels. Most of the stopes were large, open and inaccessible. The 750-foot level and the mine workings on the West Zone No. 1 and West Zone No. 2 were driven in later years. Nowhere during the course of underground mapping was any structure found that could positively be identified as bedding. The dolomite varies in color from white to gray to dark gray and black, in grain size from 0.05 to 0.30 mm, and in structure from massive to thin banded. A great deal of dolomite is composed of alternating bands and thin lenses of white, gray, and dark-gray dolomite, varying from less than an inch to several feet in thickness. The texture and the composition of all dolomite is similar except for the presence of some carbonaceous matter in the darker bands. This marked banding was found throughout the mine workings. Its strike ranges from N. 35° W. to N. 50° W., averaging about N. 45° W., and dips range from 87° SW. to vertical, to 72° NE. The average dip is probably about 88° NE. Because nothing was seen that could be identified as bedding, and because the banding (layering) is remarkably regular despite the fact that the mine rocks lie along the axis of a major fold, the banding is believed to be metamorphic rather than depositional in origin. The attitude of most of the banding is compatible with it being a foliation parallel to the axial

FIGURE 46.—Massive sulfides, sphalerite(s) and pyrite(p), in lenses, pods, and layers, make up most of the cement or matrix of dolomite breccia. Note how the sulfide bodies conform to the borders of the elongate dolomite breccia fragments (light gray to white). Fragments are devoid of sulfides. Deep Creek mine ore.

surface of the synformal anticline referred to above. This banded and streaky dolomite (fig. 46) resembles some of the very platy deformed breccia of the Calhoun mine. Therefore, it is proposed that the Deep Creek host rock was once a dolomite breccia that was mineralized and subsequently deformed. The lenticular streaks and bands probably are greatly elongated and flattened breccia fragments. Both the fragments and the matrix of the original breccia together with the sulfide mineralization have recrystallized extensively. The deformation and subsequent recrystallization and grain growth have almost, but not quite (fig. 46), concealed the original breccia texture. In several places, especially in the Zinc Zone, the banding departed from its normal planar form and appeared as U-shaped or hooked masses, suggesting that some of the banding may be relic bedding that has been transposed in the direction of the metamorphic banding.

On the upper levels of the mine the dolomite carries small amounts of fine-grained fibrous tremolite. On the 450- and 550-foot levels, tremolite is conspicuous just west of the Zinc Zone and toward the southeast. Between the shaft and the Zinc Zone on the 650-foot level, tremolite is still more abundant, sometimes occurring as gray to white rosettes up to 2 inches in diameter, cored by quartz. Similar quartz-cored rosettes are found on the 850-foot level. In the downward expression of the Zinc Zone on the 850-foot level, the dolomite is extremely hard and tough, being accompanied by a mixture of quartz and tremolite, with minor amounts of very fine-grained pyrite and sphalerite. It is quite obvious that the amount of tremolite increases with depth in the lower part of the mine; still its distribution seems not to bear any particular relation to base-metal mineralization. It may be that the deepest mine levels are approaching some part of the Spirit pluton, for typically tremolite increases in amount in dolomite near the pluton.

The five ore zones in the mine are called the Zinc Zone, Lead Zone, South Zone, West Zone No. 1, and West Zone No. 2. These zones are staggered in a kind of en echelon pattern within an area about 8,000 feet long (north-south) and 4,000 feet wide (east-west). As can be seen by referring to the composite plan of the deeper mine levels (fig. 47), the ore zones become smaller, flatter dipping, more northerly-striking, and lower grade toward the south and west. All zones except the Zinc Zone appear to be zinc-rich parts of pyritic zones that extend for at least a mile along the strike. The expressions of some of these low-grade mineralized extensions of the South Zone and West Zone No. 1 are shown on figure 47 between the Zinc Zone and the shaft. The ragged terminations of the ore zones as depicted on the composite plan are highly diagrammatic, reflecting only the fairly abrupt and irregular transition from ore to waste. The same is true of the Zinc Zone outline, except that in this wide, vertical ore shoot the ragged nature of the ore margins is not exaggerated, and to some extent it is a reflection of folds or fold relics in the sulfide lenses and veins.

The Zinc Zone ore body is up to 300 feet long and 125 feet wide on the intermediate levels. The South Zone ore body is about 180 feet long and 50 feet wide where it is best developed on the 450-foot level. All five ore bodies are made up of slightly to well-banded dolomite, containing disseminated fine-grained pyrite and disseminations, lenticles, lenses, and irregular masses of sphalerite, pyrite, and galena. Some of the more regular masses of sphalerite are relatively tabular or veinlike, with widths up to 5 feet and lengths of several tens of feet. The thin lenses and tabular masses are completely conformable with the banding of the dolomite. Some of the sulfide bodies have U- or J-shapes, or fairly regular fold shapes; wherever they are found in banded dolo-

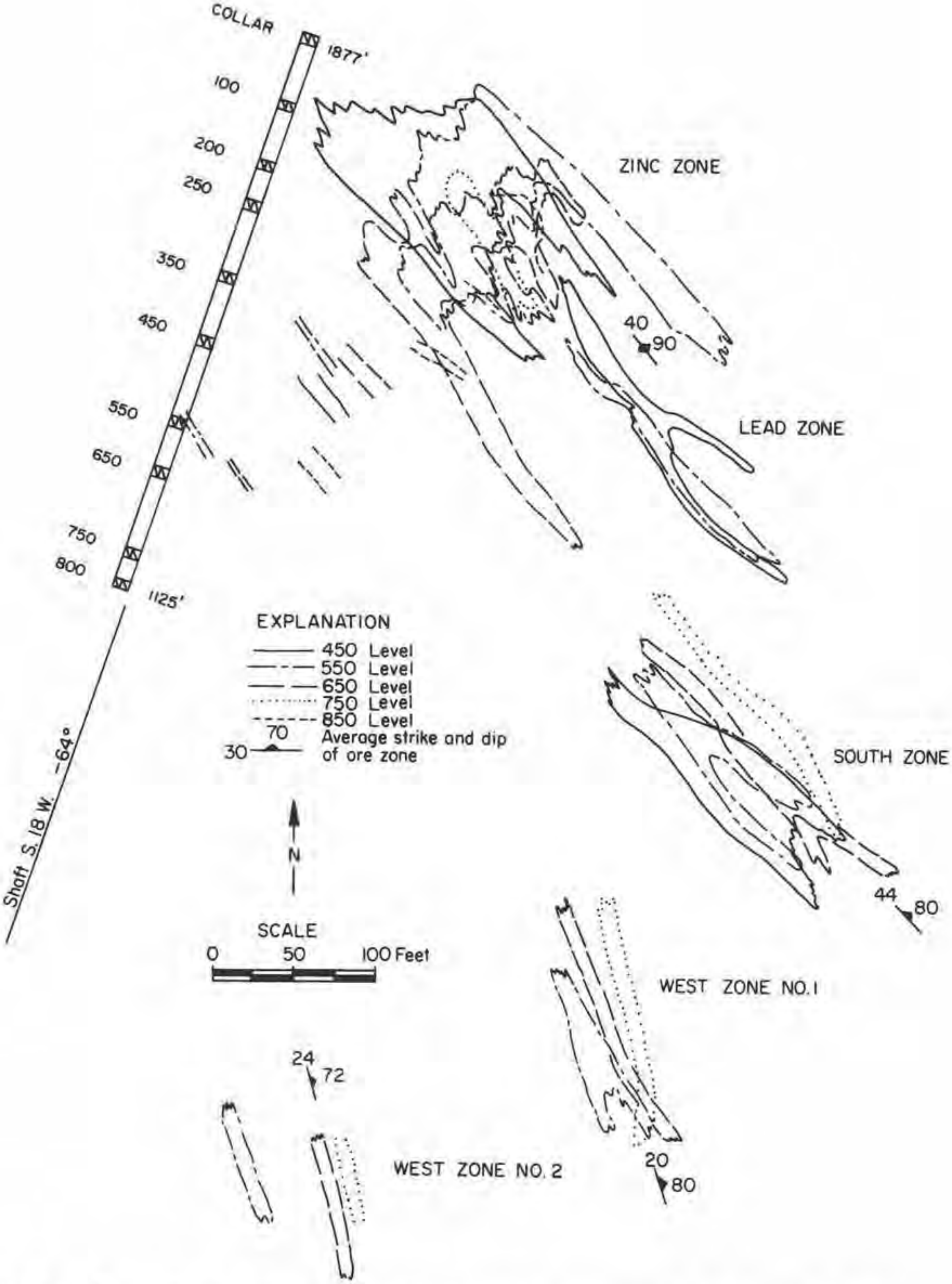

FIGURE 47.—Composite plan of principal ore zones on the deepest five levels, Deep Creek mine.

mite, the banding has a similar configuration, reinforcing the suggestion that ore veins and masses are conformable with the banding.

Except for the northwest termination of the Zinc Zone ore body, the ore bodies terminate by narrowing of the entire sphalerite-galena mineralized zone and by narrowing and pinching out of individual zinc-lead sulfide masses within that zone; pyrite-rich portions may continue beyond the ore margins. Beyond the ore bodies the mineralized zones are narrower, less intensely mineralized, pyritic, with zinc or lead sulfides only as disseminations or as sporadic small "veins" and lenticles. There seems to be no difference in the appearance, texture, or composition of the enclosing dolomite, whether it hosts high-grade, low-grade, or merely pyritic mineralization.

At the northwest end of the Zinc Zone ore body, the Zinc Zone seems to be exceptional in that the change from ore to waste may take place within inches and the usual pyritic sheath is less well developed or lacking. Furthermore, though U-shaped and J-shaped sphalerite (less often galena) masses are found in all zones, they are larger and more numerous in the Zinc Zone ore body. In fact, the northwest margin of the Zinc Zone ore body is highly dentate to smoothly arcuate, suggesting a broad, complex fold pattern. This is emphasized by the tendency for the southeast margin of the same ore body to extend as two prongs resembling the limbs of a fold (fig. 47), the axial surface of which would bisect the ore body longitudinally and would strike and dip about parallel to the elongate ore extensions and to the banding in the dolomite. The ore bodies in the Lead Zone, South Zone and West Zones on the 450- and 550-foot levels have somewhat similar shapes; however, these shapes are obtained from the configuration of mine workings, rather than by direct observation of ore margins during mapping; hence the suggestion that they may be fold controlled is very problematical. In contrast, the Zinc Zone's ore-body outline was obtained from the configuration of mine workings and by careful geologic mapping in development tunnels on the 450-, 550-, and 650-foot levels; thus confirming the ragged U-shape or horseshoe-shape of the more concentrated sulfide mineralization.

Post-ore Faults

Post-ore faults and water courses throughout the mine are generally in two prominent sets. One set has strikes ranging from north-northwest to north-northeast and dips within 5° of vertical to east or west. The other set strikes north and dips from 40° to 50° E. Ore offsets are seldom more than a few feet on even the largest of these. Sulfides adjacent to the faults may be granulated (pyrite) or plastically deformed (sphalerite and galena).

Ore Mineralogy and Texture

A detailed study of the textural relationships of the stratiform zinc-lead ores in carbonate rocks of northeastern Washington, including those of the Deep Creek mine, are discussed elsewhere (see table 5). However, it is relevant here to point out some of the more interesting and significant aspects of the study of the Deep Creek ores.

Minerals identified during the microscopic study of polished and etched sections of the Deep Creek ores are pyrite, galena, sphalerite, dolomite, tremolite, and quartz. Minimum grain size of dolomite ranges from 0.02 to 0.07 mm. Maximum grain size of dolomite is about 0.25 mm, galena is 0.40 mm, pyrite 0.50 mm, and sphalerite 3.0 mm. Commonly, irregular or nodular masses of pyrite are enclosed in sphalerite and galena that display smooth, lobate, and occasionally cuspate boundaries with each other. Many of the pyrite masses possess an internal banding brought out by the distribution of gangue inclusions or bands rich in sphalerite or galena. Much pyrite occurs as elongate, fan-shaped, or arcuate masses composed of tapering pyrite crystals arranged side-by-side with their long axes normal to the arcuate perimeter of the mass. In places, the radially columnar pyrite pattern is interrupted by areas of pyrite with a granoblastic texture. Many crystals of the enclosing sphalerite and galena possess a granoblastic polygonal texture, and sphalerite is almost invariably twinned. Annealing twins are very common and deformation twins are found in some of the larger sphalerite crystals. Tremolite occurs as straight thin blades or fibers intergrown with sulfides.

The banded, layered, nodular, botryoidal, and fan-shaped aggregates of sulfides are the relics of the original deposition in a shallow, relatively low-temperature environment, probably within the interfragment spaces of a limestone or dolomite breccia. The environment must have been similar or identical to that in which the sulfides of the Calhoun mine were formed. The high degree of banding of the host rocks and ores today, the pull-apart structures in brittle pyrite masses and their cementation by sphalerite and galena are interpreted as having developed during regional metamorphism. The lobate and cuspate boundaries between sphalerite and galena, the moderately coarse equigranular texture of sphalerite and galena, the polygonal shape of many of their grains, and the pronounced development of annealing twins in the sphalerite are attributed to post-deformational heating, which allowed strained grains to recrystallize and new grains to grow to their present size. Tremolite intergrown with the base metal sulfides is the product of the same thermal metamorphism.

Future Development

Further development of the mine will be very costly because of extensive rehabilitation required to make it operational and because of the everlasting problem of high-water pressures. However, there is no reason to believe that all of the ore grade mineralization has been won or that future ore discoveries will be any lower grade or less amenable to concentration than heretofore.

ECHO MINE

The Echo mine is in the SW¼ sec. 14, T. 37 N., R. 39 E. It is reported (Huntting, 1956) to have two adits, totaling 850 feet of underground workings. At the time of the author's visit in 1968, the workings were inaccessible. Mine dumps consist mostly of black argillite (Ordovician Ledbetter Slate) with minor gray limestone. No sulfides were seen. No production has been reported.

ELECTRIC POINT AND GLADSTONE MINES

The Electric Point and Gladstone mines are in the SE¼SE¼ and NE¼SE¼ sec. 18, T. 39 N., R. 42 E., at and near the top of Gladstone Mountain, about 3 miles northeast of Deep Lake. Both properties were located in 1914 and production began in 1916. Production to date has been as follows:

Mine	Lead (lbs)	Zinc (lbs)	Silver (ozs)
Electric Point	30,711,917	10,691	7,154
Gladstone	15,583,187	44,681	9,602

At the time of the author's visit in 1967, both properties were idle and underground workings inaccessible. Extensive bulldozer diggings had disrupted the surface so extensively as to have erased observable geologic features almost entirely. An exception is the preservation of two of the surface outcroppings of the mineralized "chimneys" at the Electric Point mine (fig. 48). From these and neighboring outcrops, and by reference to figure 49, we recognize that the mineralized "chimneys" cut through dolomite of the middle dolomite unit of the Metaline Limestone. The Gladstone workings are in mixed white and dark-gray mottled dolomite. The Electric Point shaft is collared in light-gray dolomite crowded with chert nodules and vermiform bodies up to one inch in diameter. Although the "chimneys" have very steep to vertical dips, the host dolomite dips gently (5° to 35°) to the southwest.

Although underground and former surface exposures are either inaccessible or largely concealed, we are fortunate in having detailed accounts of these

FIGURE 48.—Photograph of surface expression of mined-out lead ore pipe at Electric Point mine, Gladstone Mountain. Left and right sides are gently dipping dolomite. Dark mass at center is the galena-bearing red ground of the pipe, cutting directly across the bedding in the dolomite.

deposits (Weaver, 1920; Patty, 1921; Jenkins, 1924) prepared when the mines were active. Because these reports are now out of print and because of the valuable information they provide, much of the following text is taken from them. Where they provide especially valuable and detailed information on the geology of the deposits, extensive direct quotation is resorted to. For illustrations of the shape and pattern of mine workings at these two properties the reader is referred to Jenkins (1924, p. 81-94).

Patty (1921, p. 93) attributes the discovery of the Electric Point mine in 1914 to Chris Johnson and J. E. Yoder who "found a large float boulder of solid galena imbedded in the wash on the very crest of the point. A few shallow pits soon disclosed the first chimney of ore made up of cerussite, mixed with limonite and carrying occasional nodules of galena." The Gladstone mine holdings were located "soon after the discovery of the Electric Point ore bodies." During the next few years at least five ore chimneys were discovered at Electric Point and ten at Gladstone; not all were ore-bearing and some had no surface expression. All chimneys stand nearly vertically; they are circular or oval in plan view, ranging in maximum diameter from 30 to 150 feet and in vertical extent from 150 to 800 feet. Some, when followed downward, were found to branch into separate roots or to taper downward and finally wedge out.

The character of chimney filling at the Electric Point mine is typical and is described by Patty (1921, p. 95, 96) as follows:

> The chimney fillings are essentially limonitic clay, cerussite, called "sand carbonate" by the miners, nodules of galena and remnants of badly altered lamprophyre dikes. The galena is found as isolated nodules and boulders scattered through the carbonate. In some instances masses of solid galena weighing from 1,000 to 2,000 pounds are found. The ore

FIGURE 49.—Geologic map of Gladstone Mountain area.

> mined has averaged about one ton of galena for each six tons of cerussite, and the remarkable feature of the deposits is that this same ratio appears to hold true from the surface down to the present deepest level. Further, the same pronounced limonite and clayey selvage is as prominently developed on the 800 level as it is nearer the surface.

As an ore chimney is approached, slight brecciation of the host dolomite may be detected as much as 30 feet from the chimney periphery. Typically, the dolomite is intensely brecciated from 1 to 2 feet from the chimney wall; the breccia fragments are quite friable and can frequently be pulverized easily by hand. The matrix of the breccia next to the chimney is the same "red ground" as makes up most of the chimney. Within the chimney this material is granular and friable, commonly containing partially decomposed and slightly rounded fragments of lamprophyre in addition to friable fragments of dolomite. It is composed of hydrous iron oxides intermixed with clay and grains of disaggregated dolomite, small particles of cerussite, and galena lumps and nodules encased in a film or layer of anglesite surrounded in turn by crystals of cerussite. It is interesting to note that, although sphalerite or its oxidation product smithsonite are common in other deposits in northern Stevens County, none was found by the author and none was reported by Weaver, Patty, or Jenkins.

The red color of the chimney filling is produced by the hydrous iron oxides, which were formed by the oxidation of some unknown iron-rich primary mineral. There is no evidence that pyrite was the primary mineral and none was found. Jenkins (1924, p. 84) writes that "there is considerable evidence that the mineral siderite was one of the original gangue minerals of the galena and this iron carbonate substance has been responsible for the extensive development of soft limonite in the deposits. . . ." Dump material is too badly decomposed to have preserved any of the original iron-rich mineral, so that Jenkins' explanation of the source of the iron could not be verified.

Origin of Chimney Deposits

An answer to the question of how the original chimneys were formed is provided by the brecciation of the host dolomite adjacent to the chimneys. Jenkins (1924, p. 90) notes "a number of faults and slips with their slickensided walls and accompanying breccia zones are exposed around the edge of each glory hole"; and (p. 94) "thin ore seams were found, in places, to run out from the chimneys along the slip planes. . . ." All authors are agreed that the breccia is a fault breccia and that the localization of the chimneys is due to extensive brecciation at fault intersections. When considering the conditions leading to deposition of ore at the Electric Point mine, Patty (1921, p. 97, 98) expresses the following opinion:

> The writer believes that the Electric Point ore bodies were originally massive, irregular replacement chimneys of galena in limestone. The location of these chimneys appear to be controlled by well-marked shear zones traversing the limestone. Two major zones of this nature were observed in the mine; these strike north 35° east and north 55° east, respectively, and dip at 80° angles toward the northwest. At favorable points along the zone, particularly near the intersection of two shear zones, the limestone has been badly brecciated. These brecciated areas generally assumed the form of the present ore chimneys."

And in the discussion of the Gladstone mine, he writes (p. 103):

> The location of the irregular replacement chimneys in the magnesium limestone is controlled by two major shear-zones which are incident to each other at an angle of 40°. The shear zones strike south 40° west and south 80° west, stand nearly vertical and are marked by sharp striated walls. It is interesting to note that the trend of these shear zones check quite closely with the major zones controlling

> the Electric Point ore bodies. Each productive ore chimney so far discovered is oriented adjacent to one or the other of these shear zones, and they form the most reliable guide for directing exploration work.

The control of chimney position and attitude by fault brecciation was recognized early in the development of the deposits; Patty reports that the operators followed any streaks of iron-stained gouge-filled shear zones, for they were found in several instances to lead into chimneys of ore and offered one of the few prospecting guides available.

Although most of the fault movement and brecciation was pre-ore, there has been some post-galena shearing as well. Evidence of this is the presence of nodules of "steel galena" and the recognition in etched polished section of parallel elongate galena crystals with lengths ranging from 0.05 to 0.50 mm and widths from 0.03 to 0.08 mm. On the average, their length is 4 to 5 times their width.

Patty (1921, p. 99) reports that at least two mica lamprophyre dikes cut the ore bodies in the Electric Point mine so that the ore emplacement must have been prior to dike intrusion. Similar lamprophyre dikes at Rossland, British Columbia, about 16 miles northwest of Gladstone Mountain, have been dated (Fyles and others, 1973) as 48.2 million years old.

The present chimney filling is largely the product of oxidation, solution, and precipitation of supergene minerals, like limonite, clay, cerussite and anglesite, at the expense of the primary minerals, through the action of meteoric waters above the water table. The character of the filling is essentially the same from the surface to the deepest workings, over 800 feet beneath the surface. According to Patty (1921, p. 101) "no pumping is required from even the deepest mine workings. Such a deep-set water table would afford an opportunity for the deeper penetration of free oxygen." This great depth of oxidation is matched by only one other deposit in the region, the Black Rock mine. The deep oxidation probably took place in pre-glacial time. Somehow the resulting oxidized zone was protected from glacial scour. Many chimneys were covered by glacial drift prior to mining.

At least four other properties within a half-mile radius of the Gladstone and Electric Point mines on Gladstone Mountain have explored chimneys like those of the mines just described. These include the Red Iron, Elk, Wildcat, and Keystone mines. All of them, like the Electric Point and Gladstone, are in the middle dolomite unit of the Metaline Limestone.

FARMER MINE

The Farmer mine workings are in the NW¼NW¼ sec. 34, T. 39 N., R. 41 E., about three-eighths of a mile west of the south end of Deep Lake (fig. 35). About 400 feet south of the 27-34 section line is a caved inclined shaft, the collar of which exposes gray dolomite cut by a rusty-weathering vein zone with sphalerite and a little pyrite. The zone is 18 inches wide, strikes N. 60° W. and dips 53° NE., about parallel to bedding in country rock. Approximately 600 feet southwest of this shaft is a trench about 13X8X7 feet in jointed gray dolomite marble. Joint sets have attitudes N. 40° E. to N. 60° E., dipping 75° SE., and N. 30° W., with vertical dip. Mineralization along these joints consists of irregular blebs and streaks up to ¼-inch wide and a few inches long of sphalerite, galena, pyrrhotite, and pyrite.

Still lower on the hillside, at an elevation approximately 2,150 feet, is an adit driven in a direction N. 60° E. for a distance of 420 feet. The geology of the adit and its connecting crosscuts is shown on figure 50. Beginning about 175 feet and continuing to about 325 feet from the portal, the tunnel is in white and gray dolomite, which has an unusual mottled appearance due to the presence of ovals and indistinct areas of dolomite bordered by thin scalloped bands of dark-gray dolomite. The area enclosed by the scalloped bands is often rich in tremolite. From about 325 to 375 feet from the portal is the same mottled dolomite except that the dark scalloped bands are mostly black sphalerite with a little pyrrhotite, pyrite, and galena (fig. 51). This mineralized zone was first recognized in a hole drilled from the face when the adit extended only 120 feet from the portal (Reed and Gammell, 1947). An examination of the geologic map (fig. 50) shows that the known mineralized zone, which is about 35 feet wide, is cut off both to the west and east by post-ore faults. A second diamond drill hole was drilled for 243.7 feet in a direction N. 06° E., up at 23 degrees, from the same setup as the first hole. It intersected only scattered sulfide mineralization, mostly pyrrhotite. Possibly the lack of appreciable mineralization in this hole is attributable to right-hand offset on the western post-ore fault.

The oval-shaped mottles of the mineralized zone are seldom more than a couple of inches long, and the sulfide peripheries or scalloped bands are generally less than one-eighth of an inch thick. Where the scalloped bands close completely they are exactly like those reported and illustrated by Park and Cannon (1942, plate 26, p. 50) for ores of the Z Canyon area, Metaline mining district, Pend Oreille County. In many respects the scalloped bands, whether or not they close completely, resemble the scalloped sulfide bands in the Iroquois mine (fig. 56) and other properties in Stevens County. The pattern of the sulfides in the Farmer mine is thought to be due to the rimming of breccia fragments by hydrothermal coarse-grained dolomite and very fine-grained sulfides, as at the

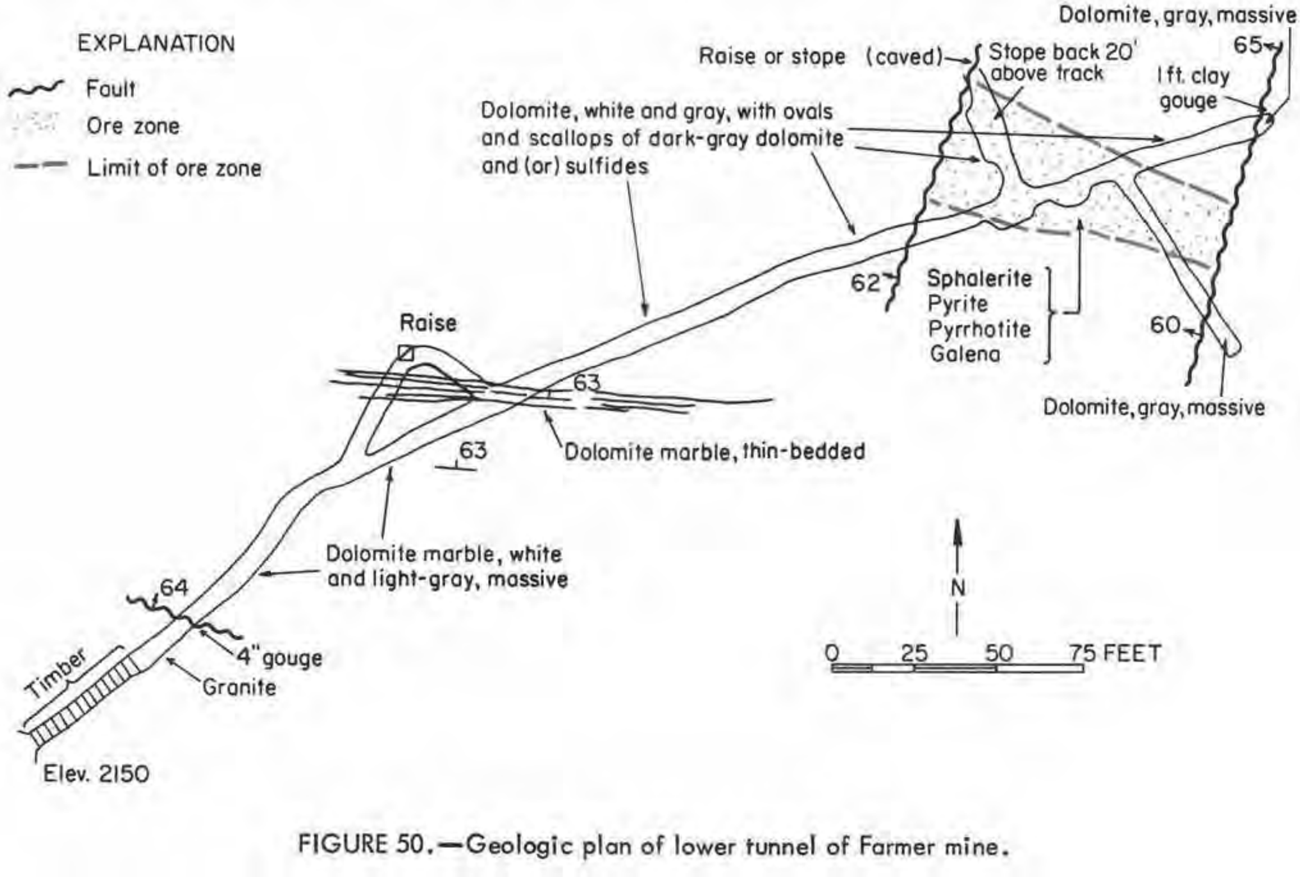

FIGURE 50.—Geologic plan of lower tunnel of Farmer mine.

FIGURE 51.—Photograph of zinc ore specimen from lower tunnel of Farmer mine, showing typical atoll texture and scalloped patterns of sphalerite(s) in coarse-grained white dolomite. Scale is cms and mms.

Iroquois mine. Later, the fragments were partially or completely replaced by tremolite or coarse-grained dolomite, as at the Lead King mine. Still later, the whole rock was recrystallized and otherwise greatly modified during thermal metamorphism by the adjacent Kaniksu batholith.

A microscopic study of several polished ore specimens from the mine reveals that dolomite of the host rock and some of the sphalerite occur as parallel elongate grains. The remainder and most of the galena and pyrrhotite display granoblastic polygonal texture produced by recrystallization and grain growth. Apparently the ores were deformed and subsequently annealed by heat from the nearby granite intrusions.

GALENA FARM

The Galena Farm mine is in the NE$\frac{1}{4}$ sec. 7, T. 37 N., R. 40 E., in a region of heavy forest and sparse outcrops. A long trench (approximately 250 feet) has been put down along the contact of a green phyllite and an overlying white micaceous marble. The marble bears a much stronger resemblance to the Reeves Limestone Member of the Maitlen Phyllite than it does to Metaline Limestone. The beds and rock contact strike N. 22° E. and dip 78° to 85° W. This contact and the limestone adjacent to it for a width of 6 to 30 inches are cut by rusty-weathering, quartz-filled fractures mineralized with fine-grained pyrite, galena, chalcopyrite, and ankerite or siderite. A shaft at the south end of the trench is filled with water. About 50 feet directly below the trench a tunnel has been driven on a quartz vein along the phyllite-limestone contact, but just a few feet beyond the portal the tunnel is inaccessible.

Although the mineralization is conformable with the bedding at least locally, the presence of quartz-siderite gangue, chalcopyrite, and the reported (Huntting, 1956) presence of tetrahedrite and silver values to 9 ounces per ton indicate that the mineralization as well as the host rocks resemble those of the Red Top Mountain area in sec. 25, T. 40 N., R. 41 E., and sec. 30, T. 40 N., R. 42 E., Stevens County.

GALENA KNOB

The Galena Knob mine is in the SE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 21, T. 37 N., R. 40 E. Three shafts, now caved, the deepest of which is reported to be 200 feet, and several trenches expose dolomite and dolomite breccia over an area about 200 by 250 feet, at the top of a small hill near the center of NE¼ sec. 21, on the southeast side of Green Mountain. The bedrock is gray to dark-gray to black, fine- to medium-grained dolomite marble, with beds and nodules of dark-gray chert or jasperoid and veins and irregular masses of white glassy quartz. Bedding in the dolomite strikes about north and dips 80° or more to the west.

In the vicinity of the workings, all rock is a dolomite breccia with angular to subround fragments of light-gray dolomite or zebra-banded dolomite up to 1 foot in diameter, and small fragments of black argillite and dolomite, in a matrix of coarsely crystalline calcite, dark-gray to black chert, and galena. The breccia is thought to be a solution-collapse breccia related to an overlying unconformity.

The only sulfide present is galena. In addition to its occurrence as irregular patches or masses up to several inches across in the breccia matrix, it occurs also as veins and shatter-fillings along at least two prominent faults. One strikes from north to N. 20° E. and dips about 80° W., parallel to bedding; the other strikes north-northwest with dips ranging from 65° to 80° W. Galena-bearing quartz veins along these faults are commonly about 6 inches wide but one vein of galena 4 feet wide was cut by a shaft put down at the west side of the workings, now caved. This vein was reported to strike northwest and dip 60° SW.

The concentration of galena along faults and associated fractures in the dolomite and filling spaces between fragments in the breccia clearly point to an epigenetic origin for the galena in both occurrences.

HI CLIFF MINE

The Hi Cliff mine is in the NW¼SE¼ sec. 3, T. 37 N., R. 39 E., adjacent to the county road from Echo to Onion Creek. It has produced (Fulkerson and Kingston, 1958) 54 tons of ore containing 81 ounces of silver, 9,456 pounds of lead, and 8,140 pounds of zinc.

The workings consist of 2 adits (crosscuts), one at 2,995 feet and the other at 3,120 feet above sea level, and rather extensive drifts, raises, and stopes from these. The upper workings were open in 1968, but the lower workings were inaccessible. Fortunately, both levels had been mapped by geologists for the Division of Mines and Geology and their maps are presented in figure 52.

On the basis of the report by Jenkins (1924, p. 116), the work of the Division geologists in 1953, and the brief examination of the upper workings by the author in 1968, it appears that dolomite breccia of the uppermost part of the upper limestone unit of the Metaline Limestone is mineralized with sphalerite and galena over a horizontal length of 80 feet, a horizontal width of 2 to 5 feet, and a near-vertical extent of 185 feet. The mineralized zone strikes north and dips 70° W., parallel to the bedding in the dolomite. The sulfides seem to be intimately associated with the breccia and to fill spaces between breccia fragments; previous workers considered that there is a slight tendency for the mineralization to be localized by slips or faults.

At a distance of 385 feet, in a direction S. 03° E. from the portal of the upper adit and at an elevation of 3,095 feet, is an open cut and a short adit (25 feet) into the cliff face that exposes a dolomite breccia zone from 1 to 4 feet wide in dark-gray dolomite. The dolomite breccia and bedding in the dolomite strike north and dip 70° W. The breccia is well mineralized with brown sphalerite. It lies between the overlying black shales of the Ledbetter Slate and the underlying gray limestone. It resembles the exposures in the Hi Cliff workings described above and no doubt is an extension of them.

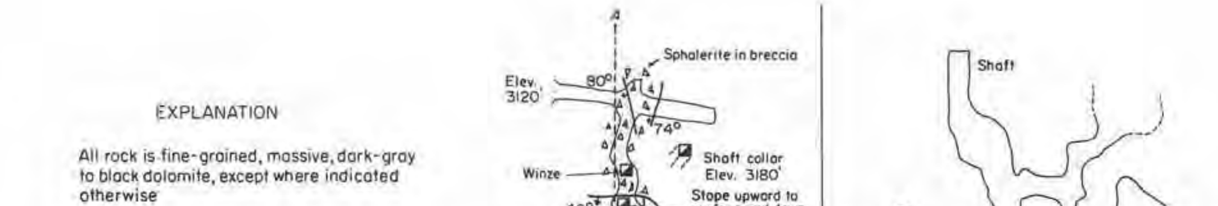

FIGURE 52.—Longitudinal section of upper and lower levels, looking east, of Hi Cliff mine. Plane of projection passes through A–A' and dips west at 75° (sec. 3, T. 37 N., R. 39 E.).

HOWARD

The Howard property is in the NW¼ sec. 2, T. 37 N., R. 39 E., east of the A and C property. It is reported to consist of 2 adits, each about 75 feet long, driven approximately east at elevations of 3,010 and 3,145 feet above sea level. A stope from the lower level has a length of 30 feet and a width of about 8 feet. It extends to a height of 25 feet to within a few feet of the surface. On the upper level a mineralized zone about 3 feet wide has been stoped over a length of 30 feet and a height of 30 feet above the sill.

Both mine levels are reported to be in white and light-gray, highly banded and tremolitic limestone marble, probably of the upper limestone unit of the Metaline Limestone. Sphalerite and minor amounts of galena and pyrite occur as widely scattered blebs, streaks, and elongate lenses parallel to the pronounced banding in the marble. The mineralized zones and the banding on both levels strike within 15° of east and dip from 70° to 80° N. A granodiorite apophysis of the Spirit pluton truncates the banded marble and its contained sulfides, about 15 feet east of the upper workings. The granite-marble contact continues up the hill in a northerly direction.

The Howard and the A and C are similar in all geological aspects. The banding in the host rock is metamorphic in origin. Field examination failed to provide incontrovertible evidence that would allow a choice to be made between sulfide metasomatism and pseudomorphism of the banded rocks, as contrasted with a metamorphic origin for the banding of both the carbonate rock and its contained sulfides. However, at both properties the sulfide mineralization is truncated by the granitic rocks of the Spirit pluton, an observation that is compatible with a pregranite and premetamorphic origin for the sulfides.

IROQUOIS MINE

The Iroquois mine workings are in the SW¼ sec. 20, NW¼ sec. 29, and NE¼ sec. 30, T. 40 N., R. 42 E., about 1 mile southeast of the top of Red Top Mountain (fig. 53). Several pits, trenches, two short tunnels and a glory hole trace out the mineralized zone on the north-facing slope above the main underground workings. The principal workings are illustrated in figure 54. The main adit bears S. 43° E. at elevation 2,810 feet, for 780 feet. For the first 250 feet, it is in black argillite of the Ledbetter Slate. For the next 10 feet, the adit cuts through intensely sheared and distorted argillite and dolomite marking the position of the steeply south-dipping Russian Creek Fault (Yates, 1964). The remainder of the adit, the 880 feet of drifts, and 1,350 feet of crosscuts are in what Yates has called "intraformational breccia" of the Metaline Limestone.

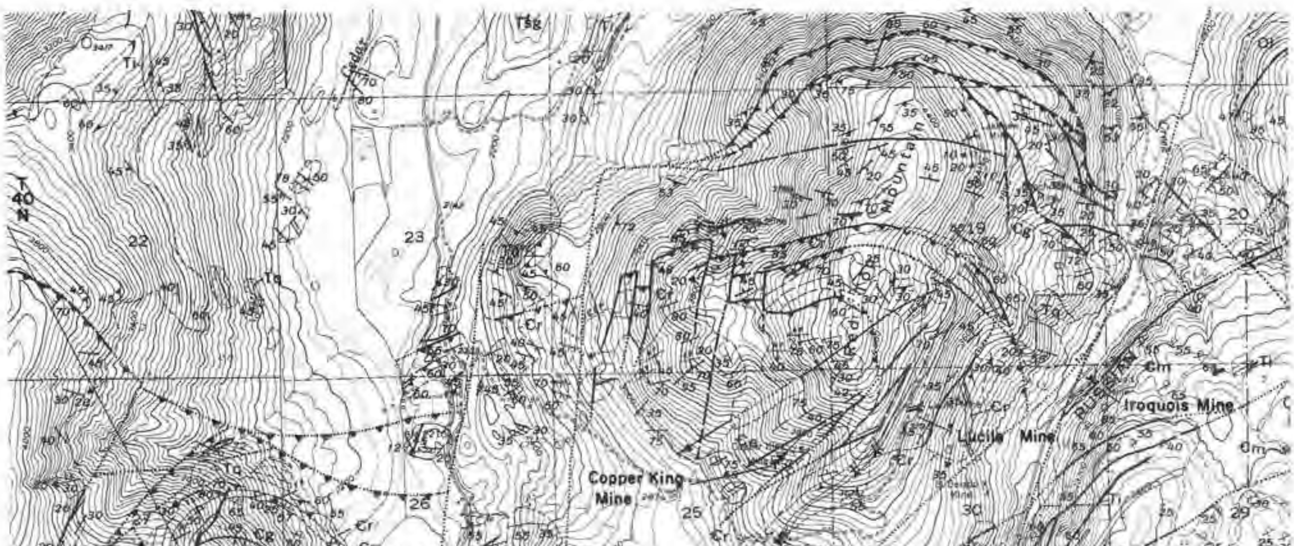

FIGURE 53.—Geologic map of Red Top Mountain area, showing location of Copper King, Red Top, Lucile, and Iroquois mines.

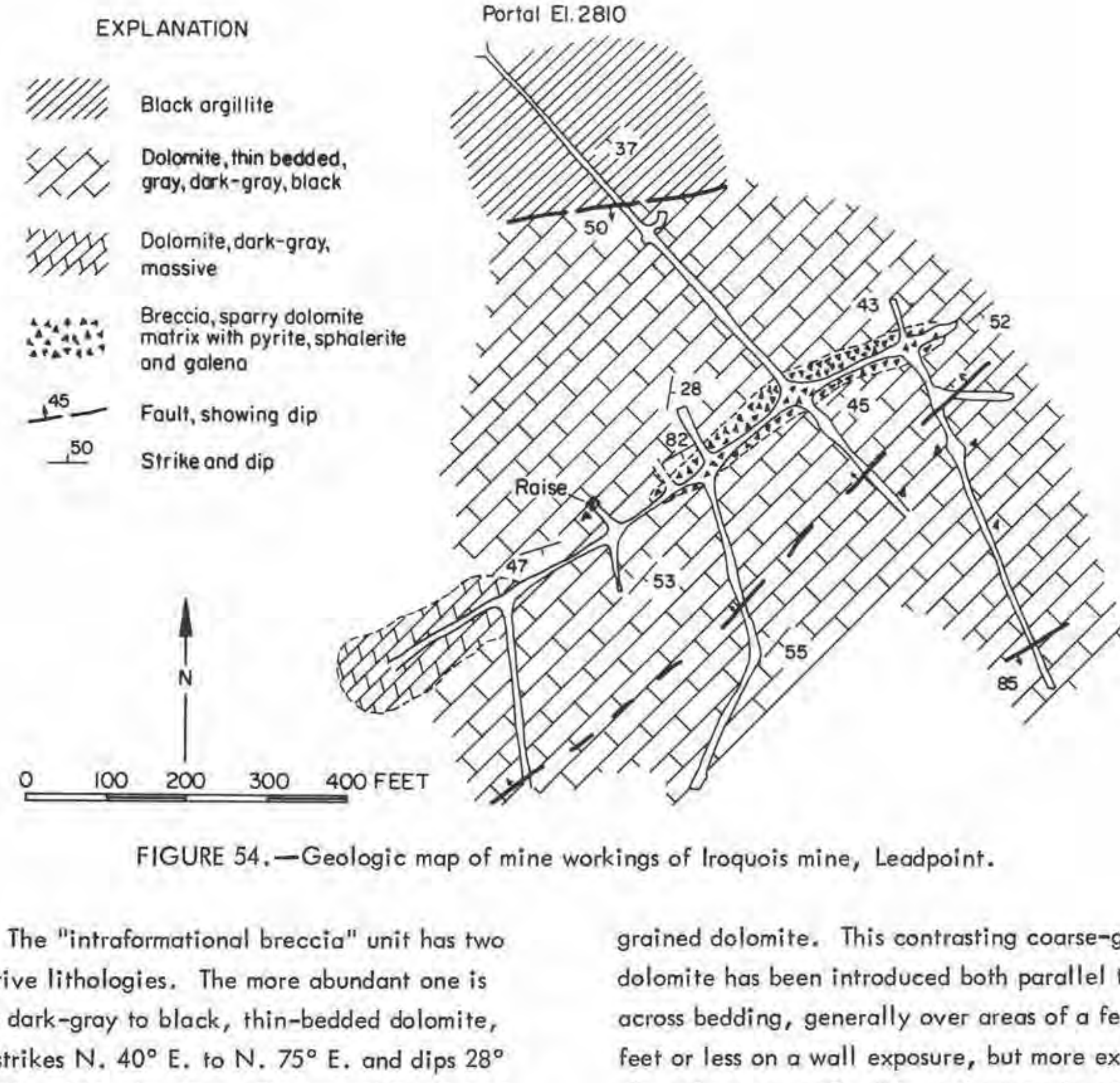

FIGURE 54.—Geologic map of mine workings of Iroquois mine, Leadpoint.

The "intraformational breccia" unit has two distinctive lithologies. The more abundant one is gray to dark-gray to black, thin-bedded dolomite, which strikes N. 40° E. to N. 75° E. and dips 28° to 82° SE. within the mine. The second is a breccia composed of tabular, angular to subangular fragments of the thin dolomite beds in a fine-grained, gray dolomite matrix which contains many small dolomite clasts (fig. 55). This breccia is a true sedimentary rock developed by the breaking up of partially consolidated beds and the incorporation of the fragments in the new strata, which are nearly contemporaneous with the original beds.

At numerous places within the mine, the thin-bedded dolomite and intraformational breccia is cut by small veins and irregular patches of white coarse-grained dolomite. This contrasting coarse-grained dolomite has been introduced both parallel to and across bedding, generally over areas of a few square feet or less on a wall exposure, but more extensively along the main drift. Where the introduced dolomite is more abundant than the host dolomite, the latter appears as dark fragments surrounded by white dolomite, giving the rock a brecciated appearance. The dark fragments seem not to have been disrupted wherever the introduced dolomite makes up only a few percent of an exposure, but where it is abundant, the fragments are often disoriented. They are quite angular, with sharp and distinct edges. Commonly, the coarse white dolomite of the fragment matrix contains fine-grained pyrite and pale-yellow sphalerite, less often galena. The sulfides occur in looping and cus-

FIGURE 55.—Photograph of typical intraformational breccia of the Metaline Limestone. Contrast enhanced by mild hydrochloric acid etch. Layered (bedded) tabular fragments of fine-grained dolomite are immersed in a darker matrix of very fine-grained to sand-size clastic dolomite. Iroquois mine.

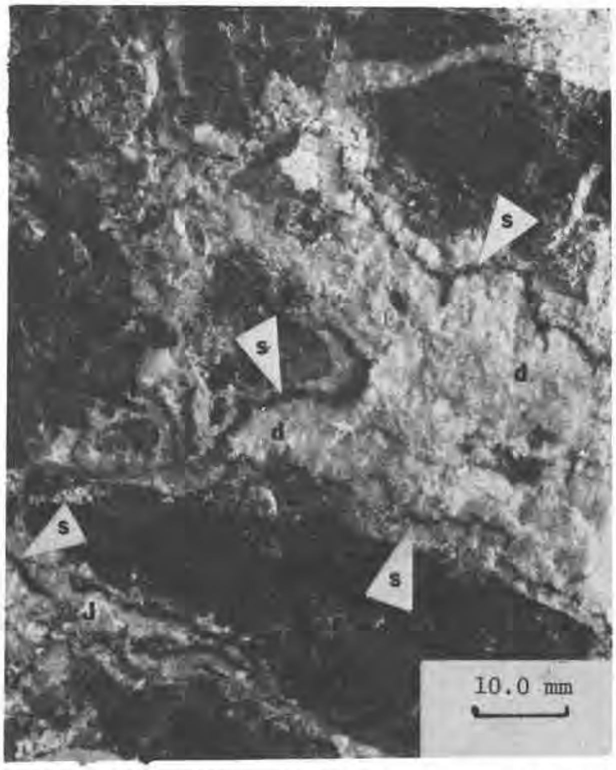

FIGURE 56.—Photograph of zinc ore from Iroquois mine, showing sphalerite(s) in white to light-gray, coarse-grained dolomite(d), which is the matrix of a dolomite breccia. Dolomite breccia fragments (black to dark gray) are separated from the sphalerite, which parallels fragment boundaries, by a layer or cockade of coarse-grained dolomite, the crystals of which are elongate in a direction about normal to fragment surface. (See also figs. 12 and 13.)

pate layers, seldom more than 2 mm thick, that parallel the outlines of the dolomite fragments, but are separated from them by 4 to 8 mm of coarse white dolomite (figs. 12, 13, 56). Similar white matrix dolomite is on the side of the sulfide layer farthest from the fragments. This unusual pattern of sulfide distribution could have been brought about by (1) brecciation of thin-bedded dolomite and intraformational breccia, followed by (2) deposition of coarse white dolomite on the fragments, then (3) precipitation of sulfides, with (4) subsequent resumption of filling by white dolomite. Generally, the latest precipitation of dolomite filled all available interfragment space, but sometimes filling was incomplete and vugs up to 20 mm wide may be found. Less often, the later dolomite deposition was followed by quartz deposition, filling or partially filling the remaining interfragment space. In some places, the deposition of white dolomite was not interrupted by the deposition of sulfides so that the resulting breccia matrix is barren.

Exposures of this coarse-matrix breccia, both mineralized and unmineralized, are highly irregular in outline and distribution, showing no connection with through-going fissures or fractures. The most extensive and best mineralized zone of this kind is the main ore body exposed discontinuously over a length of about 450 feet (fig. 54), and a width of as much as 50 feet, along and adjacent to the main drift and in the raise. This area of brecciation seems to conform roughly with the bedding in the dolomite. In its richest part, in the main drift up to 150 feet west of the principal adit, assays of more than 8 percent have been reported over widths of several feet.

Ore bodies of this kind are very difficult to explore and exploit because of their irregularity of form, and the vagaries of their distribution. However, they do seem to be more continuous along than across bedding. They seem not to bear any relation to fractures, fault zones, or stratigraphic position. However, the facts that the sulfides are confined to breccias and that they are invariably accompanied by coarse, light-gray to white crystalline dolomite are useful in exploration because both the breccia and the crystalline dolomite are more extensive than the ore bodies and so provide larger exploration targets.

LAST CHANCE CONSOLIDATED

The Great Western and Last Chance workings of Last Chance Consolidated Mines are in the SE¼ sec. 24, T. 39 N., R. 40 E., about 3,000 feet east of Deep Creek (fig. 37). The position and shape of the principal workings are shown on the geologic map (figs. 41 and 57). None of the underground workings were accessible at the time of the author's visit.

The vein on the Great Western ground was located in 1888 (Weaver, 1920). Between 1904 and 1954 when the mine shut down permanently, the Last Chance mine produced 5,937,708 pounds of lead, 110,110 pounds of zinc, and 18,567 ounces of silver. The Great Western produced 434,072 pounds of lead, 936,524 pounds of zinc, and 125 ounces of silver between 1916, when it began production, until 1929. The Great Western was the first mine (1916) in Stevens County to produce zinc.

All veins fall within a block of ground about 450 feet wide and 2,400 feet long, composed of dark-gray mottled dolomite belonging to the middle dolomite unit of the Metaline Limestone. This block is bounded on the west by a major north-trending fault, probably younger than the veins. Within the block there are at least four mineralized veins. Two distinct veins within the Last Chance workings are remarkably uniform in strike (N. 25° E.) and dip (64° W.), over a combined strike length of at least 650 feet and a dip length of at least 500 feet.

According to Weaver (1920, p. 311) the principal adit of the Great Western workings intersected a "fracture mineralized zone" about 100 feet from the portal having an east-west strike, which "was followed for 40 feet where it split, and one branch continued in a direction almost due east and the other approximately N. 40° E. for 60 feet, where it turns and continues N. 10° E. . . ." The Great Western mineralized zone is shown as a single vein zone in figures 41, and 57, with an east-west strike in its western part and a northeast strike in its eastern part. Dips are toward the north and northwest at angles from 40° to 60°. The vein zone consists of silicified dolomite cut by quartz veins and galena-sphalerite veins over a width of 2 to 5 feet. About 200 feet southeast of the principal workings is the Ronka shaft and its attendant level and stope, now inaccessible. Where the ore shoot has been worked through to the surface, it consists of a vein zone 14 inches wide, and parallel galena veins up to 2 inches wide, striking N. 32° E. and dipping 63° NW. It is not known whether this vein zone and a lesser one about 60 feet to the east are extensions of the principal vein zone of the Great Western workings or of the Last Chance veins.

The Last Chance workings, from 500 to 1,500

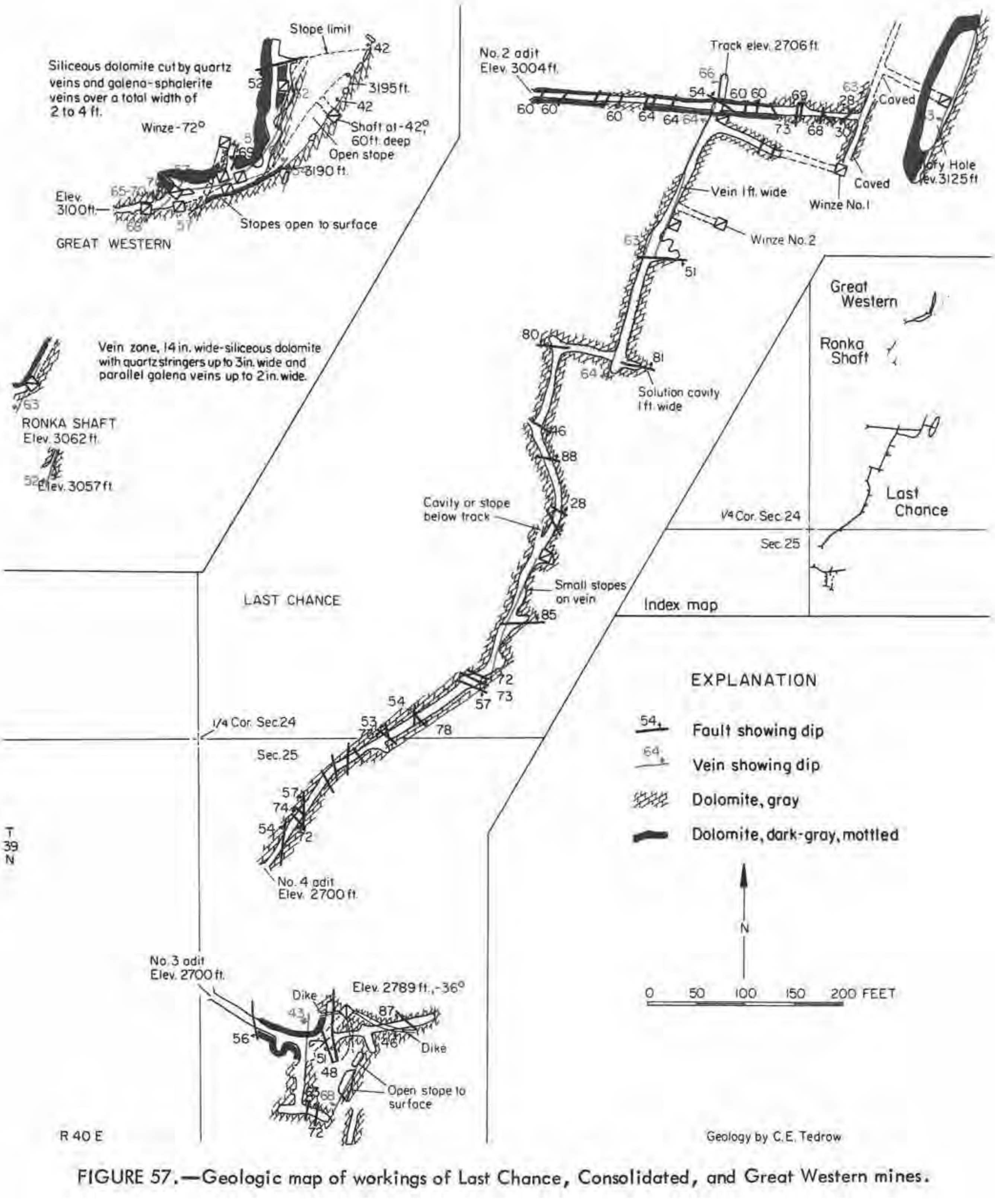

FIGURE 57.—Geologic map of workings of Last Chance, Consolidated, and Great Western mines.

feet south of the Ronka shaft, consist of four adits, several open cuts and trenches, and a "glory hole" where a stope was mined through to surface. The positions of the principal workings are shown in map view on figure 57. The most extensive workings, both drifts and stopes, are those on a vein system extending from the 2,700-foot level (No. 4 adit) through the 3,000-foot level (No. 2 adit) to the surface at 3,125 feet above sea level (fig. 58). The No. 4 adit level exposed two veins, parallel to each other and about 10 feet apart, over a length of about 500 feet. The veins strike from N. 20° E. to N. 25° E. and dip 63° NW. The mineralization, like that of the Great Western workings, consists of quartz, galena, and minor amounts of sphalerite, as veins up to 1 foot thick in a fractured and silicified zone up to 4 feet wide, in gray and dark-gray dolomite.

Due to the inaccessibility of most of the mine workings and to the scarcity of recognizably bedded rock exposures, it is not possible to determine precisely what geometric relationship the veins bear to the bedding. However, it is clear that the veins are emplaced along faults, and they appear to be parallel or nearly parallel to bedding. However, the branching character of the veins in the Great Western workings illustrates that the veins are not strictly conformable everywhere.

Laboratory studies of polished sections prepared from dump specimens are greatly hampered by the highly oxidized condition of the specimens. Nevertheless, it is clear that the ore minerals have been deformed and subsequently annealed, for some sphalerite displays deformation twins and some galena possesses well-developed triple junctions in a granoblastic polygonal texture.

LEAD KING

The Lead King mine is on the steep northwest side of Gladstone Mountain (fig. 49) in the $SE\frac{1}{4}SE\frac{1}{4}$ sec. 12, and $NE\frac{1}{4}NE\frac{1}{4}$ sec. 13, T. 39 N., R. 41 E., about 1 mile northwest of the Gladstone mine and $1\frac{1}{2}$ miles southeast of Leadpoint. The lower workings consist of a tunnel driven southeasterly into the face of the mountain below a talus slope for a distance of 326 feet (Patty, 1921, p. 107). These workings are now inaccessible, but Patty reports that the tunnel cuts thinly bedded argillites (Ledbetter Slate), lampro-

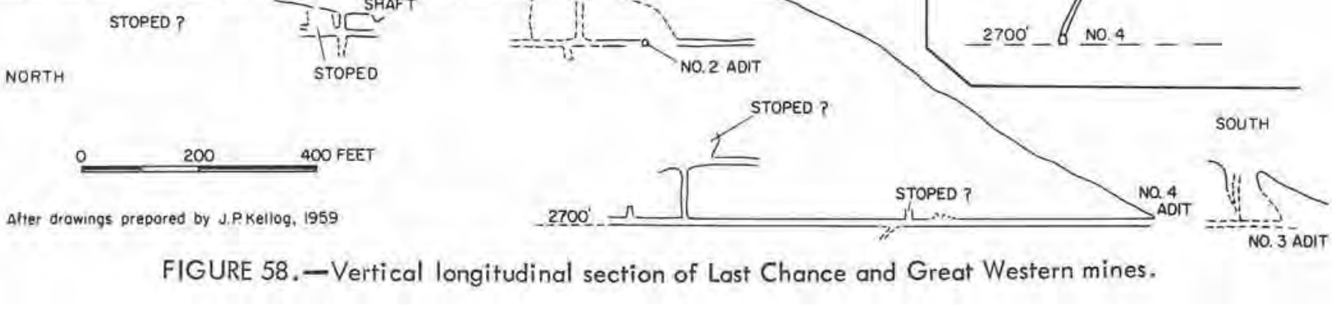

FIGURE 58.—Vertical longitudinal section of Last Chance and Great Western mines.

phyre and monzonite dikes, and limestone (Metaline Limestone) that contain a small galena-cerussite vein and "several small vertical slips filled with gouge and badly iron-stained material." Yates (1964) shows the argillite of the Ledbetter Slate to be in fault contact with the "limestone," or more correctly with "intraformational breccia." According to Yates' map, intraformational breccia is conformably and stratigraphically above the middle dolomite unit of the Metaline Limestone. The intraformational breccia is described and illustrated under "Iroquois mine." The upper contact of the intraformational breccia is generally shown as a fault contact with either younger or older rocks, but in secs. 9 and 16, T. 40 N., R. 42 E., Yates has mapped it in normal contact with Ledbetter Slate.

About 200 feet above the tunnel, at an elevation of 3,600 feet, a trench has been cut in dolomite bedrock starting at the cliff face and extending in a southeasterly direction for 100 feet. It exposes unmineralized intraformational dolomite breccia and highly jointed and mineralized dolomite breccia over the entire length of the north wall. Bedding in the unmineralized intraformational breccia dips about 22° SW. Joints in the mineralized breccia are in two sets; one strikes N. 20° W. and dips 90°, the other strikes N. 20° E. and dips 65° SE. The mineralized dolomite breccia is composed of a network of highly irregular veins and masses of white to yellow-white, very coarse-grained dolomite in which dolomite crystals are commonly up to 10 mm across—in contrast to the grains in the dark-gray dolomite of the intraformational breccia, which seldom have a grain size as great as 2 mm. Most of the veins and masses are parallel to bedding of the dolomite, some are about right angles to bedding, but many have highly irregular shapes and courses unrelated to bedding orientation. Typically, they have highly irregular unmatched walls and many irregular or wispy inclusions of dark-gray dolomite, indicating that the coarse-grained, white dolomite has replaced the finer grained, dark-gray dolomite. Frequently, the coarse dolomite veins contain vugs scattered along their medial portions; such vugs are most often lined with dolomite rhombs, but quartz crystals are common as well, and occasionally galena is present. In many places, the former vug is entirely filled with white quartz. In those parts of the breccia that are entirely coarse-grained dolomite, galena is found, often with quartz, as thin irregular veinlets a few inches long and as lumps or cuspate masses up to a few inches across. Such lumps are always about halfway between the nearest relict dark-gray dolomite fragments, and are separated from them by the coarse-grained, white dolomite. The general appearance of the more highly mineralized breccia is of a white, coarse-grained dolomite enclosing irregular "patches" of dark-gray, finer grained dolomite and studded with randomly scattered and isolated lumps and highly irregular short branching veins of galena, accompanied by quartz. Since the galena bodies are seldom more than an inch or two across, the value of the mineralized rock is much more dependent on their number and spacing than on their size. This coarse-grained dolomite and associated galena and quartz is identical to the lead mineralization on the south slope of Comstock Mountain in the Big Chief workings described earlier. Deposits of this kind are readily identified by the universal presence of white, coarse-grained dolomite. However, they are difficult to explore and exploit effectively because the areas of coarse-grained dolomite are irregular and show no consistent localization by structural or stratigraphic features, and because galena occurs in a random manner in the coarse-grained dolomite or may be absent entirely.

LEAD TRUST

The Lead Trust mine property is in the SE¼SE¼ sec. 12, T. 39 N., R. 41 E., and SW¼SW¼ sec. 7, T. 39 N., R. 42 E., east and northeast of the Lead King mine (fig. 49). The old workings, now mostly inaccessible, are described by Jenkins (1924, p. 95) as follows:

> The principal upper surface workings consist largely of a glory hole opened on an irregular shaped chimney of ore. A 216-foot tunnel directed S. 21° E. and driven into the hill at a lower position cuts the ore body and stopings have been made on it to the surface.
>
> The ore occurs as irregular bunches of galena in a zone of brecciated limestone, which strikes N. 73° E. dipping southeast at an angle of 60°. Besides the rock breccia, crystals of dolomite form the gangue with some siderite, which has been partly altered to limonite. Where this has taken place, nodules of galena occur weathered separate from the rest of the rocks and associated with some lead carbonate material. An inclined winze 30 feet deep, directed S. 24° E., sloping 75° was sunk on the ore in the tunnel.
>
> A tunnel lying about 150 feet lower in elevation than the above-described tunnel is over 500 feet long, driven in dolomitic limestone. The face of the tunnel was in a faulted and brecciated rock with some galena in the fracture zone forming an ore body from 16 inches to 2 feet wide. The galena occurs as irregular veinlets surrounded by crystals of dolomite and some siderite. The strike of the ore zone encountered is N. 55° E., dipping southeast at an angle of about 85°.

At the time of the author's visit in 1967, a surface rock excavation about 40 feet wide, 135 feet long, and 75 feet deep (probably the site of the glory hole referred to by Jenkins) exposed light-gray, fine-grained dolomite, dark-gray to black, fine-grained dolomite, and intraformational breccia of the Metaline Limestone. Although the rock in the steep walls was too loose for safe examination, many boulders on the floor of the pit are identical to the mineralized breccia of the Lead King mine. That is, white to yellow-white, very coarse-grained dolomite forms the matrix of a dolomite breccia, and this matrix contains galena veins up to ¼-inch wide and several inches long, lumps, and disseminated grains. The galena is often accompanied by dark-gray, very fine-grained quartz or chert. The distribution, size, and attitude of the mineralized body from which the pit boulders came was not determined. Presumably it is part of the zone described by Jenkins as striking north-northeast and dipping steeply southeast.

LONGSHOT

The Longshot mine is in the NW¼ sec. 18, T. 36 N., R. 41 E., 3½ miles northeast of Old Dominion Mountain. The mine was not visited by the author.

The country rocks are reported to be quartz-biotite-andalusite schist, hornblende schist, mica schist, and limestone marble, possibly belonging to the Maitlen Phyllite. The schists are highly foliated and the limestone is thin-banded. Foliation and banding are parallel to each other (N. 65° E., 70° to 80° NW.), and approximately parallel to bedding. Tightly appressed parasitic folds are common; they plunge about 40° SW.

Workings consist of several pits and trenches, a 600-foot crosscut and a 320-foot drift, at about 3,600 feet elevation, and an upper level drift 245 feet long, at 3,680 feet elevation, approximately. The crosscut was driven N. 20° W. to connect with the lower level drift that bears N. 55° E. along the contact of the schists (exposed in the crosscut) and the overlying marble. There is a very little sphalerite and galena disseminated parallel to the banding of the limestone marble at the southwest extremity of this level. The upper level bears N. 60° E. along the same contact. The western part of this drift exposes coarse-grained sphalerite and galena in disseminations, lenticles, and lenses, up to 1 foot wide, distributed and oriented parallel to the banding of the limestone marble. The mineralized banding and ore lenses strike N. 60° E. to N. 65° E. and dip 70° to 80° NW. The zone is about 150 feet long and extends from the schist-marble contact up to 20 feet into the limestone marble. The sphalerite and galena are accompanied by a considerable amount of coarse crystalline calcite and a little pyrite or pyrrhotite. Within the zone, sphalerite and galena are found also in a breccia composed of blocks of banded marble, scarcely different in orientation from the unbrecciated marble, in a matrix of coarsely crystalline calcite with a very little dolomite and quartz. Its origin is unknown. A few thin veins of quartz, calcite, sphalerite, galena, and possibly tetrahedrite, oriented N. 20° W., 23° NE., cut across the banding. They are parallel to a joint set that is well developed in this area.

Any further exploration should concentrate on the extension of the marble-schist contact. In view of the regular and pronounced plunge to the southwest exhibited by parasitic folds and lineation, there is a good likelihood that sulfide ore shoots plunge similarly. This may explain the confinement of mineralization to the very west end of the lower level, rather than directly down dip from the upper level. Possibly the extension of the upper-level mineralization lies southwest of the lower-level drift face.

MAGMA

The Magma mine is in the E½SW¼ sec. 28, T. 38 N., R. 41 E., east of the Sierra Zinc mine. The workings consist of several small rock cuts, a 610-foot adit, a 110-foot shaft, and other workings, for a total of about 1,800 feet (Huntting, 1956). The mine was not visited by the author. Workings and mineralization consisted of (1) a quartz-calcite vein up to 2 feet wide with much pyrite and a little scattered galena, (2) an adit driven east in banded marble mineralized with pyrite and sphalerite and minor amounts of galena, and (3) a vertical shaft sunk on banded dolomite mineralized with sphalerite, pyrite, and galena. Where the marble is in contact with granite, it contains tremolite, garnet, epidote, quartz, and some molybdenite.

Although the zinc-lead-iron mineralization has been classified as a "contact metamorphic replacement of limestone" (Huntting, 1956), the author is of the opinion that only the silicates-quartz-molybdenite association is a contact metamorphic deposit and that it has been superimposed on an older pregranite mineralization of the Yellowhead type. That is, the zinc-lead-iron mineralization is a metamorphosed rather than a metamorphic deposit. The host rock dolomite, now banded marble, is probably the middle dolomite unit of the Metaline Limestone.

MAKI AND DOSSER PROSPECTS

The Maki prospect is in the center of the SW¼NW¼ sec. 35, T. 39 N., R. 41 E., on a south-facing hillslope 600 feet north of Currant Creek (fig. 35). It consists of 21 surface pits, trenches, and steeply inclined shafts up to 50 feet deep, scattered over an area 300 by 400 feet. These workings are in slightly schistose portions of gray banded dolomite marble.

The marble is part of a band of limestone marble, dolomitic limestone marble, and dolomite marble of the upper unit of the Metaline Limestone that extends for more than a mile in an east-west direction, along the hillside north of Currant Creek. It is in contact to the south with biotite granite and to the north with Ledbetter Slate and has an estimated true thickness of 650 feet. Pronounced banding in the dolomite marble strikes N. 80° W. to due west and dips 45° to 80° N., probably averaging about 60° N.

Mineralization in the shafts, pits, and trenches appears as hydrous iron-oxide gossan zones containing lead and zinc carbonates and sulfides as streaks and disseminations oriented parallel to the banding of the host rock. The more strongly mineralized streaks and bands may be as much as 3 or 4 feet wide and are estimated to contain up to 4 percent each of lead and zinc. Single streaks or bands seem only to extend a few feet or tens of feet along the strike, so that mine-making possibilities seem dim despite the extensive area over which the mineralization has been found. However, the band of host rock marble continues along the strike for over a mile in all, and hence deserves attention.

The Dosser prospect is in the SE¼NW¼NE¼ sec. 35, T. 39 N., R. 41 E., about 2,000 feet west of the Maki workings. Outcrops and four surface trenches expose limonite containing scattered grains and streaks of galena and sphalerite in thin-bedded gray and black dolomite and dolomite marble. The host rock and mineralization are in all respects similar to those described above for the Maki prospect.

One section of gangue and ore minerals from the Maki mine was polished and studied under the reflecting microscope. Crystals of dolomite gangue (host rock) may be elongate (up to 1.5 mm X 3 mm) or about equigranular. Where equigranular, they commonly display good granoblastic polygonal texture. Some sphalerite is found as discrete grains along dolomite grain boundaries, but most is found in elongate grain clusters up to 3 mm in length. Elongate clusters of sphalerite grains are parallel to each other and to the banding in the host rock. Most clusters are composed of several sphalerite grains, each of which displays well-formed straight-sided annealing twins. Both pyrrhotite and pyrite were also identified in polished section. The latter, though not abundant, is in well-formed crystals up to 0.10 mm in diameter.

The rock banding, elongate dolomite crystals, and elongate clusters of sphalerite grains suggest that both the sulfides and carbonate host rock were subjected to the same regional deformation. The coarse grain size and the development of granoblastic polygonal textures indicate that subsequently the strained rocks and ores were recrystallized and annealed. Since the host rock is unusually coarse in the vicinity of the biotite granite contact, it may be concluded that the ore minerals were emplaced before granite intrusion and were annealed at the time the intruded rocks were heated by the granite magma.

MICHIGAN BOY

The Michigan Boy prospect is in sec. 4, T. 36 N., R. 40 E., and sec. 33, T. 37 N., R. 40 E., north of the Cherry Prospect. It was not visited by the author but is reported by Huntting (1956, p. 244) to consist of a "spotty distribution of (lead and zinc) sulfides replacing limestone in fault zone. Exposed length of 65 feet, width of 1 to 3 feet, and depth of 35 feet." It is presumed to be similar to the mineralization at the Cherry Prospect.

NEGLECTED

The Neglected property is in the SW¼ sec. 11, T. 37 N., R. 39 E., one-half mile east of the county road from Echo to Onion Creek. It was visited in 1953 and 1955 by geologists of the Washington Division of Mines and Geology and the following descriptions are taken from their notes.

Two small adits at an elevation of 4,135 feet are reported to connect with a shaft and with a raise (4 by 4 feet) inclined at 45° in a direction N. 40° W. for a length of 30 feet. This raise followed a small chimney of brecciated limestone mineralized with galena. About 85 feet above the two adits is a short 7-foot adit, bearing N. 30° W. exposing a breccia zone in gray fine-grained limestone. The breccia is slightly mineralized with galena and sphalerite. A fourth adit, at elevation 4,100 feet, is reported to be roughly L-shaped and 150 feet long; the adit is in gray, massive limestone for the first 70 feet and in limestone breccia and dolomite breccia for the last 80 feet. Some galena is disseminated in the breccia zone.

The only working place examined by the author was the 7-foot adit to which he was directed in 1975 by J. Eric Schuster, geologist with the Washington Division of Geology and Earth Resources. Earlier, Schuster had found fossils (graptolites) in brown or tan argillite fragments in the breccia at the adit and their presence was confirmed during our visit. The graptolite-bearing fragments clearly belong to the Ledbetter Slate Formation. The breccia contains numerous angular fragments of dolomite, limestone, and argillite up to 4 feet across in a coarse-grained, light-gray to white dolomite matrix, slightly mineralized with galena and pale-yellow sphalerite. That is, the rock is typical Josephine Breccia. The complete lack of evidence for faulting and the presence of graptolite-bearing breccia fragments of Ledbetter Slate at least 500 feet stratigraphically below the Metaline-Ledbetter contact strongly support the hypothesis that the breccia is a solution-collapse breccia related to an overlying unconformity.

NEW ENGLAND

The mine workings of the New England mine are in the SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 26, T. 39 N., R. 40 E., a few hundred feet south of the workings of the Deep Creek mine (fig. 37). They consist of two open pits and a 350-foot adit (Huntting, 1956). At the time of the author's visit, the portal was caved and the tunnel inaccessible. However, it could be seen that the tunnel had been driven along a fault separating granodiorite of the Spirit pluton on the southwest from tremolitic dolomite of the middle unit of the Metaline Limestone on the northeast. At the portal the fault contact strikes N. 29° W. and dips 82° E.

Patty (1921, p. 110-111) described the workings and mineralization as follows:

> At the base of the mountain, near the level of Deep Creek, an exploratory tunnel has been driven for a distance of 350 feet along the contact of the intrusive Loon Lake granite with the Republican Creek limestone. The contact has an average strike of north 30° west and stands at about a 30° angle with the limestone forming the hanging wall of the drift and granite the footwall. There have been intense movements along the plane of the contact and both the limestone and granite exhibit well-defined striated walls. Between these walls there exists varying amounts of gouge matter. The limestone is badly iron-stained and also shows considerable dendritic stains of manganese dioxide. In places the granite has been altered to a talcose serpentine. Only an occasional stringer of sphalerite was found for the first 150 feet in the drift. An irregular mass of low-grade zinc ore, associated with small amounts of galena, was then encountered and as cut by the drift this mass appears to be almost five feet thick, but its extent has not been determined. The drift has been extended about 200 feet beyond this point without exposing any commercial ore.

That is, the adit driven across the strike of the dolomite intersected a sulfide body, one that is conformable with the banding, presumably identical to those of the neighboring Deep Creek mine.

Studies of polished sections of the ore and gangue minerals indicate that the grain size of dolomite, pyrite, and sphalerite varies considerably. Most mineral grains fall into one of two grain-size categories—one in which grain size ranges from 0.02

to 0.30 mm, and the other, very much larger grain size, ranging in maximum dimension from 1.0 to 1.7 mm. Grains of both sulfides and dolomite of the smaller size range are commonly interlocking in a granoblastic texture characteristic of annealed metals and minerals. Crystals of dolomite, sphalerite, and pyrite of the larger size generally have widths of about 0.30 to 0.35 mm and lengths from 1.0 to 7 mm; that is, they have a length to width ratio of 4:1. The long dimensions of these grains seem to be parallel to each other and to the long dimensions of the pods and lenticles of sulfides in the dolomite, and probably to the banding in the dolomite. This parallelism is believed to have been produced during regional metamorphism. Many of the larger sphalerite grains possess excellent deformation twins and these show little or no sign of recovery or recrystallization. The granoblastic (annealing) texture of the smaller grains was probably formed during the emplacement of the Spirit pluton, after the regional metamorphism.

NEW LEADVILLE

In the SE¼ sec. 3, T. 37 N., R. 39 E., a tunnel has been driven in a direction S. 85° E., straight into the foot of a limestone bluff. The first 50 feet of the adit is in dolomite. Beyond the dolomite is light-gray to gray to black, fine-grained limestone right to the face, about 965 feet from the portal. A branch tunnel bears S. 25° W. for about 75 feet from a point 495 feet from the portal. No mineralization was seen either underground or in the dump rock. According to an early report (Colville Engineering Co., 1941, p. 8), this tunnel was driven for 1,250 feet(?) to explore the downward extension of lead and silver mineralization "high on the mountainside," but none was found.

OLD DOMINION

The Old Dominion mine is in the S½ sec. 4 and N½ sec. 9, T. 35 N., R. 40 E., on the south slope of Old Dominion Mountain. It is reported (Huntting, 1956) to have had 8 miles of workings on at least 11 levels. It was first located in 1883 (Weaver, 1920) and produced more than $625,000 worth of silver-lead ore by 1920 (Huntting, 1956). The mine was essentially worked out by 1926, although production continued at intervals at least until 1940. Total production to 1946 was about $750,000, representing about 6,000 tons of ore (Washington Division of Geology and Earth Resources). Practically all of the workings are now inaccessible. The following information was abstracted from various published and unpublished reports, with minor additions from my notes taken on a visit to the mine area in 1968.

A contact between granitic rocks to the south and carbonate rocks to the north strikes about N. 65° E. and dips very steeply south, approximately through the midpoint of the south boundary of section 4. Slickensides along the contact indicate that it is a fault contact. The steeply dipping carbonate rocks to the north of the granite constitute a band about one-quarter of a mile wide and extending for at least a mile along the contact.

Within 60 feet of the granite contact, in the vicinity of the principal workings of the Old Dominion mine, this band of carbonate rocks is cut by at least two major faults extending for more than 350 feet along the strike and by several lesser faults of more limited extent. All strike about N. 60° E. and dip 70° to 85° S. That is, they are about parallel to the granite-carbonate rock contact. Many other lesser faults, joints, and tension fractures within 60 feet of the granite contact have strikes both parallel to and almost at right angles to the major faults, with low dips, commonly less than 10°. The carbonate rock, all white to light-gray dolomite and silicified dolomite here, is brecciated. Some of the breccia is "crackle breccia" with little or no rotation of the fragments; other breccia has many rotated fragments. A review of the literature indicates that many of these faults and fractures were pre-ore and some are post-ore. Some ore-bearing fractures are said to have terminated against barren faults. It is quite likely that there was post-mineral movement on some of the pre-ore fractures. There is insufficient data available for any clear interpretation of the sequence of events prior, during, and subsequent to ore deposition.

Most fractures are mineralized with quartz to some extent, and many contain one or more of the following minerals: dolomite, siderite, calcite, galena, sphalerite, tetrahedrite, stephanite, chalcopyrite, and pyrite; especially well mineralized are the gently dipping fractures subsidiary to the principal faults. Many of the veins and ore shoots are vuggy, and some vugs are lined with dolomite and(or) quartz crystals; some with galena crystals. The silicified dolomite is very much coarser grained than the unaltered dolomite, with crystals of dolomite up to one-half inch long in the highly fractured zone. Much of the early work was in silver-rich highly oxidized ore composed of quartz, cerussite, anglesite, limonite, native silver, and secondary silver sulfide. Ores were oxidized to the deepest levels exposed, about 900 feet below the surface.

Ore shipments from the upper workings contained from 100 to 400 ounces of silver per ton, and 13 percent to 60 percent lead (Huntting, 1956). Between 1921 and 1927, 2,446 tons of ore contained, on the average, 0.093 ounce gold and 102.85 ounces silver per ton, 10.93 percent lead and 17.36 percent zinc. According to the U.S. Bureau of Mines (Fulkerson and Kingston, 1958), total production from the Old Dominion mine was 744,391 pounds of lead, 148,563 pounds of zinc, and 342,517 ounces of silver.

Three polished sections of the Old Dominion mine ore were found to contain sphalerite, galena, tetrahedrite, chalcopyrite, and pyrite. Sphalerite appears as large (0.75 to 2.50 mm) twinned crystals; both growth and deformation twins are present, but not annealing twins. Some of the sphalerite includes very small (0.001 mm) blebs of chalcopyrite; these are especially abundant in sphalerite that is surrounded by chalcopyrite. Galena was identified under the ore microscope in grains up to 3 mm across, often including irregular and cuspate patches of tetrahedrite up to 0.08 mm in longest dimension. Chalcopyrite occurs in sphalerite, galena, tetrahedrite, in quartz, and interstitial to these. Some chalcopyrite occurs as tiny blebs in sphalerite, as indicated above, some as very thin (less than 0.001 mm) veinlets in sphalerite. Tetrahedrite is always in close association with galena either entirely within the galena or between galena and sphalerite where it appears to have replaced the galena. Pyrite is found as euhedral crystals from 0.05 to 0.25 mm across, generally crowded with gangue and galena inclusions in their cores.

The association of tetrahedrite and chalcopyrite with sphalerite and galena, the high silver content of the ore, the association of all sulfides with quartz (and siderite?) gangue, and the strong control of the discordant ore shoots by fractures serve to distinguish this and similar silver-bearing deposits from the generally strata-bound lead-zinc ores.

PLUG

The Plug prospect is in secs. 28 and 33, T. 39 N., R. 41 E., just west of the Farmer mine. The property was not examined during this study. It is reported to be a "replacement zone in limestone near granite contact . . . 12 feet wide" and at least

1,000 feet long (Huntting, 1956, p. 380). Presumably, it is similar in all respects to the Farmer mine mineralization.

RED TOP MOUNTAIN AREA

Red Top Mountain is in secs. 19 and 30, T. 40 N., R. 42 E., and secs. 24 and 25, T. 40 N., R. 41 E., about 6 miles north of Deep Lake. It is bounded to the west, north, and east by Cedar Creek, East Fork Cedar Creek, and Joe Creek, respectively. Its summit, at elevation 4,565 feet, about 2,400 feet above Cedar Creek, is at the common corner of secs. 19, 30, 24, and 25, referred to above. According to Yates (1964), the mountain consists of a stack of at least six south-dipping thrust plates (fig. 53). The lower three plates consist of siliceous black argillite, argillite, chert, and greenstone. The siliceous black argillite is host to at least three quartz vein deposits carrying galena and values in silver, but these are of no interest to this study. The upper three plates are composed of Gypsy Quartzite and Maitlen Phyllite (Early Cambrian age), both of which are older than the rocks of the lower plates. Yates has divided the Maitlen Phyllite into phyllite, one limestone horizon known as the Reeves Limestone member, and an overlying argillite called the Emerald Member. This terminology conforms with that used by Canadian geologists for similar rocks just a few miles to the north. The mines of interest in this study are the Anaconda, Copper King, Red Top, and Lucile, all of which are in the Reeves Limestone Member.

The phyllite and limestone are folded into a syncline that is overturned to the northwest and plunges southwest. Yates (1964) shows numerous minor folds, presumably related to the main synclinal fold, with axial planes striking north of east and dipping moderately to the southeast. In the course of examining several outcrops of Maitlen Phyllite along the county road about 1½ miles southwest of the summit of Red Top Mountain, the author observed that both bedding and phyllite foliation are strongly folded into a series of nearly upright symmetrical folds on several scales. These folds plunge regularly from 30° to 40° to S. 54° W. and are no doubt the same generation as those mapped by Yates. It was also observed that the same outcrops contained isoclinal recumbent folds, the axial planes of which are parallel to the foliation in the phyllite and are folded like the phyllite foliation. That is, the recumbent folds belong to an earlier fold generation of isoclinal folds. The fold pattern shown by Yates for the Maitlen Phyllite on Red Top Mountain is attributable to the more open and upright younger folds of the second generation.

The rocks are cut by numerous planar and slightly curviplanar joints that strike about N. 30° W. and dip steeply northeast, about normal to the second generation fold axes. They are extension joints developed during second generation folding.

While gathering data for incorporation in the following section dealing with individual mines and prospects, the author recorded the strikes and dips of bedding, dikes, veins, and mineralized zones of the Red Top and Lucile mines. These data were plotted on an equal-area stereogram for analysis. The resulting pattern of pole plots showed that all poles to bedding and to sphalerite-galena mineralized zones fall in the southeast quadrant, and all poles to quartz veins fall in the northeast quadrant. The position of the bedding poles is such as to indicate that bedding attitudes in the two mines range from N. 44° E., 80° NW. to N. 13° W., 35° W. and that their distribution is such as to indicate that the beds lie on the southeast limb of a syncline plunging approximately 30°, S. 58° W. This is in substantial agreement with structural findings discussed above. Sphalerite-galena zones lacking quartz and tetrahedrite are conformable with bedding and follow limestone-schist contacts. Quartz vein attitudes (4 in Red Top and 6 in Lucile mine) range from N. 56° W., 25° SW. to N. 70° W., 75° S. and average N. 64° W., 44° SW. In addition to quartz, they contain scheelite, pyrite, galena, tetrahedrite and occasionally sphalerite. They cut across bedding and in at least one instance (end of upper adit, Lucile mine) appear to have been superimposed on an older conformable zinc-lead mineralization.

Poles to 13 lamprophyre dikes fall into two sets. The more prominent set is oriented N. 70° E., 48° SE.; the other is N. 16° E., 75° SE. In several places the dikes have cut across both conformable zinc-lead zones and transverse quartz-scheelite-tetrahedrite veins.

Although additional work in the mine and field would be necessary to verify it, the interpretation placed on the above observations is that there were two periods of mineralization—an early lead-zinc mineralization and a later, possibly very much later and quite unrelated, quartz-vein mineralization. Lamprophyre dikes were intruded still later.

Red Top Mine

The Red Top mine, in the NE¼SE¼ sec. 25, T. 40 N., R. 41 E., consists of an adit driven in a northeasterly direction for 2,700 feet and some 1,500 feet of drifts, raises, and winzes off the adit (Huntting, 1956). At the time of the author's visit in 1967, the adit near the portal had caved and the workings beyond were inaccessible. In 1941 when the workings were mapped by W. A. G. Bennett (Division of Mines and Geology), the adit extended about 2,100 feet in a direction N. 30° E. from the portal. The longest sections of the adit are along the contact of limestone and schist striking northeast and dipping northwest. Bennett reports at least four separate mineralized zones striking N. 56° W. to N. 70° W. and dipping 25° to 75° SW., directly across the bedding of the limestone host rock. Each of the zones is less than 1 foot wide and is composed of quartz stringers less than 1 inch wide, containing galena, tetrahedrite, pyrite, and scheelite. In addition to the mineralized zones running transverse to bedding, Bennett has also recorded six different mineralized zones up to 5 feet wide in limestone along the contact of limestone and phyllite or schist. The mineralization in these conformable shoots is sphalerite and galena. They lack the tetrahedrite, scheelite, and quartz of the transverse vein zones. Lamprophyre dikes cut across both the conformable and transverse mineralized zones.

About 150 feet north and 50 feet above the portal a raise breaks through to surface. It must have been driven on one of the transverse veins zones. Dump specimens are thin- to medium-bedded micaceous limestone marble identical to the Reeves Limestone mapped by Yates (1964) along the county road to the west. Many of the dump specimens are rusty-weathering and are cut by quartz-dolomite-siderite(?) veins, up to 10 inches wide, carrying sphalerite and galena. Some of the veins parallel the bedding foliation, others are normal to it.

Lucile Mine

The Lucile mine is in the NE¼NW¼ sec. 30, T. 40 N., R. 42 E. It consists of two adits and several winzes and drifts. Both adits were open in 1967.

The upper adit was driven for 200 feet in a northwest direction across the prevailing strike of the metasedimentary rocks. The first 60 feet of the adit is in quartzite and the next 140 feet in micaceous limestone marble, striking N. 8° W. to N. 16° E. and dipping from 23° to 50° W. At the end of the adit is a drift to the north about 30 feet long, following a zone from 1½ to 2 feet wide along the contact of the limestone and the overlying schist. This zone is mineralized with quartz, pyrite, galena, tetrahedrite, and scheelite. It strikes N. 10° E. and dips 50° NW. (Division of Mines and Geology notes). In at least five other places in winzes and drifts in the limestone, there are quartz veins less than 1 inch wide carrying scheelite and occasionally sphalerite, galena, and tetrahedrite. These five veins strike northwest and dip southwest, cutting across bedding. Several lamprophyre dikes are present, striking northeast and dipping southeast, a couple of which cut directly across quartz veins and bedding.

A lower adit, about 75 feet below and 100 feet south of the upper adit, was driven for 430 feet in a direction N. 75° W. through quartzite and quartz mica schist and into micaceous limestone marble striking northeast and dipping 35° to 45° NW. No mineralization has been reported.

Dumps at both portals contain blocks of white micaceous limestone marble traversed by white quartz veins, both parallel and normal to bedding. The veins are vuggy, with acicular quartz crystals up to ¼ inch long, mineralized with brown or black sphalerite, tetrahedrite, galena, and pyrite. The limestone marble adjacent to the quartz veins weathers brown or brown-gray, suggesting that iron in some form has been introduced into the vein walls by the quartz-depositing fluids.

Anaconda Mine

This mine is in the NW. cor. sec. 30, T. 40 N., R. 42 E., several hundred feet northeast of the Copper King mine. It was not visited by the author. Weaver (1920, p. 301) reports that a 40-foot inclined shaft and a 30-foot drift exposed a vein from 2½ to 4 feet wide carrying quartz, calcite, sphalerite, and galena. The vein follows the contact of limestone and overlying schist striking N. 30° E. and dipping 60° NW. According to Bancroft (1914, p. 57) this deposit is about 18 inches wide and contains quartz, galena, sphalerite, and tetrahedrite distributed through the rock in distinct bands.

Copper King Mine

The Copper King mine is in the NE. cor. sec. 25, T. 40 N., R. 41 E. It was originally located in 1896. The principal workings are three adits, the longest and highest of which in 1967 was completely caved at the portal and inaccessible. According to Weaver, this adit was driven northeasterly for 285 feet in banded limestone and argillite, striking N. 33° E., dipping 40° NW. About 70 feet from the portal, a raise was driven on a mineralized zone along the contact of "decomposed argillite resting on a footwall of banded white limestone" (Weaver, 1920, p. 300). Mineralization consists of sphalerite and galena in a zone 4 to 8 inches wide. Dump specimens contain veins up to 2 inches wide composed of quartz, dolomite, and black sphalerite.

A second adit is in a N. 10° E. direction for an unknown distance. The first 50 feet is in barren white dolomite marble. For at least the next 60 feet the tunnel follows a silicified, thin-bedded zone from 1 to 1½ feet wide, parallel to bedding in the white marble. Dump specimens are highly silicified dolomite with vugs containing quartz crystals up to ½ inch long. Many rusty-weathering boulders contain black sphalerite and a very little pyrite in a dolomite gangue with dolomite rhombs up to 1½ inches in diameter.

Weaver (1920, p. 300) refers to a lower tunnel, presumably the workings just discussed, driven for 221 feet in a northeasterly direction, which exposes a mineralized zone along the contact of quartzitic schist and white limestone marble striking N. 40°

E., dipping 55° NW. It contains a vein of sphalerite 4 inches wide and a vein of galena 10 inches wide.

Evergreen Property

Huntting (1956, p. 241) refers to this property in sec. 25, T. 40 N., R. 42 E., on the south slope of Red Top Mountain. Workings are reported to have consisted of a 145-foot adit, a 177-foot adit, and several shafts. Galena, sphalerite, and pyrite are associated with quartz veins in limestone, at least one of which lies along the contact of limestone and "argillite" (phyllite).

Past and Future Production

Of the mines in the Red Top Mountain area, the U.S. Bureau of Mines (Fulkerson and Kingston, 1958) reports production only for the Red Top and Lucile mines. Their production to 1956 is shown below:

	Lead (lbs)	Zinc (lbs)	Silver (ozs)
Red Top	207,371	140,595	6,339
Lucile	42,603	25,861	1,517
Total	249,974	166,456	7,856

The maximum reported width of vein zones carrying quartz, scheelite, tetrahedrite, etc., is 1½ to 2 feet (Lucile) and most such veins or vein zones are less than 1 foot wide; lengths are only a few tens of feet. The largest zinc-lead zone in limestone has a maximum width of 5 feet (Red Top) and others are generally much less. Lengths are only a few tens of feet.

There is nothing about the geology of the area to suggest that undiscovered ore shoots in the quartz veins, if present, are likely to be any larger, more persistent, or better grade than those that have been discovered in the past 75 years. Therefore, there is no justification for further exploration or development of the quartz veins.

In contrast to the quartz veins, the conformable zinc-lead deposits in limestone marble have received little attention. In view of the very productive deposits of this kind in the same stratigraphic position—the Reeves McDonald mine in British Columbia, and the Sierra Zinc mine, Stevens County—it is recommended that any further work on Red Top Mountain be directed primarily toward the exploration for stratiform zinc-lead deposits in the Reeves Limestone.

SANTIAGO SHAFTER MINE

The Santiago Shafter mine is in the NW¼ sec. 7, T. 35 N., R. 38 E., about 2 miles south of the mouth of the Colville River. The mine workings consist of a small open pit and several adits (figs. 59, 60). Only two adits were open in 1966 when the property was visited; their total length is 480 feet. Short drifts totaling 50 feet in length extend from the adits. There has been no significant production.

Underground and surface workings expose sulfides in dolomite breccia of the Metaline Limestone beneath Ledbetter Slate. These strata are folded into an anticline plunging gently south. The principal exposures are along and just a few feet west of the axis of the anticline. The main workings are along a north-trending zone, about 600 feet long, 100 feet wide, and 300 feet deep, in which dolomite breccia is cut by a few quartz and quartz-sulfide veins that strike east-west and dip 50° northerly. The quartz veins are from 1 to 12 inches wide and a few feet long, and are mineralized with pyrite, chalcopyrite, argen-

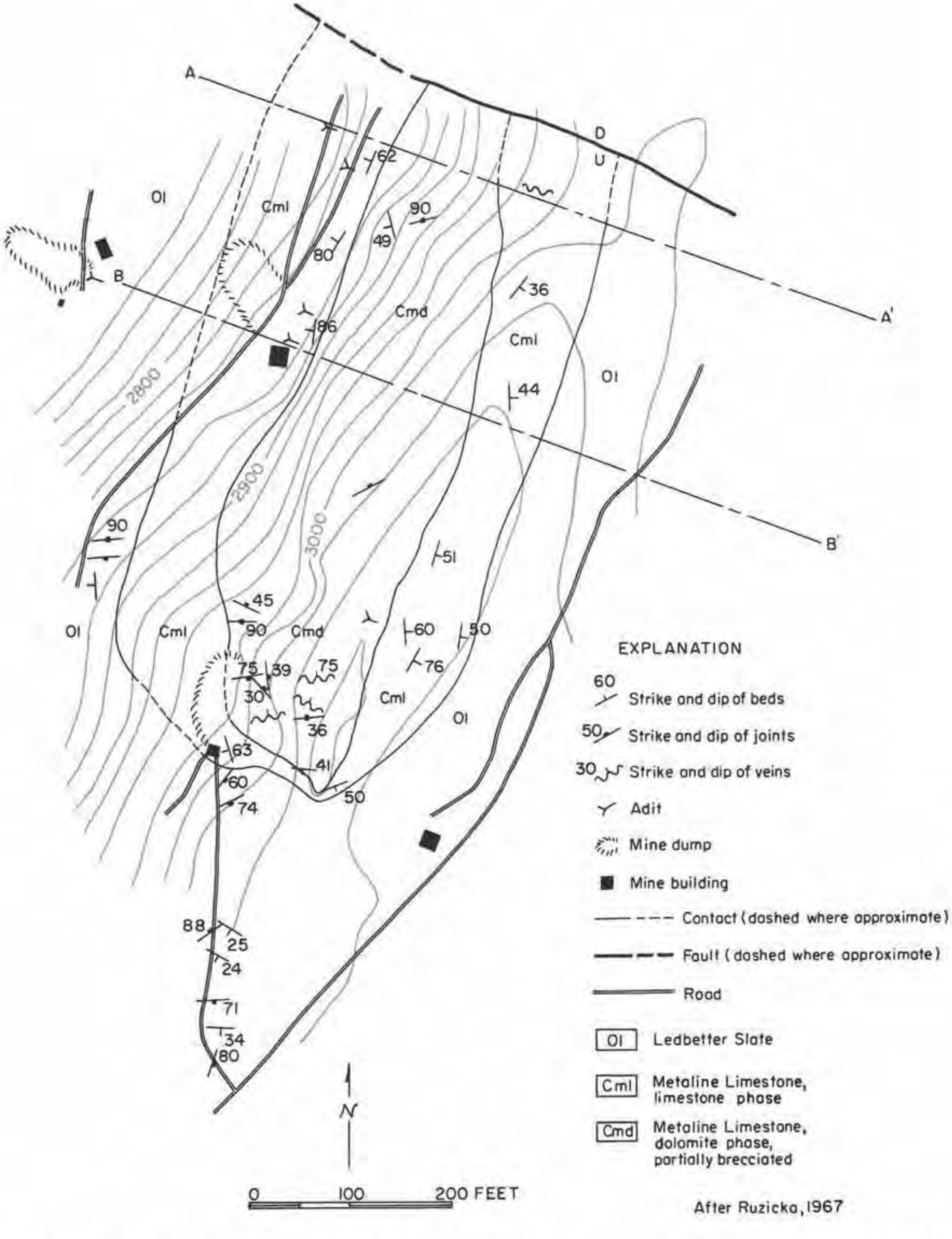

FIGURE 59.—Geologic-topographic map of the Santiago Shafter mine area (NW$\frac{1}{4}$ sec. 7, T. 35 N., R. 38 E.). See figure 60 for cross sections.

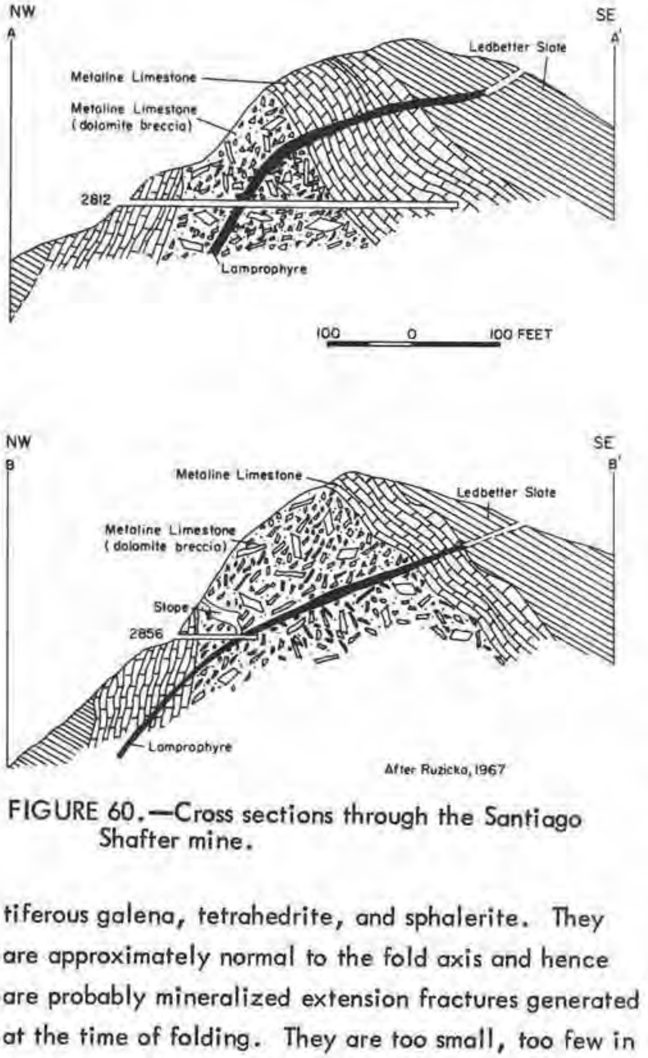

FIGURE 60.—Cross sections through the Santiago Shafter mine.

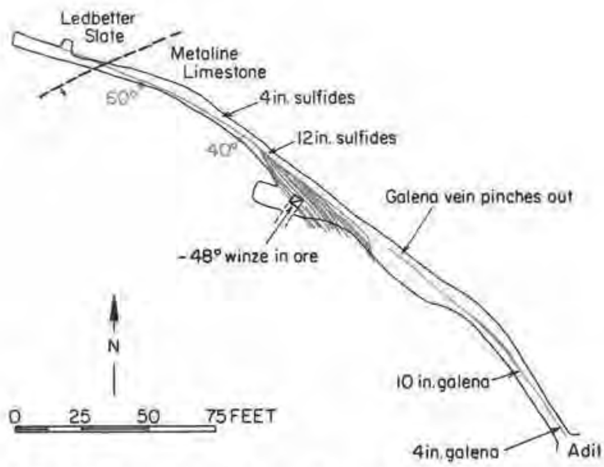

FIGURE 61.—Map of the Scandia mine tunnel (NW¼NE¼ sec. 23, T. 39 N., R. 40 E.).

tiferous galena, tetrahedrite, and sphalerite. They are approximately normal to the fold axis and hence are probably mineralized extension fractures generated at the time of folding. They are too small, too few in number, and too weakly mineralized to offer much hope for production.

SCANDIA PROSPECT

The Scandia prospect consists of several small trenches, a 30-foot tunnel, a 100-foot winze (Hunting, 1956) and a tunnel 262 feet long, in the NW¼ NE¼ sec. 23, T. 39 N., R. 40 E. (fig. 37). Only the long tunnel was examined by the author. It is shown in figure 61.

Galena, yellow-brown to pale-yellow sphalerite, and coarse-grained, gray and white calcite are exposed along a zone striking northwesterly and dipping from 50° to 80° southwesterly in dark-gray to black, fine-grained limestone, dolomitic limestone, limestone breccia, and dolomite breccia. The carbonate rocks strike from N. 75° E. to east-west and dip from 30° to 60° S. About 35 feet back of the tunnel face, the mineralization passes from limestone into graphitic slate of the Ledbetter Slate. It narrows abruptly in the slate and pinches out within a few feet. The wide mineralized zone at the winze has a flatter dip than the narrow high-grade veins and may be nearly conformable with the bedding of the host rock. Although the mineralization is discordant with respect to the host rock bedding, it is referred to the Josephine based upon the following: (1) its host rock—a dark-gray to black limestone, dolomite, and breccia of the upper limestone unit of the Metaline Limestone, (2) its position—just below (stratigraphically, not topographically) the Ledbetter Slate, and (3) the association of galena, pale-yellow sphalerite, and coarse, cleavable calcite, and the lack of pyrite.

As of 1958, twelve diamond drill holes had been drilled under the sponsorship of DMEA (Defense Minerals Exploration Admin.). This drilling is reported to have outlined a mineralized zone 750 feet long, 300 to 350 feet wide, and 15 feet thick, averaging 4 percent zinc. Further exploration was conducted by the Bunker Hill Co. but the results are not known to the author. On the basis of the brief examination of the property and the several attempts by government and private interests to test the property, it seems that there is little suitable grade mineralization within the area explored. However, the property is in what might be regarded as favorable ground. Any further exploration should be directed toward establishing the likelihood of a large, low-grade breccia deposit. It is important to keep in mind as well that any mineralized breccia zone can be expected to bottom on the Ledbetter Slate beneath.

SHOEMAKER MINE

The Shoemaker mine is in the SE¼ sec. 8, T. 36 N., R. 40 E., due west of Little Roundtop, just west of the junction of Jumpoff Joe Creek and Mill Creek. The road from Colville to Spirit is only a few hundred feet east of the lowermost workings.

The workings consist of four adits (crosscuts) driven westerly into an east-facing hillside until they intersect the vein(s), and about 1,000 feet of drifting along the veins and several raises. The uppermost adit (elevation 2,845 feet) was not examined. The second level (elevation 2,745 feet), third level (elevation 2,645 feet), and fourth level (elevation 2,405 feet) adits were mapped (figs. 62, 63, 64) and a vertical east-west cross section prepared (fig. 65).

All four adits expose conformable sedimentary rocks striking within a few degrees of north and dipping quite uniformly about 35° W. The most extensive exposures are in the lowermost adit, which exposes a true thickness of almost 800 feet (tunnel length, 1,310 feet) of sedimentary and metasedimentary rocks as follows, from east to west and from oldest to youngest:

Description	Distance from portal 2,405-ft level (ft)	Stratigraphic thickness (ft)
Sericite phyllite, calcareous phyllite, and phyllitic limestone	0- 200	120
Dolomite, dark-gray, in beds up to 1 in. thick, alternating with black argillite partings and beds up to ½ in. thick; beds pinch and swell	200- 239	22
Limestone, very fine-grained; beds ½- to 8-in. thick, estimated 5 percent argillite as very thin shaly partings	239- 485	140
Dolomite, like 200-239 ft. above	485- 662	102
Dolomite, dark-gray to black, fine-grained, massive	662- 675	8

Continued

Shoemaker—Continued

Description	Distance from portal 2,405-ft level (ft)	Stratigraphic thickness (ft)
Limestone and argillite, highly graphitic, schistose and crumpled	675- 745	40
Limestone, dark-gray, very fine-grained and very thin bedded, with up to 10 percent interbedded dark-gray argillite	745- 970	130
Dolomite, gray, medium-grained, thin- to medium-bedded, with patches of "zebra" rock	970-1125	90
Dolomite, gray, medium-grained, massive, with much "zebra" rock	1125-1217	58
Like 1125-1217, but slightly mineralized with disseminated pyrite and sphalerite along small fractures beneath black argillite	1217-1223	3
Argillite and calcareous argillite, black, locally quite schistose and highly graphitic	1223-1313	52

The oldest rock exposed, phyllite, belongs either to the Maitlen Phyllite or to the lower phyllitic part of the younger Metaline Limestone. Stratigraphically above these phyllites for the next 442 feet are thin-bedded limestones and dolomites, with shaly partings and pinching and swelling of beds like that described by Park and Cannon (1943, p. 19) and Dings and Whitebread (1965, p. 11) for rocks of the lower limestone unit of the Metaline Limestone. This writer is of the opinion that the entire limestone-dolomite section of the Shoemaker mine belongs to the lower unit of the Metaline Limestone.

The stratigraphic position of the black argillite and graphitic argillite overlying the carbonate rocks is not clear. In some respects, these rocks resemble the black argillite of the Ledbetter Slate. If they are Ledbetter, then their contact with the carbonate rocks must be a fault or unconformity, for the middle dolomite unit and the upper limestone unit of the Metaline Limestone, which normally lie between the Ledbetter and the lower limestone unit, are not found in this mine. The schistose nature of the argillite at its contact with the carbonate rocks, its highly graphitic and locally contorted nature, and the presence of sulfide mineralization along it, support the suggestion that the contact is a fault.

Whether or not the amount of movement on the fault was sufficient to have omitted the upper and middle units of the Metaline Limestone, it was at least sufficient to render the argillite very fissile, often greatly distorted, and highly graphitic over a width of a few inches to several feet. It also developed parallel fractures and subordinate randomly oriented fractures in the massive dolomite of the footwall. Some of the fault movement took place after the emplacement of the sulfides because deformed and gneissic galena and microbrecciated sphalerite are common in the veins.

The ore mineralization takes the form of from one to four veins of sphalerite and galena, with minor

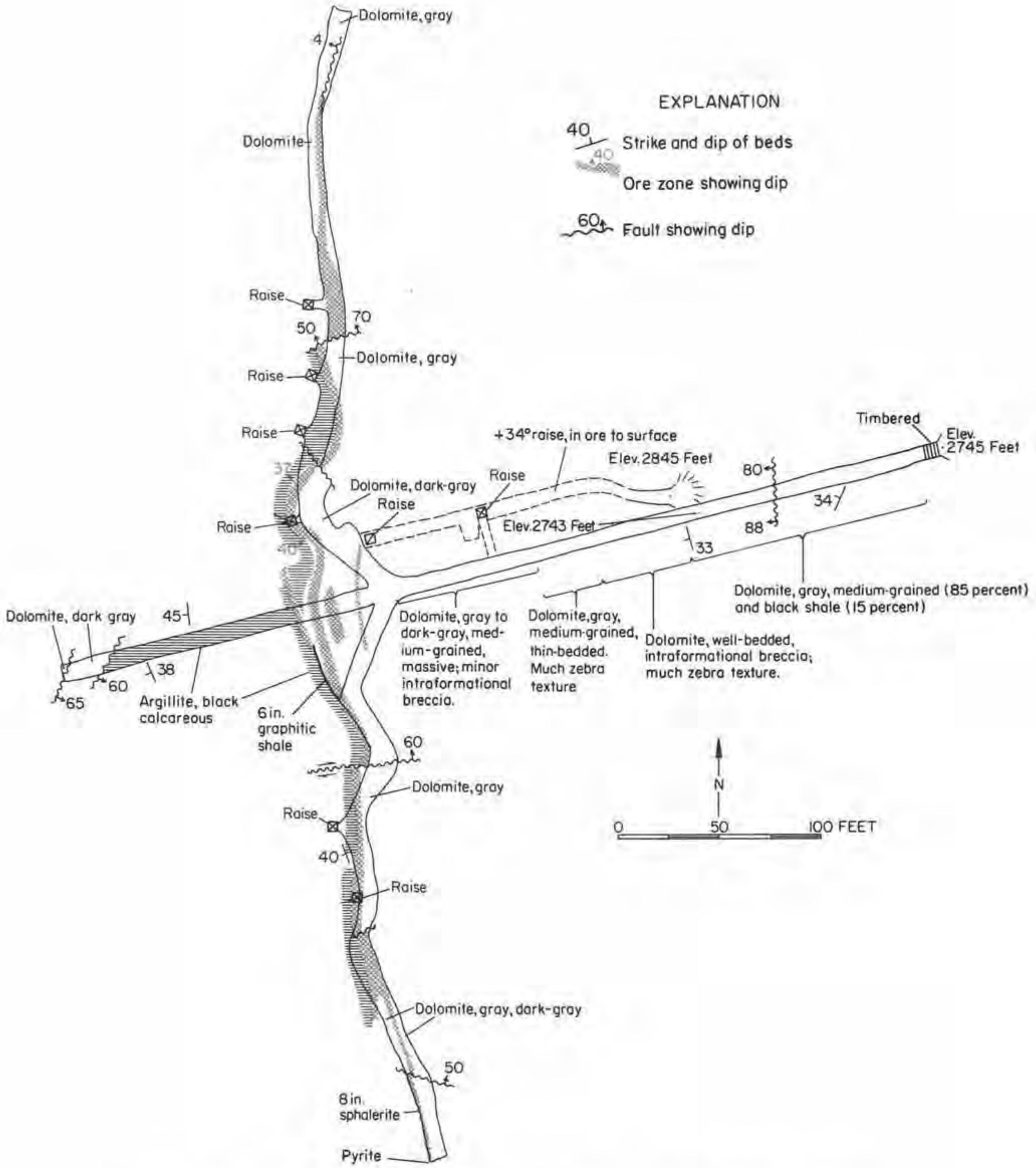

FIGURE 62.—Geologic map of first and second mine levels, Shoemaker mine.

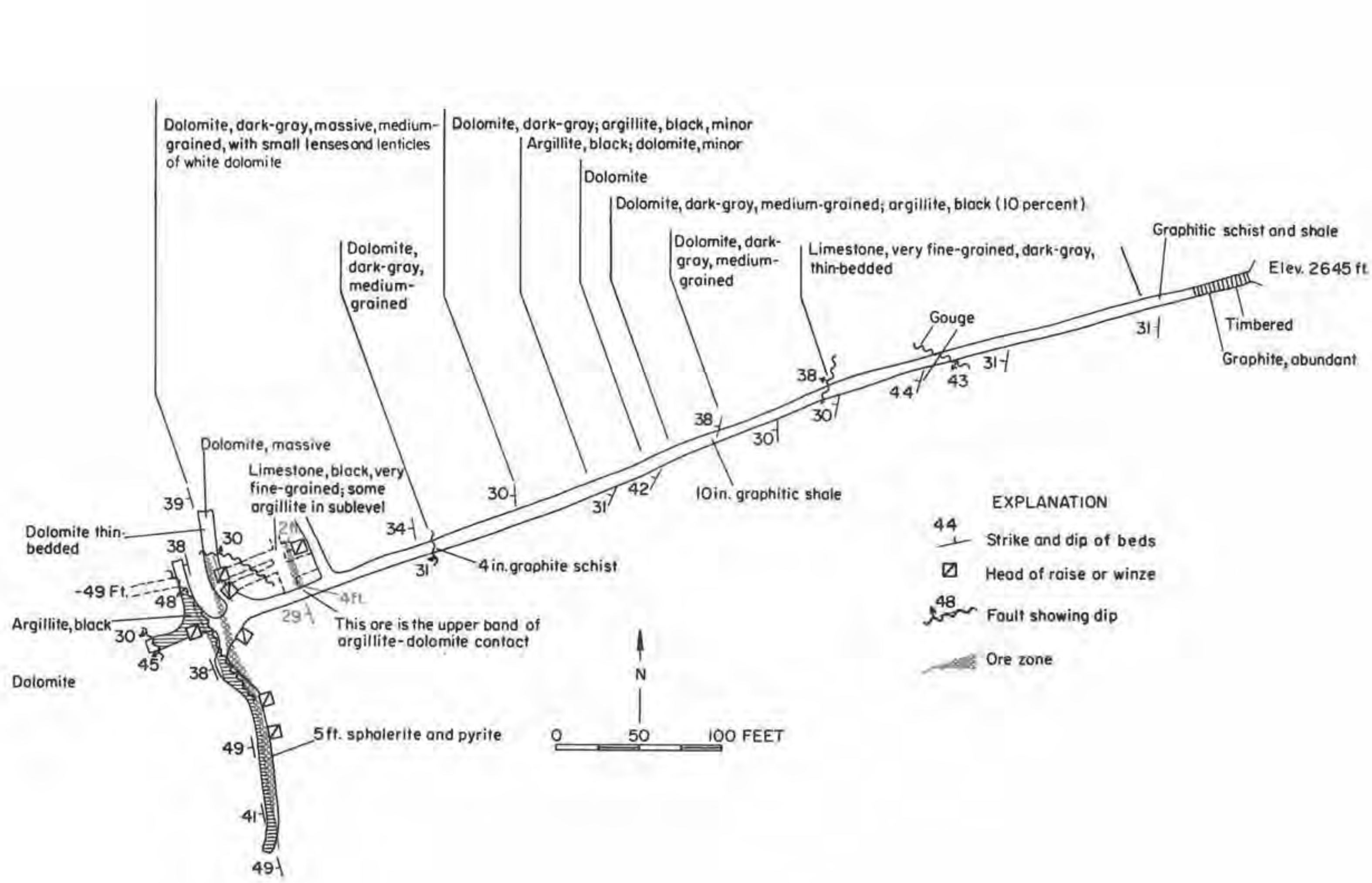

FIGURE 63.—Geologic map of third mine level, Shoemaker mine.

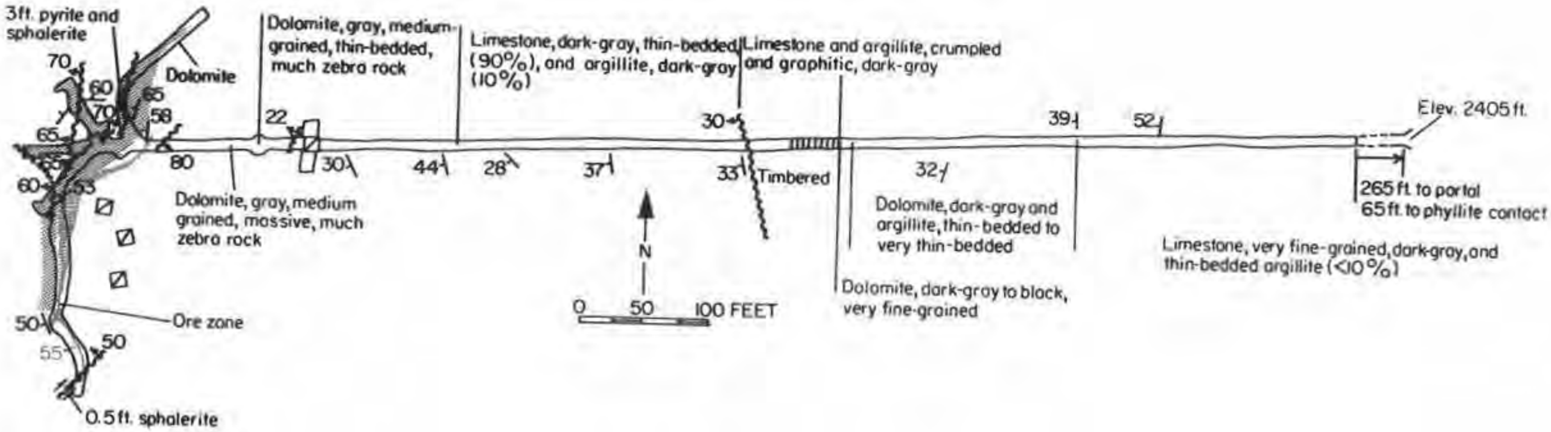

FIGURE 64.—Geologic map of fourth mine level, Shoemaker mine.

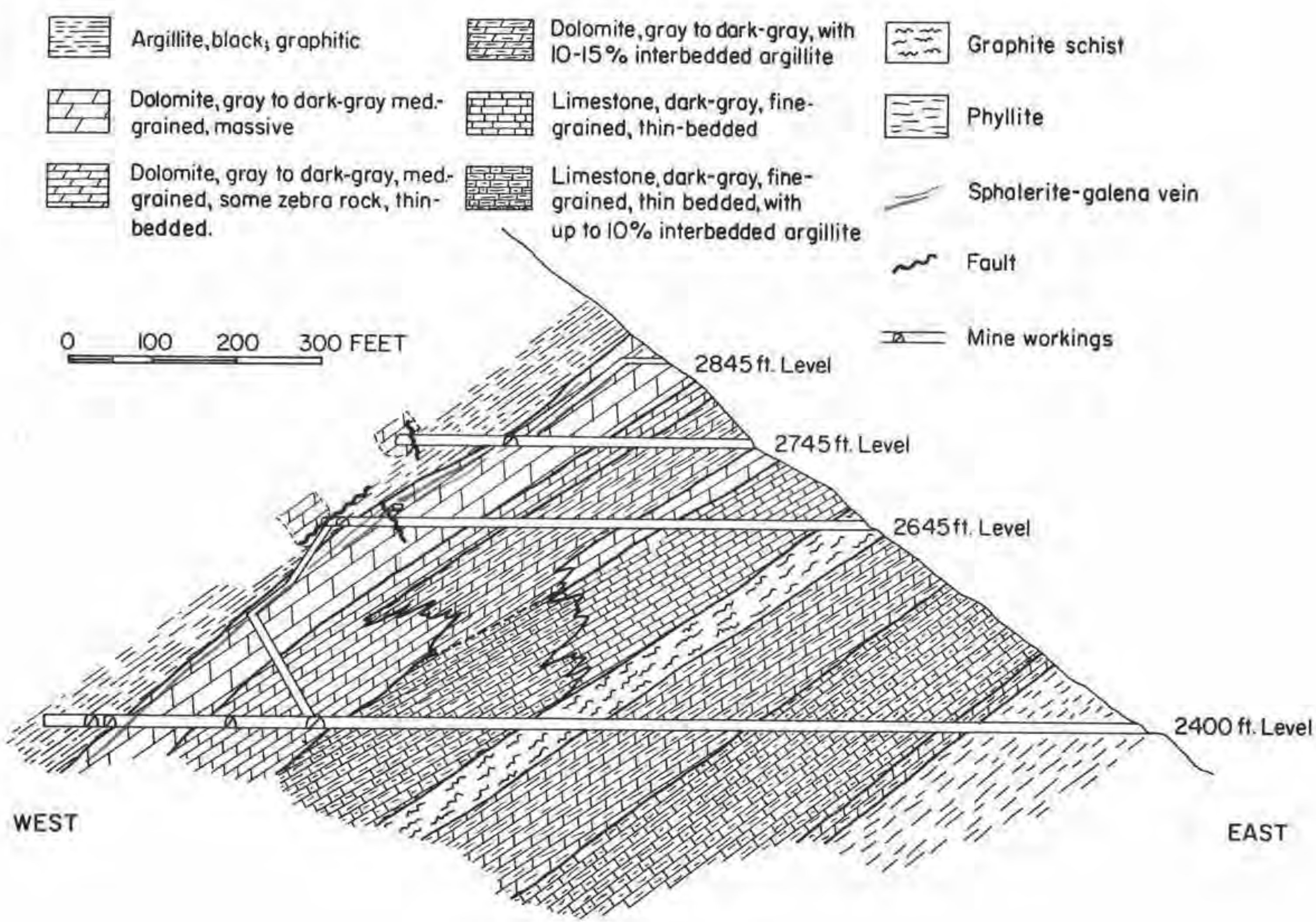

FIGURE 65.—Vertical east-west cross section through Shoemaker mine.

amounts of pyrite. The veins generally strike north, and dip from 30° to 55° W., parallel to the bedding in the dolomite, the bedding in the black argillite, and to the fault contact of the dolomite and argillite. Where the bedding and fault are somewhat sinuous (as on the 2,645- and 2,405-foot levels), the veins are likewise sinuous. Their width varies from a fraction of an inch to as much as 7 feet, but is generally less than 4 feet. The principal vein is the one at and just below the argillite-dolomite contact on the lower three levels. It is longest on the 2,745-foot level (560 feet), considerably shorter (175 and 200 feet) on the 2,645- and 2,405-foot levels, respectively. Approximately the southern half of this vein is along the argillite-dolomite contact, but toward the north (fig. 62) it gradually leaves the contact and follows a subparallel fracture in the footwall dolomite. It is probably the same vein that is exposed for a length of 30 feet in the 2,675-foot sublevel and the upper part of the two raises shown on the map of the 2,645-foot level. There the vein of sphalerite and galena is from 2 to 4 feet thick. On both the 2,745- and 2,405-foot levels the principal vein branches toward the south; one branch continues along the argillite-dolomite contact, the other extends into the footwall dolomite.

Lesser veins are to be found in the black argillite within a foot of the argillite-dolomite contact and within the footwall dolomite up to 30 feet (horizontally) east of the contact. The most important one of the latter type is found in the north drift and the lower half of the two raises driven northeasterly from this drift on the 2,645-foot level, and in the north and east raise on the 2,745-foot level. The latter raise and the 2,845-foot level where the raise terminates were not examined, but the raise begins on this footwall vein, not on the principal vein.

In hand specimens, the sphalerite is exceedingly fine-grained, with a dull lustre and a hardness somewhat greater than normal. Its fracture is subconchoidal. Angular inclusions of black argillite and dolomite are common in the sphalerite, and highly irregular patches of galena are not uncommon. The sphalerite is a very fine-grained sulfide breccia or mylonite, thus accounting for the distinctive properties.

Polished ore surfaces, under the reflecting microscope, are composed of sphalerite, galena, and dolomite with a small amount of pyrite. The sphalerite is of two distinctly different grain sizes. The larger grains, ranging from about 0.10 to 0.20 mm in diameter, display pronounced polysynthetic deformation twins and possess very ragged boundaries that interfinger with the masses of smaller sphalerite grains. The smaller grains generally are only 0.008 to 0.03 mm in diameter, nearly equiaxial, with good annealing twins. Some of the smaller grains have a length: width ratio of about 2:1; these grains tend to have their long dimensions parallel to each other, giving the specimen a lineation. The larger grains are interpreted as being the remains of pre-existing coarse-grained sphalerite that has been intensely deformed to produce a sphalerite-mylonite, composed of the very fine-grained sphalerite with lineation and included rock fragments. Since the deformation, there has been a certain amount of recrystallization, annealing, and development of annealing twins in the small granoblastic grains, though the annealing and recrystallization have not progressed very far. Further evidence for intense deformation of the ores is the numerous bent cleavage pits in galena, and the fact that essentially all of the pyrite is intensely shattered.

No mining other than that required to develop the mine has been done in these workings. It seems reasonable to suppose that a small-scale operation could profitably extract the ore that extends at least from the 2,405-foot level, where its minable length is about 150 feet, through the 2,645-foot level, where its minable length is about 125 feet, to the 2,745-foot level, where its minable length is 400 feet, and through to surface. The dip- or slope-length of the vein from the deepest level to surface is 750 feet.

No sampling was done in this study, but it is expected that vein width would average at least 4 feet over the minable lengths given above, and the zinc content would be about 15 percent. Lead content is more difficult to estimate, but is probably a couple of percent.

Before any serious thought is given to mining these veins, mill tests should be run to determine whether or not the very fine grain size of the minerals and the presence of abundant graphite pose problems for effective concentration.

A few hundred feet north of the Shoemaker mine workings just described, there are two older adits, now inaccessible. Geologists for the Division of Mines and Geology examined these workings in 1953. They report that a lower adit extends for about 200 feet in a direction N. 85° W., then south about 150 feet, with several lesser connected tunnels, a winze, a raise, and at least one small stope. Workings are in gray and dark-gray dolomite, some of which is massive, some thin bedded, and some is a dolomite breccia with angular to subangular fragments of dark-gray to black dolomite, in a matrix of light-gray to white, coarser grained dolomite. The breccia grades into zebra-banded dolomite in some places. The matrix is reported to contain pyrite as disseminations, thin "veins", and concentric bands around fragments. No sphalerite was reported. There are several faults in the workings, mostly striking north and dipping from 25° to 57° W., parallel to bedding, apparently bearing no relation to the pyrite mineralization.

About 67 feet above the lower adit of these old workings, an upper adit extends for about 85 feet in a southwest direction, connecting with a raise near its western extremity. Sphalerite mineralization is reported to be scattered sporadically throughout much of the adit and is present in abundance in a zone 7 feet thick at the southwest face. All of the sphalerite appears to be associated with pyrite in the matrix of the dolomite breccia.

SIERRA ZINC

The main workings of the Sierra Zinc mine are in the SW¼SW¼ sec. 20, T. 38 N., R. 41 E., one-half mile west of the Colville-Spirit county road about 3½ miles south of Spirit. The workings consist of stopes and four levels, the two upper ones being adits connected by a 37°, 260-foot-long, inclined shaft to the lower levels, which are entirely underground. The original claim in the area was first worked in 1889. Five tons of lead concentrates from ore mined on the south part of the property was shipped between 1906 and 1910 by the Aladdin Mining Co. In 1925 and 1926, several cars of lead ore and lead-zinc ore were shipped by the Blue Ridge Mining Co. There is no record of further production until 1941 when shipping of concentrates was begun by the Sierra Zinc Co. Mining continued until 1944 when the mine closed. Mine production totaled 919,837 pounds of lead, 5,740,139 pounds of zinc, and 29,058 ounces of silver (Fulkerson and Kingston, 1958).1/ In 1945, most of the stopes above the main level collapsed.

These brief notes on the history of the mine are abstracted from a report by Charles D. Campbell (1946), who geologically mapped the surface and underground workings in 1943 and 1944. In preparing the following section, the author has drawn heavily on Campbell's report; figures 66 and 67 are taken directly from his illustrations with only minor modifications and change of scale.

1/ Production figures include 29,900 pounds of lead, and 36,900 pounds of zinc produced at the Sierra Zinc mill in 1956 from ore mined at other than the Sierra Zinc mine.

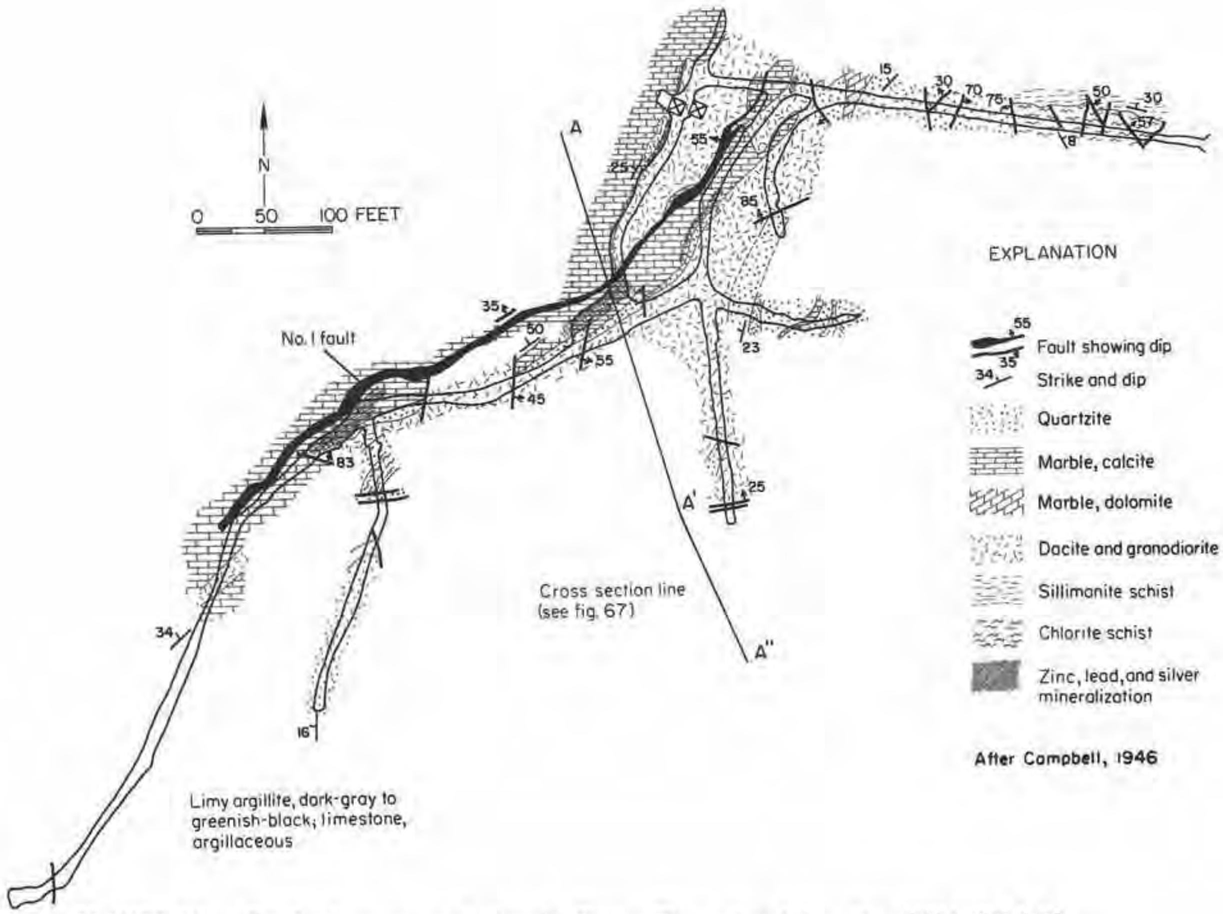

FIGURE 66.—Geologic map, main level, Sierra Zinc mine (elevation 2206–2214 ft).

The main workings are in quartzite, schist, and calcitic marble, making up a re-entrant in the south side of the Spirit pluton. The rocks are of higher metamorphic grade than the Gypsy Quartzite and Maitlen Phyllite that lie to the southwest, and from which they are separated by an east-trending fault (Yates, 1964). Furthermore, they are intensely folded, display pronounced axial plane foliation, and are cut by numerous faults. They are intruded by numerous sills, dikes, and irregular masses of granodiorite and dacite, both of which are facies of the nearby Spirit pluton of Cretaceous age. Therefore, it is not known for certain where the metasedimentary rocks belong in the stratigraphic section. For this reason, Yates (1964) has referred to them as the Blue Ridge sequence, "an assemblage of related stratigraphic units whose position in the local and regional stratigraphy is obscure or indefinite." In many respects, the assemblage resembles the assemblage of quartzite, schist, and limestone south of Northport, the limestone of that is considered by Mills and Nordstrom (1973) to be the Reeves Limestone Member of the Maitlen Phyllite.

Beds generally strike north to north-northeast, with dips to west, ranging from 10° to 40° within the mine, steepening to 70° or 90° from 1/4- to 3/4-mile west of the mine. On the best developed mine level (Main Level) the sequence from east to west is schist, quartzite with some schist intercalations, and calcitic marble and limestone, interrupted irregularly by sills and dikes and irregular masses of dacite and granodiorite. One of these is a dacite sill, 20 to 30 feet thick, in and above the main ore zone in the mine. The cal-

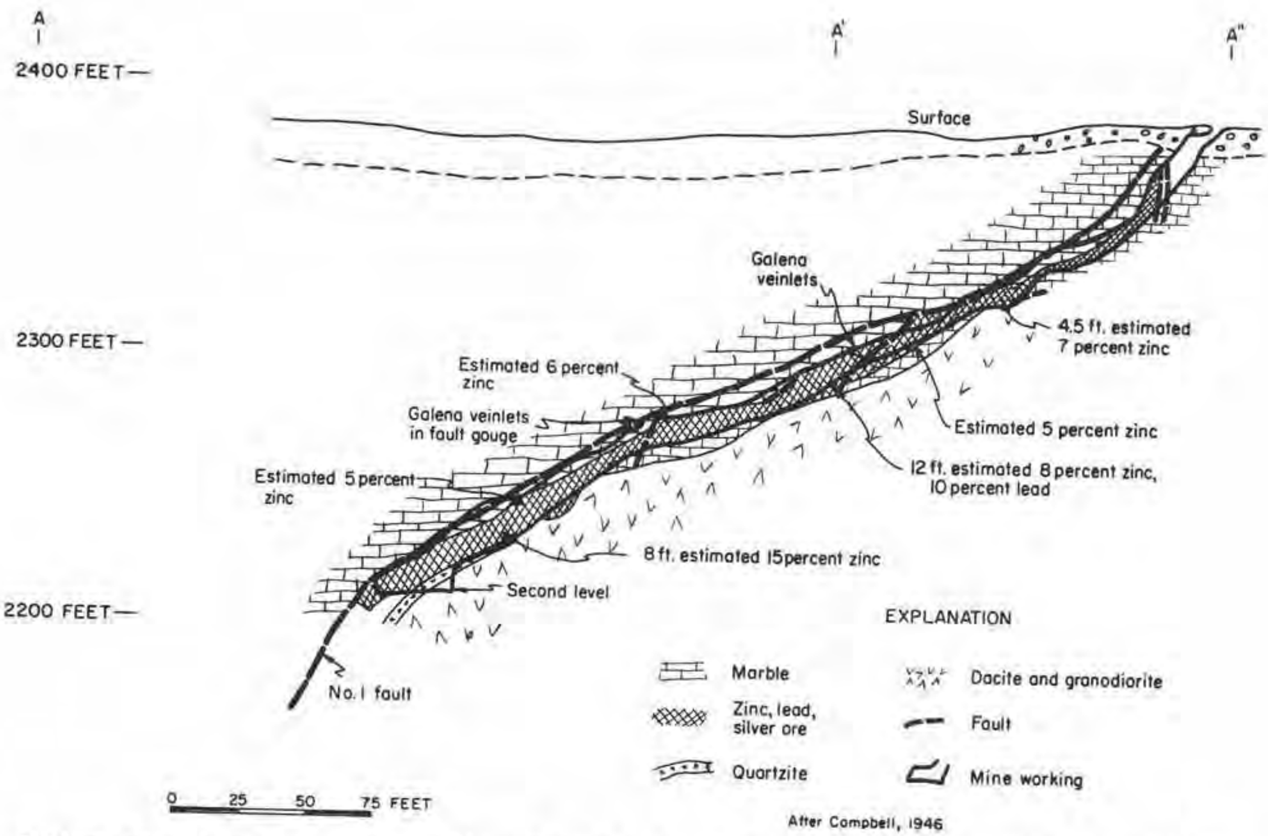

FIGURE 67.—Vertical cross section through principal workings above main (second) level, looking N. 70° E., Sierra Zinc mine.

citic marble or limestone is the principal ore host. In the mine workings, a maximum thickness of 44 feet of marble is exposed on the Main Level (fig. 66). The section is given by Campbell as follows:

Top: No. 1 Fault	Thickness (ft)
Marble, calcite, fine-grained, with dark-green (chlorite?) seams and films	10-18
Marble, dolomite, light-buff, pyritic, ... 4 percent zinc	4
Marble, similar to upper member	20-22
Marble, similar to upper ore member, but 8 percent zinc	10-22
Total thickness exposed of marble	44

The metasedimentary rocks are sharply folded. Some of the minor folds trend northeast, parallel to the regional strike, but most of them trend northwest to west and plunge westerly, with axial planes that are vertical or inclined southwest. Some folds are open, and some are almost isoclinal, according to Campbell.

Faults on a variety of scales are common throughout the area. Campbell found concentrations of sphalerite along about 20 small "pre-mineral" faults, all but two of which fall into one of two sets. One set strikes approximately east and dips steeply north; one strikes northeast and dips at moderate angles northwest. He also recognized post-mineral faults and post-mineral movements that faulted the sulfides along earlier faults. By far the most prominent fault in the mine is the No. 1 fault shown on the geologic map and section (figs. 66, 67). It has a variable northeast strike and dips northwest generally at 20° to 40°, transecting the bedding irregularly at a low angle and faulting the igneous rocks. It is marked by green muddy gouge, from a few inches to 10 feet thick. Campbell found galena veinlets in the gouge of No. 1 fault in four places, which led him to conclude that the fault formed "before the deposition of at least some of the galena." However, since the writing of his report, numerous writers have stressed the mobility of galena under stress. The galena in No. 1 fault gouge may have been deposited prior to faulting, then was mobilized during faulting. That is, the presence of galena in the fault gouge is not unassailable evidence for the fault being pre-mineral in age. The importance of this is considered further below where the origin of the ore deposit is discussed.

The ore-bearing marble consists of two ore horizons separated by 10 to 20 feet of barren calcitic and dolomitic marble or by wedgelike sills of granitic rocks. The best mineralized zones, illustrated in plan and section (figs. 66, 67) seem to follow the contact of the marble with the underlying quartzite, or to follow the west contact of the marble with the dacite sill. Campbell reports that the ore is not continuous along an ore horizon, but is offset every few yards by minor faults, and ore beds thin laterally, though their grade remains the same.

Most of the ore is marble, containing sphalerite, with more or less pyrite, in bands about 1 mm thick, parallel to the bedding. In the rich exposures the ore type contains a few "beds" of nearly pure sphalerite, each several inches thick. In a few places the ore is not clearly banded, and the sulfides form disseminated knots of intergrown crystals, which are generally somewhat coarser than the banded ore. These textures are very much like those of the Deep Creek mine, about 7 miles north-northwest of the Sierra Zinc mine, on the other side of the Spirit pluton.

Other occurrences of mineralization are described by Campbell as follows:

> Bedded ore also occurs in the tunnel 1000 feet south of the main portal, and in cuts 600 and 750 feet southwest of the portal.

He records mineralized "bed" thicknesses of from 1 to 3 feet. A visit to the area about 1,000 feet south of the mill in 1971 revealed some recent work on an old tunnel which exposed a 2½-foot-thick, calcitic marble bed containing abundant black and dark-brown sphalerite, galena, and pyrite, in layers from one-quarter of an inch to 3 inches thick, parallel to the bedding in the thin-bedded calcitic marble. That is, the mineralization is entirely conformable with bedding; both strike N. 85° W. and dip 21° north.

Campbell concluded that the Sierra Zinc ores were formed by the selective replacement of the marble host bed after the granodiorite and dacite had solidified. Solutions rose along steeply dipping minor faults, then spread laterally as they were diverted by the impervious gouge of the low-dipping No. 1 fault. However, he realized that the position of the ore far below the impervious gouge, separated from it by unmineralized marble, and the shapes of the ore shoots were not well explained by this hypothesis. He attempted to correlate the positions of the ore shoots with particular structural features, such as "rolls" in the fault surface, zones of shattering, and structural terraces in the beds, but was unsuccessful. He concluded that "either some unsuspected control of ore deposition was operative, or the controlling pre-mineral structure was obscured by the process of ore deposition or later tilting." With regard to the time of mineralization and igneous intrusion activity, Campbell suggested two possibilities:

> The Sierra Zinc ores were deposited after the granodiorite and dacite. . . . the emplacement of the igneous rocks, the formation of No. 1 fault, and the deposition of the ore may all have occurred in a relatively short time.

or

> It is at least equally possible that No. 1 fault and the ores are much younger than the Loon Lake granite.

However, Campbell maintained that the ores are younger than the No. 1 fault, as the zinc ores are localized below the fault and galena veinlets occur in the fault gouge.

In contrast to this view, the author believes that ore deposition took place long before the emplacement of the granitic rocks and before No. 1 fault formed. The following observations support this hypothesis:

1. The footwall ores are not adjacent to the impervious gouge, but are several feet below it.
2. One extensive mineralized area is several feet above the impervious gouge.
3. For the most part, the zinc mineralization is not along and adjacent to fractures, but is parallel to bedding and to foliation of the more micaceous rocks.
4. The various textural features of ore and gangue minerals, which have been brought out by etching of polished ore sections, are best explained by a sequence of events involving early ore deposition, regional metamorphism, intrusion, annealing, faulting, and some sulfide mobilization. That is, the ores today exhibit only textures generated relatively late in the geologic history of the deposit. Earlier depositional textures have been erased by subsequent events.

Exploration by diamond drilling was carried out in 1944 by the U.S. Bureau of Mines in cooperation with the U.S. Geological Survey. Six vertical holes were drilled from surface, aggregating 1,587 feet. They were planned to intersect projections of known ore exposed in the mine, in old workings south of the main adit and to the north of the mine workings. Mineralization was found in only one hole. It consisted of a 2-foot width of phyllite estimated to contain 25 percent zinc and 2 percent lead, about 200 feet north of the present workings and at an elevation a few feet above the 4th level.

Both mining and diamond drilling emphasize the lenticular shape of the ore shoots and their modest size. Thus, the search for more of them will need to be detailed. In view of their confinement to a marble bed, geologic mapping of the position and extent of that bed is desirable. More importantly, the rock structures, especially folds and faults, should be recorded and analyzed for their relation to the known ore concentrations. Because of the highly appressed nature of many of the folds and the recognition of two stages of folding, any sulfides emplaced prior to folding could be expected to show a strong localization by folds, especially to fold hinges, because of the susceptibility of galena to mobilization during dynamic metamorphism. Such a relationship should be sought for the known mineralized areas and, if found, should be extended to unexplored ground, especially to the west of the old mine workings.

TENDERFOOT

The Tenderfoot mine is in the SW$\frac{1}{4}$ sec. 23, T. 37 N., R. 39 E., low on the west slope of Gillette Mountain. Huntting (1956, p. 237) reports the presence of two adits, a drift, and two winzes, for a total of 800 feet of workings. In 1955 there were at least 12 separate surface cuts and eight underground workings, three of which had caved. At the time of the author's visit in 1970, most of the workings had been destroyed as a result of recent bulldozer activity that had not improved the exposures.

Weaver (1920) described the deposit as follows:

> The ore deposits lie in a zone of fracturing and alteration along the western side of the limestone belt and within the belt. The limestones have been shattered and along the shattered zones mineral-bearing solutions have penetrated and replaced the limestone along the fractures. The ore minerals are galena, cerussite, pyrite, and a little calamine. Galena predominates as the ore-bearing mineral.

and further (p. 239),

> The ore zones have been subjected to much secondary brecciation of a later age than the original mineralization.

Most of the galena occurrences described by Weaver were "kidney-shaped nodules" in soft, iron-stained clay and gouge along zones of faulting, crushing, and brecciation of the host rock.

An examination of the workings in 1955 indicated that they were strung out over a distance of about 350 feet more or less along the contour of the hill at an elevation of about 3,700 feet. Most of the cuts and adits were collared in dolomite within a few feet, or at most a few tens of feet, of the Ledbetter Slate to the west and northwest. They were driven southerly or southeasterly, exposing light-gray and dark-gray silicified dolomite, probably of the middle dolomite unit of the Metaline Limestone, cut by many slips and fault zones up to 4 or 5 feet wide. These zones are marked by intense brecciation of the dolomite walls and a strong development of microbreccia and gouge. The gouge (Weaver's "clay") is heavily stained with hydrous iron oxides and contains pods and small veins of galena and a little quartz over widths of a few inches, at most. The most pronounced and best mineralized fault zones strike between north and N. 30° E. and dip to the east or southeast of angles ranging from 15° to 35°.

The Ledbetter-Metaline contact is exposed in one place near the workings; it does not appear to mark a zone of intense movement, although it must be a fault or an unconformity if, as is suggested, the dolomite is the middle unit of the Metaline Limestone. The contact strikes north and must have a very steep dip (probably to the west), judging from its relatively straight trace in this rugged terrain. Although the lead-bearing lesser faults have strikes that may nearly parallel the contact, their dips are very much less.

About one-quarter of a mile farther up the hill to the south, probably in the NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 26, is a trench about 100 feet long and 10 feet deep, in well-bedded dolomite and dolomite breccia, striking N. 15° E. and dipping 70° W. The breccia fragments are fine-grained, light-gray dolomite and black, white-mottled dolomite typical of the middle dolomite unit of the Metaline Limestone. The breccia matrix is a light-gray to yellow-white, coarse-grained dolomite. This rock is cut by an iron-stained fault zone, from 0.5 to 1.5 feet wide, carrying abundant galena between fault breccia dolomite fragments. The zone strikes N. 30° W. and dips 30° NE., cutting right across the bedded dolomite breccia.

In summary, all of the galena mineralization at the Tenderfoot mine is (1) in dolomite and dolomite breccia of the Metaline Limestone (middle dolomite unit), (2) within a few feet or tens of feet of the Ledbetter Slate, and (3) associated with breccia and gouge in faults that are transverse to the bedding of the host rocks. Also, pyrite and sphalerite are very scarce or absent.

VAN STONE

The Van Stone mine open pits are in the E$\frac{1}{2}$ sec. 33, T. 38 N., R. 40 E., at the headwaters of Onion Creek, 10$\frac{1}{2}$ miles due south of Northport. The history of the mine, in part as given by Cox (1968, p. 1512), is as follows:

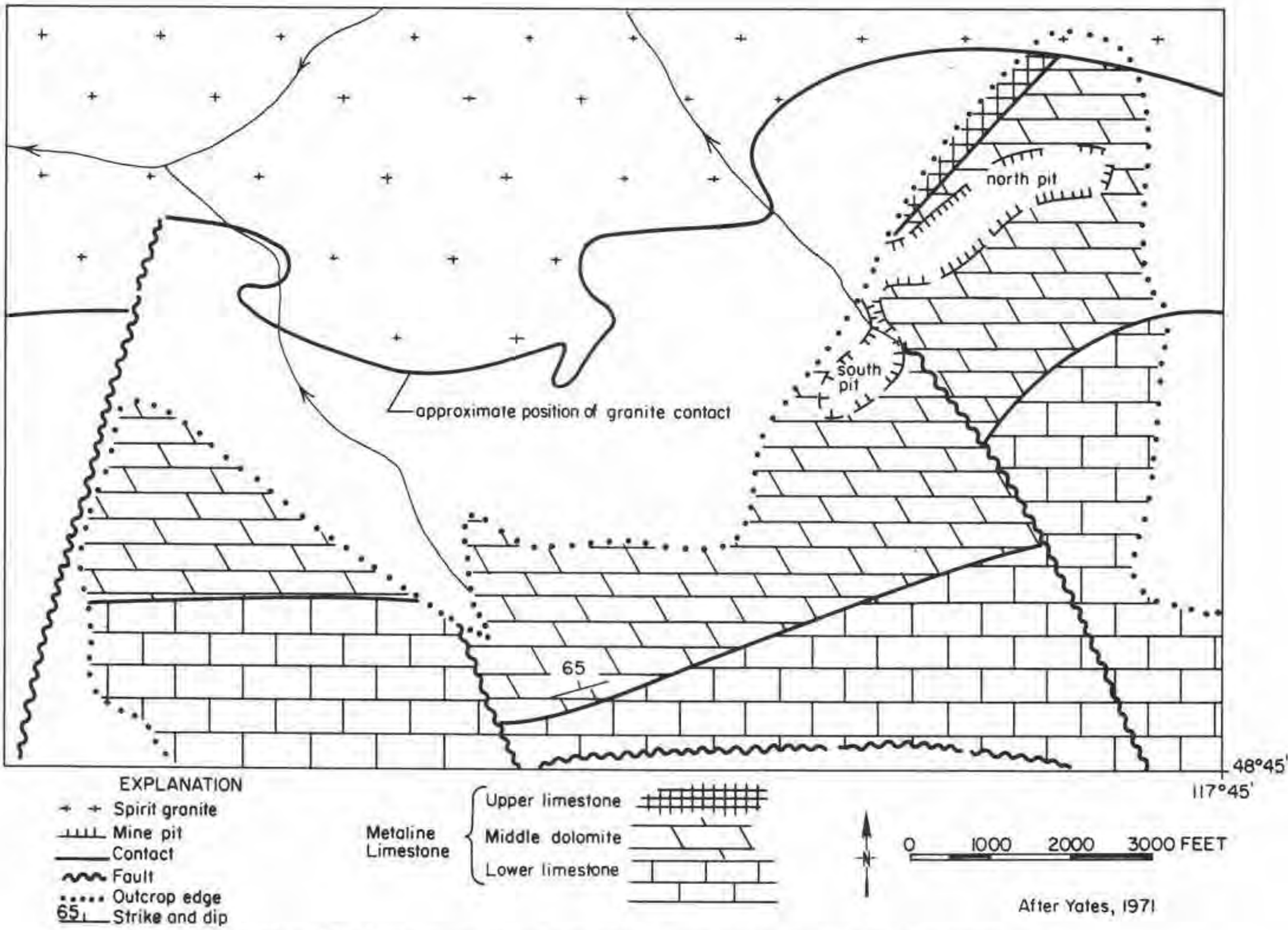

FIGURE 68.—Geologic map, showing approximate position of Van Stone mine pits.

Prior to World War I	Discovery
1920–1926	Owned and worked by Geo. Van Stone and Harry Maylor
1926–1927	Hecla Mining Co. diamond drilling
1930	Van Stone Mining Co.
1938–1942	Willow Creek Mines drilling and underground exploration
1950–1971	American Smelting and Refining Co. exploration and discontinuous production
1972–present	Callahan Mining Co. underground exploration

Production to the end of 1956 (Cox, 1968, p. 1513) was 2,242,960 tons of ore milled, yielding 10,700 tons of lead concentrates and 120,000 tons of zinc concentrates. The average grade of the concentrate was 62 percent lead and 54 percent zinc. This corresponds to an average ore grade of approximately 3 percent zinc and 0.3 percent lead. No other metals were present in the concentrates in any significant amount. Production has been from two open pits (fig. 68) a few hundred feet south of the south margin of the Spirit pluton. The ore deposit is within the middle dolomite unit of the Metaline Limestone, only about 200 feet from the overlying upper limestone unit at its closest point.

The host rock is a fine- to medium-grained dolomite, most of which is dark gray, though white, gray, and black varieties are not uncommon. Banding in the dolomite is present throughout the mine and is produced by alternations of dark-gray, gray, and light-gray to white dolomite. Individual bands extend for only a few feet before pinching out or splitting into two or more bands. Some show irregular foldlike convolutions before they pinch out. The banding is interpreted as bedding by Cox, who speaks of the host rock as thinly bedded rock (1968, p. 1516). However, neither Neitzel (1972) or the author recognized any structure that unequivocally could be said to be bedding. It is considered that the banding is metamorphic in origin.

Often the fine-grained, dark-gray rock is traversed by veins(?) and irregular masses of medium-grained, light-gray dolomite that may be so abundant as to make up 50 percent of the rock, giving it a blotchy appearance resembling a breccia. In such cases, angular to sub-angular, fine-grained, dark-gray dolomite "fragments" are surrounded by lighter gray dolomite "matrix." The more tabular veins(?) of light-gray dolomite are generally parallel to the banding of the host rock dolomite. The origin of the veins(?) and irregular masses of light-gray dolomite, enclosing "fragments" of finer grained, dark-gray dolomite, is unknown. It looks as though the lighter is replacing the darker. This "breccia" resembles breccias at such mines as the Iroquois, Lead Trust, and Lead King in having (1) dark-gray fragments in a coarser grained, lighter gray or white matrix, (2) sulfides confined to the matrix, and (3) coarser dolomite matrix apparently developed at the expense of the finer grained "fragments." However, it differs from the breccias at the other mines in having less contrast in shade and grain size between matrix and fragments, and in its development in fairly massive to banded dolomite, rather than in the thin-bedded intraformational breccia of the other mines.

Most, if not all, of the base metal sulfide mineralization is associated with the light-gray or "matrix" dolomite, not with the darker dolomite "fragments." However, the lighter, coarser dolomite is found in sulfide-free areas as well. Whatever its origin, it provides a useful exploration target because sulfides are almost entirely lacking outside the areas of vein(?) and matrix dolomite.

The banded dolomite rock, where unaltered and unmineralized, consists of dolomite, commonly with grain size ranging from 0.05 to 0.10 mm, up to 5 percent chert, and from 0 to 10 percent graphite. Graphite is the pigment upon which the blackness of the dolomite depends. Dark bands rich in graphite are invariably finer grained than the white or light-gray bands. Most dolomite has a granoblastic polygonal texture indicating that there has been annealing recrystallization and grain growth following regional deformation.

Most of the dolomite exposed in the pits is highly silicified, containing fine-grained translucent silica having a subconchoidal fracture. The silica replaces the beds of dolomite (Cox, 1968, p. 1516). Some of this silicified rock looks like the unsilicified dolomite but is very much harder. The only other abundant mineral is tremolite, which is found as needles and radiating sheafs of needles or thin laths in the dolomite near jasperoid, in the jasperoid, and in the ore. Neitzel (1972, p. 33) also found diopside and quartz to be present, usually associated with tremolite.

The jasperoid-tremolite alteration zones are highly irregular in shape and distribution but in general they conform to the banding in the dolomite and the trend of the ore concentrations. Their configuration (fig. 69) strongly suggests attenuated folds. The alteration zones may be ore bearing or barren. That is, their relation to the sulfide mineralization is not

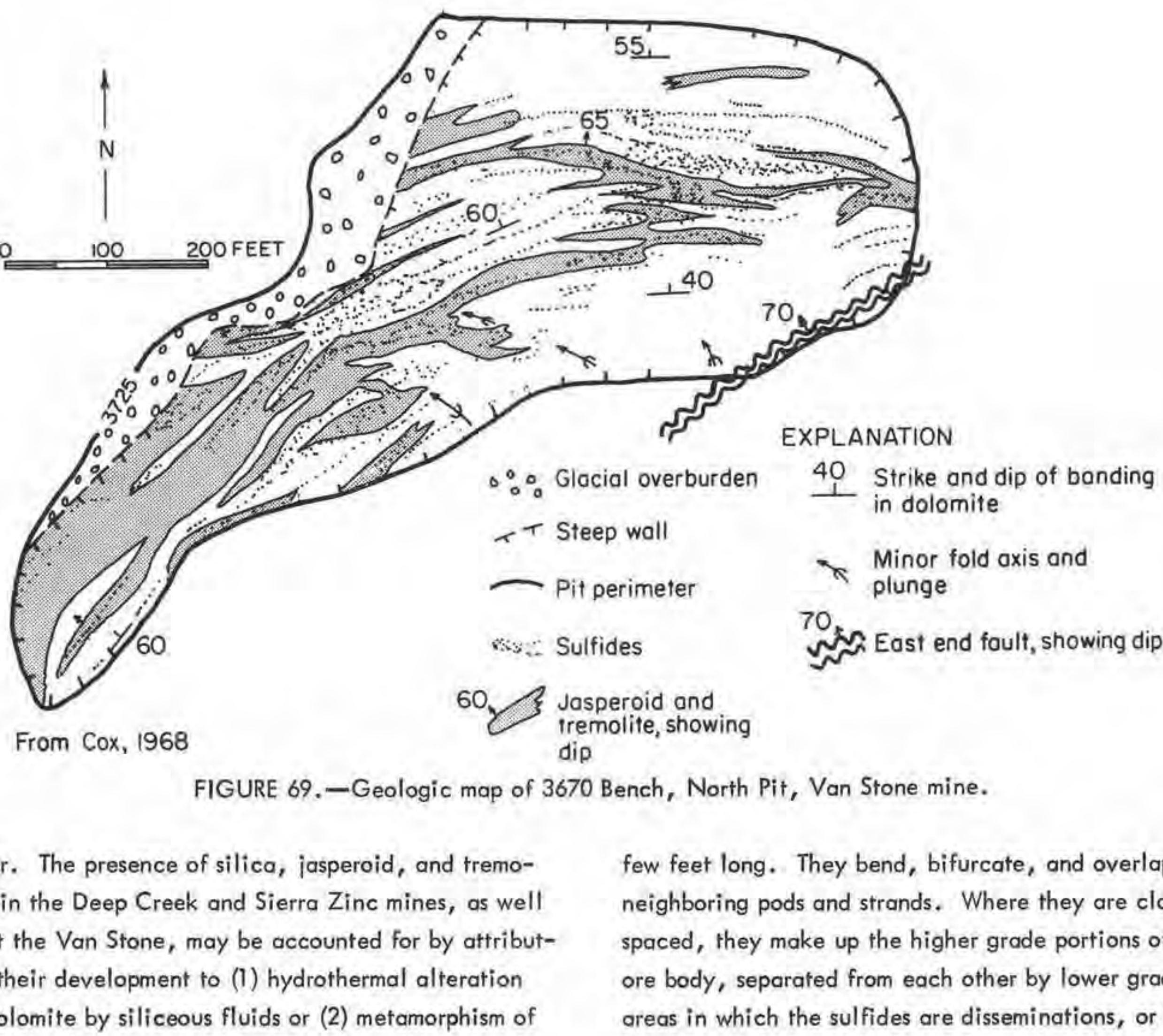

FIGURE 69.—Geologic map of 3670 Bench, North Pit, Van Stone mine.

clear. The presence of silica, jasperoid, and tremolite in the Deep Creek and Sierra Zinc mines, as well as at the Van Stone, may be accounted for by attributing their development to (1) hydrothermal alteration of dolomite by siliceous fluids or (2) metamorphism of silica-bearing dolomite or dolomite breccia. The latter explanation is the one preferred by the author, for reasons given in a later section.

Ore Deposits

The sulfide mineralization of the ore body takes the form of streaks, pods, lenticular and elongate tabular masses of sphalerite, pyrite, and galena parallel to the banding in banded dolomite or jasperoidal and tremolitic dolomite. Individual sulfide masses are seldom more than a few inches wide and a few feet long. They bend, bifurcate, and overlap neighboring pods and strands. Where they are closely spaced, they make up the higher grade portions of the ore body, separated from each other by lower grade areas in which the sulfides are disseminations, or knots, or small streaks and lenticles. A typical distribution pattern for the mineralization is illustrated in figure 69. The aggregate thickness of the ore body is as much as 300 feet. The total length of the workings in the two pits is about 1,350 feet.

The ore concentrations, alteration zones, and banding in the dolomite strike east-west and dip 60° to 70° N. at the north end of the North Pit; strike N. 55° E. to N. 60° E. and dip 60° to 80° NW. in the central part of the North Pit; and strike N. 40° E., and dip 60° NW. at the south end of the North Pit and the north end of the South Pit. Farther to the southwest, the trend swings more westerly, so that at the south end of the South Pit it is almost east-west, with north dips. This plan pattern is what Cox refers to as an S-shaped fold.

A diamond-drilling program, begun in 1969 and completed in 1970, was designed to test the depth continuation of the North Pit ore body. It revealed a hitherto unknown ore body, of comparable size and grade to the main ore body, lying west of the North Pit and extending to an elevation at least 300 feet lower than the floor of the North Pit. Neitzel (1972) studied the North Pit ore body and the drill core logs and analyses and prepared a model consisting of five vertical sections across the ore zones. The model established that the newly discovered ore body is really a relatively low-dipping, down-dip extension of the North Pit ore body, and is connected to it by a relatively thin ore zone. The new and old ore bodies form one large northwest-dipping mineralized zone, which is S-shaped in vertical section as viewed from the southwest and is similar in shape to the plan view of the mineralized zone comprising the north and south ore bodies.

Faults of northeast trend and little displacement are quite common. They are post-ore faults that develop sphalerite mylonite, sphalerite breccia, and steely galena wherever they cut the ore zone. One large fault at the northeast end of the North Pit is a "crushed and gougy zone up to 100 feet in thickness" (Cox, 1968, p. 1515), deeply oxidized and hazardous to mining operations. It strikes N. 60° E. and dips 70° to 75° NW. Cox believes the fault to be pre-ore but with post-ore adjustments. The zone is in ground that is too steep and unstable for surface examination so that Cox's premineralization age assignment, based upon the presence of zinc and iron sulfides in the fault zone, could not be checked. That there was post-mineralization movement on the fault was confirmed by Neitzel who found microbrecciated sphalerite and jasperoid in the fault hanging wall. Another fault is shown by Yates (1971), following the valley of the branch of Onion Creek that passes between the South and North Pits. A 12-foot-wide, yellow-weathering zone of brecciated jasperoid, dipping steeply northeast at the north entrance of the South Pit, may mark the position of this fault. Its relation to the mineralization is undetermined; presumably, it is post-ore as there are no known ore concentrations along it.

Neitzel recognized three prominent joint sets in the mine, by far the most prominent of which comprises joints that strike N. 45° W. and dip 55° NE. All joints are post-ore, as they cut all mineralization.

Lamprophyre dikes in the ore zone are reported both by Cox (1968) and Neitzel (1972). Cox describes them as notoriously irregular, strongly hydrothermally altered, and mineralized with sphalerite. Neitzel maintains that the dikes are post-ore, as they cut the mineralization and, although sphalerite may be concentrated in the dolomite near dike borders, the dikes contain no lead-zinc mineralization. Neitzel believes that the intense alteration of the dikes is meteoric, not hydrothermal, and that they probably are similar in kind and origin to many lamprophyre dikes in northern Stevens County that Yates (1971) has mapped as Eocene in age.

The dominant metallic minerals of the ore zone are sphalerite, galena, pyrite, and pyrrhotite. Pyrite is the more abundant iron sulfide but pyrrhotite is dominant near the granite contact.

Pyrite occurs as disseminated euhedral cubic grains, up to 1.2 mm in diameter, sometimes showing pyritohedral cores after etching, and frequently enclosing inclusions of dolomite, sphalerite, and galena. It is also found as irregular areas or bands that take a fine polish and which, upon etching, are found to consist of nearly equidimensional grains, often with good granoblastic polygonal texture and 120° triple junction points indicative of annealing. Grain size variation within a mass or band is small but the range in grain size in different masses is from 0.05 to 0.50 mm. Individual grains may contain many small subround inclusions of gangue and ore minerals. Within the mass as a whole, the inclusions are often arranged in wavy or scalloped patterns, probably a relict texture. The outer rim of such a mass is often made up of planar segments, which are crystal faces of the marginal pyrite grains. Some pyritic masses, upon etching, are seen to consist of fan-shaped clusters of elongate, radially arranged crystals. Etching may also bring out beautiful parallel growth zones in these elongate pyrite crystals. One such section shows thin scalloped galena layers parallel to the growth zones within the pyrite (fig. 26). Some pyrite bands or layers are interlayered with bands of sphalerite (fig. 23) and bands of dolomite. Such pyrite bands may display a smooth straight contact on one side and a highly irregular dentate contact on the other. This texture is no doubt inherited from the original depositional banding.

Pyrrhotite was found in a few polished sections in grains up to 0.40 mm wide, often surrounded by or including islands of pyrite rich in gangue inclusions. Some areas of pyrrhotite or slightly anisotropic pyrite take a poor polish compared to most pyrite and pyrrhotite. At magnifications of 3,600 times, such areas display a brickwork pattern; the "bricks" are pyrite and the "mortar" is an indeterminate mixture of other sulfides (Neitzel, 1972, p. 25). Most pyrrhotite is the hexagonal variety, altering to the monoclinic variety along fractures and grain boundaries.

Sphalerite occurs as disseminations in the dolomite, as small round or oval inclusions in pyrite and galena, as crystal aggregates in association with galena, and as layers alternating with layers of pyrite or dolomite. It may be dark brown, red brown, yellow, or light green in color. According to Neitzel, the color is to some degree indicative of the texture. The dark-brown and red-brown sphalerite is composed of a mixture of deformation-twinned grains and equidimensional grains of granoblastic polygonal texture with many 120° triple junction points. Annealing twins (fig. 30) are common in the equigranular sphalerite. Yellow sphalerite occurs as entirely equigranular grains with granoblastic polygonal texture and excellent 120° triple junction points and well-developed annealing twins. In twelve polished sections studied by the author, almost all sphalerite had well-developed granoblastic polygonal texture and annealing twins in grains that ranged from 0.02 to 0.30 mm in diameter. A typical lobate and scalloped contact between sphalerite and galena is pictured in figure 70 (before etching). Such a pattern is typical and diagnostic of well-annealed sphalerite-galena mixtures. Sphalerite that is included within single crystals of galena or pyrite is round in outline. Green sphalerite is a mylonitized or microbrecciated sphalerite.

Galena is found most commonly in close association with sphalerite, often as cuspate bodies along sphalerite grain boundaries or at sphalerite grain triple junction points, as irregularly shaped masses, and as isolated round inclusions in sphalerite (fig. 70). Grains range from rather rare elongate crystals, about 0.20 mm wide and 1.0 mm long, to the common smaller equidimensional grains, from 0.03 to 0.30 mm in diameter. The latter invariably display good polygonal texture and 120° triple junction points indicative of annealing. Galena is also found as curving linear arrays of galena blebs in pyrite. Some of these look like discontinuous or disjointed very thin galena veins (fig. 25) until the pyrite is etched, whereupon the "veins" are seen to be of the same scale and orientation as growth zones in the columnar pyrite host (fig. 26). The cusps of the "veins" fall at the interfaces of adjacent pyrite columnals. The pyrite has retained its original growth record, as well

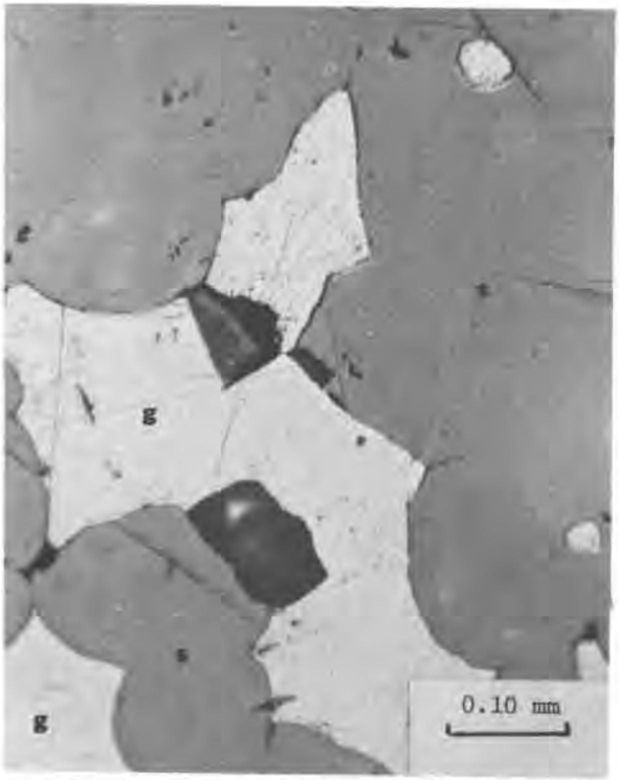

FIGURE 70.—Photograph of polished section of zinc-lead ore from Deep Creek mine, showing lobate and scalloped nature of sphalerite-galena contacts in zinc-lead ores that have been extensively recrystallized and annealed. Etching of such a specimen would bring out the granoblastic polygonal texture and annealing twins (in sphalerite) described and illustrated elsewhere in this report.

as the galena layers that must have been deposited during the growth of the pyrite crystals.

Tremolite is generally intergrown with sulfides in a texture that has yet to be considered. Polished sections of ores from the Van Stone, Deep Creek, A and C, Howard, New England, and Sierra Zinc mines display intergrowths with sulfides in which the tremolite appears as long laths in longitudinal section or as rhombus-shaped euhedral crystals when the sections are transverse to the tremolite crystals (fig. 33). Cox (1968, p. 1518) mentions that sphalerite is "often intergrown with tremolite, and in such cases the tremolite takes on a brown or purple aspect." The relative age of the sulfides and the intergrown tremolite is in question. Cox believes that the tremolite is the product of the alteration of dolomite host rocks by the ore-forming solutions and therefore is essentially contemporaneous with the sulfides. Except for the observation that sphalerite and tremolite are intergrown, he gives no evidence for their relative age. Yates (1970), however, is of the opinion that the tremolite is a product of thermal metamorphism of the host rocks near the Spirit pluton and that the sulfides are younger than the tremolite. He writes (p. 38):

> . . . . the ores are found in thermally metamorphosed rocks, in particular at the Deep Creek and Van Stone mines where pseudomorphing of tremolite by sphalerite is common, and at many prospects.

Neither the author nor Neitzel in the course of examining about 20 tremolite-bearing polished sections of ores from the Deep Creek and Van Stone mines found any indication of pseudomorphing of tremolite by sphalerite. On the other hand, we found many examples of euhedral tremolite crystals containing inclusions of annealing-twinned sphalerite where the orientation of the twin planes in the sphalerite inclusion is identical to that of twin planes in sphalerite bordering the tremolite. Such a texture (unsupported oriented residuals) has long been held to be diagnostic of replacement, and would testify to the tremolite as being the younger. Neitzel (1972, p. 24) reports that oriented segments of sphalerite grains may be included within a single crystal of tremolite and euhedral crystals of tremolite may be included within single sphalerite crystals. These conflicting reports and interpretations may be reconciled if it is kept in mind that the tremolite-bearing rocks and ores have been completely recrystallized. The enigmatic sulfide-tremolite intergrowths could have been brought about by recrystallization and grain growth of siliceous dolomite and sulfides and the simultaneous generation of tremolite during thermal metamorphism by the nearby granodiorite pluton. According to this interpretation, the textures have been generated by solid-state diffusion during thermal metamorphism, replacement playing no part whatsoever.

Following is a summary of the sequence of events that led to the formation of the ore body as it exists today, based upon evidence provided in the foregoing text. The record of later events is clear.

Events	Evidence at the Van Stone mine
Initial deposition of sulfides and silica in dolomite under conditions of low confining pressure (and low temperature?)	1. Alternating fine-grained layers of dolomite, sphalerite and pyrite. 2. Concentrically arranged alternating bands of dolomite and pyrite. 3. Discontinuous curving linear arrays of sphalerite or galena blebs, in pyrite. 4. Growth zones in radiating pyrite columnals, with concentric layers of galena. 5. Very fine grain size of associated silica.
One or more periods of regional metamorphism, with generation of strongly appressed and isoclinal overturned folds, metamorphic banding, transposition of bedding; greenschist metamorphism.	1. Distribution and shape of sulfide, tremolite, and jasperoid concentrations. 2. Banding of rocks and ores and its general conformity with contact of overlying and underlying formations. 3. Cataclasis of pyrite and deformation twins in sphalerite.
Thermal metamorphism; recrystallization and grain growth of dolomite and sulfides simultaneously with generation of tremolite.	1. Granoblastic polygonal textures and 120° triple junction points well-developed in dolomite, galena, sphalerite, and in some pyrite. 2. Annealing twins in sphalerite. 3. In mixtures of sphalerite and galena, the mineral present in lesser amounts is localized along grain boundaries and at triple junction points of the mineral present in greater amount. 4. Pyrite and tremolite porphyroblasts. 5. Smaller grain size of graphitic dolomite as compared to pure dolomite; interpreted as inhibition of grain growth by impurity (graphite). 6. Conflicting evidence for replacement between euhedral tremolite and anhedral sphalerite and galena. 7. Similarity in structure and mineralogy and mineral textures to other mines (Deep Creek, Sierra Zinc) close to Spirit pluton.
Late faulting and jointing	1. Shear zones, gouge, breccia, mylonitized sphalerite, steely galena, and cataclastic pyrite. Prominent joint sets cutting both rocks and ores.

The record of initial deposition of the sulfides has been greatly modified by later events, so that its reconstruction is tenuous.

The evidence above supports an origin as outlined previously, an origin quite different from the post-granite hydrothermal replacement origin generally proposed. The absence of any obvious feeder channels for hydrothermal fluid circulation, the lack of any wall rock alteration regularly disposed with respect to the ore concentrations, and the absence of textural evidence for replacement combine to deny a replacement origin, but are entirely compatible with the origin outlined.

YOUNG AMERICA MINE

The Young America mine is in the NE¼NW¼ sec. 33, T. 38 N., R. 38 E., about a quarter of a mile northeast of the town of Bossburg, which is located on State Highway 25. This property was first discovered in 1885, making it, with the Old Dominion and the Bonanza Lead, one of the three oldest properties in the Colville district. Production has been (Fulkerson and Kingston, 1958) 939,719 pounds lead, 771,629 pounds zinc, and 69,893 ounces silver.

The mine was not examined in the course of this study. A good account of the mineralogy and geologic setting of the deposit is provided by Purdy (1951). The following descriptions of the deposits are taken directly from Purdy's report.

> The principal ore zone is just beneath a flat-lying shear in a gray to white massive fine-grained dolomitic limestone. The shear strikes . . . about N. 65° E. and dips between 15° and 25° N., averaging about 20° N. The attitude of this plane of thrusting is more or less controlled by the attitude of the dolomitic limestone. In the latter part of 1948 the ore had been mined along its strike for 300 feet and along the dip for 200 feet. The zone, containing numerous flexures, varies in thickness from a few inches to 10 feet.
>
> This tabular S-shaped ore zone is cut . . . by a calcite vein 2 to 4 feet thick striking N. 20° E. and dipping 72° E. . . . the calcite vein is definitely post-ore and contains fragments of ore, this same plane may nevertheless have also been a plane of pre-ore movement.

According to Purdy (p. 152), the history of the lead-zinc mineralization took place in the following stages:

> 1. Pre-ore fracturing which prepared the dolomitic limestone for the introduction of mineralizing solutions. Fracturing probably continued into the early part of the next stage.
>
> 2. Introduction of quartz and euhedral pyrite with minute cobaltite inclusions. Generally, the best ore bodies are found where the concentration of silica in the limestone is the highest. Hydrothermal alteration of the felsite dikes and deposition of pyrite and chalcopyrite along fractures in the dikes may have taken place at this stage.
>
> 3. Deposition of dark-brown sphalerite with stannite inclusions in silicified limestone, followed by depletion of copper, tin, and most of the iron from the mineralizing solutions (as evidenced by the deposition of light-brown sphalerite alone) as the final phase of the zinc mineralization.
>
> 4. Deposition of the second generation of quartz.
>
> 5. Deposition of geocronite and galena, perhaps in that order.
>
> 6. Formation of the calcite vein and subordinate stringers, preceded by some displacement. The calcium in the calcite vein may have been derived from that which was displaced from the dolomitic limestone at the time of its replacement by the mineralizing solutions.
>
> 7. Deposition of drusy quartz.
>
> 8. Post-mineral movement on calcite vein.

APPENDIX A

SULFUR ISOTOPES

Sulfur has four stable isotopes with the following abundances: S^{32}=95.1 percent, S^{33}=0.74 percent, S^{34}=4.2 percent, and S^{36}=0.02 percent (Jensen, 1967). Sulfur is present in nearly all natural environments. It occurs as a minor component, mostly as sulfides, in igneous and metamorphic rocks; in the biosphere and related organic substances like crude oil and coal; in ocean water as sulfate; and in marine sediments as both sulfide and sulfate. It may be a major component, as in ore deposits where it is the dominant nonmetal, and in evaporites where it occurs as sulfate (Hoefs, 1973).

The ratio of the two most abundant isotopes, S^{32} and S^{34}, varies considerably among these environments. This is reflected in δS^{34} values which range from about +80 to about -60 per mil, where the δS^{34} value of a rock or mineral sample is defined (Jensen, 1967) as:

$$\delta S^{34} \text{ per mil} = \left[\frac{S^{34}/S^{32} \text{ sample} - S^{34}/S^{32} \text{standard}}{S^{34}/S^{32} \text{ standard}}\right] \times 1000$$

in which S^{34}/S^{32} standard is the sulfur isotopic composition of the mineral troilite of the Cañon Diablo meteorite (Macnamara and Thode, 1950). Positive and negative per mil values represent, respectively, enrichment and depletion of S^{34} relative to the standard.

Sulfides in igneous rocks have δS^{34} values greater than -7 per mil and less than +10 per mil; that is, they are rather close to the meteorite standard (0 per mil). Sulfides from some carefully studied hydrothermal ore deposits have δS^{34} values that range from -35 to +27 per mil. Some of these deposits have δS^{34} values that fall within a narrow range of only a few per mil while others have a very wide range of 40 to 45 per mil (Rye and Ohmoto, 1974). Sulfur isotope studies can be of value in determining the origin of the sulfur in ore deposits and the processes by which the ore deposits were formed, as will be seen in the following discussion.

In order to study the sulfur isotope distribution in zinc-lead ores from Stevens and Pend Oreille Counties, Washington, 22 samples of sulfides were hand picked from ore specimens of pyrite, sphalerite, and galena. Isotope analyses were made by M. L. Jensen, Department of Geology and Geophysics, University of Utah, Salt Lake City. The results of these analyses are shown as follows:

County	Mine	Ore conformability	Sulfide	δS^{34} per mil
Stevens	Calhoun	Conformable	Pyrite	11.8
			Sphalerite	15.8
			Galena	12.7
Stevens	Van Stone	Conformable	Pyrite	6.1
			Sphalerite	12.5
			Galena	20.7
Stevens	Farmer	Conformable	Pyrite	9.7
			Sphalerite	28.8

Continued on next page

Analyses—Continued

County	Mine	Ore conformability	Sulfide	δS^{34} per mil
			Galena	12.9
Stevens	Scandia	?	Sphalerite	22.3
			Galena	17.4
Stevens	Sierra Zinc	Conformable	Pyrite	13.3
			Galena	21.1
Pend Oreille	Yellowhead	Conformable	Pyrite	23.8
			Sphalerite	6.7
			Galena	15.5
Pend Oreille	Pend Oreille	Conformable	Sphalerite	16.5
			Galena	15.5
Stevens	Electric Point	Discordant	Galena	10.6
Stevens	Shoemaker	Discordant	Galena	4.8
Stevens	Lucile	Discordant	Galena	12.4
Stevens	Old Dominion	Discordant	Galena	9.2

Observations

1. The δS^{34} values for northeastern Washington zinc-lead ores are very high (+4.8 to +28.8 per mil).
2. The range in δS^{34} values is very large. The range for pyrite from 5 deposits is 17.7 per mil, the range for sphalerite from 6 deposits is 22.1 per mil, and the range for galena from 11 deposits is 16.3 per mil. That is, the range of δS^{34} values for individual mineral species is almost as large, especially for sphalerite, as the range of δS^{34} values (24.0 per mil) for all sulfides.
3. Under equilibrium conditions it is to be expected that, as a result of isotope fractionation, δS^{34} values for pyrite will be larger than for sphalerite, and both pyrite and sphalerite will be larger than for galena (Rye and Ohmoto, 1974). No such relationship is apparent for the isotope analyses of pyrite, sphalerite, and galena of the Yellowhead, Calhoun, Van Stone, and Farmer mines.
4. The range of δS^{34} values for sulfides from the conformable deposits of northeastern Washington is +6.1 to +28.8 per mil and the average of 18 samples is +15.7 per mil. These "heavy" sulfides with their wide range of δS^{34} values are much like those of (1) the Bonne Terre district, Missouri, where sulfur ranges from +12.2 to +20.7 per mil and averages +17.8 per mil (Ault and Kulp, 1960), (2) the Monarch and Kicking Horse mines, Field, British Columbia, where δS^{34} values range from +17.6 to +31.3 per mil (Evans, Campbell, and Krouse, 1968), and (3) Sardinia, where δS^{34} ranges from +14.4 to +37.2 (Jensen and Dessau, 1966). All these ores are stratiform and in carbonate rocks of Cambrian age. A similar range of δS^{34} values (+12.1 to +25.9 per mil) is found in stratiform zinc-lead ores in phyllite of Cambrian age at the Anvil mine, Yukon Territory, Canada (Campbell and Ethier, 1974).

Conclusions

There are far too few specimen analyses to lead to any unequivocal conclusions. However, on the basis of the data to date, the following tentative conclusions may be drawn:

1. Sulfides from the Josephine Breccia (Scandia and Pend Oreille mines) and from the Yellowhead horizon (Yellowhead, Calhoun, and Van Stone mines) have δS^{34} values that are comparable, hence not distinctive for either horizon.
2. Average δS^{34} values for galena from the discordant vein deposits (Lucile, Electric Point, Old Dominion, and Shoemaker mines) in carbonate rocks is +9.2 per mil, a figure that is significantly less than the average δS^{34} value (+16.5 per mil) for galena from concordant deposits in carbonate rocks (Sierra Zinc, Van Stone, Scandia, Pend Oreille, Yellowhead, Farmer, and Calhoun mines). In fact, the highest δS^{34} value (+12.4 per mil) for galena from a discordant deposit is less than the smallest value (+12.7 per mil) for galena from any of the seven concordant deposits.
3. The difference in δS^{34} values (δS^{34} pyrite - δS^{34} sphalerite) for pyrite and sphalerite within deposits seems to correlate with the nearness of intrusives and degree of recrystallization. The difference is δS^{34} values changes from positive to negative as thermal metamorphism increases, as shown below:

Mine	Degree of thermal metamorphism	δS^{34} pyrite - δS^{34} sphalerite
Yellowhead	None	+17.1 per mil
Calhoun	Little	-4.0
Van Stone	Much	-6.4
Farmer	Very much	-19.1

This relationship is provocative, but it may be purely fortuitous.

4. The great variability in δS^{34} values within and between mineral species from different mines indicates that precipitation of the sulfides took place under conditions of isotopic disequilibrium.
5. The combination of Observations 1, 2, and 3 above; that is, a variable and wide range of positive δS^{34} values, is incompatible with a magmatic hydrothermal origin for the sulfur. This rules out the possibility that the ore-depositing fluids were the products of differentiation of the magmas that gave rise to the plutonic rocks of the region. However, the observations are quite compatible with a source of sulfur in sea-water sulfate or connate brines where the sulfate was reduced to sulfide through bacterial action.

In a recent review of sulfur isotopes and ore genesis, Rye and Ohmoto (1974, p. 836) point out that sulfur of a deposit that has a wide range of δS^{34} values may be either biogenic or magmatic in origin.

> In surficial low-temperature environments the only known means of reducing sulfate to H_2S and precipitating sulfides is by the life processes of sulfur-reducing bacteria. These bacteria are ubiquitous in low-temperature environments and it seems likely that they have played an important role in many stratiform deposits which occur in nonvolcanic environments. Bacteriogenic sulfide deposits may also occur in ocean basins in volcanic environments. However, sea water sulfate may readily be reduced by deep circulation into rocks of high temperature and syngenetic and(or) epigenetic sulfides may precipitate from the inorganically reduced sulfur at lower temperatures on or near the sea floor.

In view of the lack of any evidence for volcanism in the Cambrian and Ordovician rocks of northeastern Washington, a low-temperature biogenic origin for the reduced sulfur seems more likely than a high-temperature inorganic origin. Commonly, sulfides whose sulfur has been derived by the bacteriogenic reduction of sea-water sulfate have a large range of δS^{34} values, though in certain cases it may be small. The δS^{34} values in an ore deposit may vary drastically within a small distance and sulfur isotope disequilibrium may be very common among coexisting sulfides (Rye and Ohmoto, 1974, p. 836). The δS^{34} values of sulfides from the strata-bound zinc-lead deposits of northeastern Washington exhibit these characteristics. Their sulfur is probably bacteriogenic.

There remains the question of the source of the sulfate. Whatever its source, it had to have a δS^{34} value equal to or greater than the δS^{34} value of the sulfides formed from it because during bacteriogenic reduction of sulfate the H_2S generated (and the subsequent metal sulfides) is depleted in S^{34} by 0 to 25 per mil, according to whether the bacteria metabolic rate is fast or slow (Harrison and Thode, 1958). Sulfate in sea water of Cambrian and Ordovician time, or evaporites precipitated from it had average δS^{34} values of +28.8 and +26.9 per mil, respectively (Thode and Monster, 1965). Starting with sea-water sulfate of this isotopic composition, bacterial reduction of sulfate at widely different rates could well have yielded sulfides with δS^{34} values in the range of the northeastern Washington strata-bound ores.

APPENDIX B

ALPHABETICAL LIST OF 98 PROPERTIES

Mines and prospects	No.[1]
A and C	50
Admiral	22
Advance	37
Aichan Bee	92
Aladdin	65
Anaconda	19
Anderson	23
Ark	74
Bechtol	32
Big Chief	57
Black Rock	39
Bonanza	61
Brooks	88
Bullion	13
Burrus	64
Calhoun	24
Cast Steel	14
Carbo	33
Cherry	68
Chewelah Eagle	78
Chloride Queen	58
Chollet	52
Cleveland	84
Copper King	45
Copper King	18
Daisy	75
Deep Creek	42
Deer Trail	87
Double Eagle	83

Mines and prospects	No.
Echo	56
Electric Point	30
Evergreen	16
Farmer	35
Frisco Standard	1
Galena Farm	48
Galena Hill	97
Galena Knob	66
Gladstone	29
Great Western	40
Hi Cliff	53
Hoodoo	89
Howard	51
Hubbard	12
Iroquois	21
Jackson	7
Jay Dee	77
Jay Gould	79
Keough	4
Keystone	31
Lakeview	6
Last Chance	41
Lead King	26
Lead Trust	25
Legal Tender	86
Little Frank	85

[1] Numbers correspond to the numbers used for the mines and prospects with lead and zinc deposits, in Stevens County, shown on figure 5, p. 12.

LIST OF 98 PROPERTIES—Continued

Mines and prospects	No.
Longshot	70
Lucile	20
Lucky Stone	60
Magma	44
Maki	34
Melrose	8
Michigan Boy	67
Middleport	71
Minorca	98
Morning	63
Mountain View	10
Mullen	80
Myeera	3
Neglected	55
Nevada	82
New England	43
New Leadville (Botts)	54
Old Dominion	72
Orazada	93
Perry	95
Plug	36
Pomeroy	94
Providence	11
Ranch View	5
Red Iron	27
Red Top	17
Rock Cut	96
Santiago	73
Saturday Night	91
Scandia	38
Shoemaker	69
Sierra Zinc	46
Silver Crown	15
Silver Queen	90
Silver Summit	81
Silver Trail	49
Sunset	9
Tenderfoot	59
United Treasure	2
Van Stone	47
Wildcat	28
Winslow	76
Young America	62

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