Geology and Ore Deposits of the Metaline Zinc-Lead District Pend Oreille County Washington

By McCLELLAND G. DINGS *and* DONALD H. WHITEBREAD

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A study of the ore deposits, rock alteration, stratigraphy, and structure in the most economically important zinc-lead district in the State of Washington

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By McCLELLAND G. DINGS and DONALD H. WHITEBREAD

ABSTRACT

The Metaline zinc-lead district, the most important mining district in the State of Washington, is an area of about 75 square miles in Pend Oreille County, which adjoins British Columbia to the north and Idaho to the east. The region is brushy and heavily forested. The main topographic feature is the valley of the northward-flowing Pend Oreille River, a tributary to the Columbia River. The Pend Oreille River is bordered by two conspicuous terrace levels; beyond these terrace levels lie somewhat smoothed hills and mountains. The highest point in the district is Boundary Ridge, 5,219 feet in altitude; the lowest point, about 1,750 feet, is at the Pend Oreille River where it enters Canada. The Cordilleran ice sheet covered the entire area, and erosional and especially depositional glacial features, such as till, glaciofluvial gravels, and silty lake deposits, are common.

The units mapped, exclusive of the Quaternary surficial deposits, are chiefly sedimentary and metamorphic rocks of Paleozoic age. They form a small part of a northeastward-trending belt of rocks that are cut by large and small bodies of granitic rock, chiefly quartz monzonite, of the Kaniksu and Nelson batholiths. Semiconsolidated clastic rocks of Tertiary age occur locally and sparingly in the district.

The Paleozoic rocks are chiefly limestone, dolomite, slate, argillite, phyllite, and quartzite. Fossiliferous beds are, as a whole, rare and widely spaced stratigraphically. The units mapped are the Monk Formation (Cambrian(?)), Gypsy Quartzite (Cambrian), Maitlen Phyllite (Lower or Middle Cambrian), Metaline Limestone (Middle Cambrian), Ledbetter Slate (Lower and Middle Ordovician), and an undifferentiated series of rocks, largely black argillite containing some limestone and conglomerate of Silurian and Devonian ages. Rocks of Silurian age had heretofore been unknown in this area. The total thickness of the Paleozoic units (including the Monk Formation) in the region centering around and extending outward for several miles from the district is roughly 24,000–27,000 feet. The most economically important and widespread formation in the district is the Metaline Limestone—the host rock of the ores in the district—which attains a maximum thickness of about 5,500 feet. The Metaline Limestone is irregularly dolomitized. Two periods of dolomitization are recognized, an early diagenetic stage and a much later hydrothermal stage closely related to the ore bodies.

Igneous rocks of probable Laramide age are widely exposed a short distance to the north and to the south of the area studied, but in the main part of the Metaline mining district, igneous rocks are represented only by widely scattered and generally narrow dark mafic dikes of probable Late Cretaceous or early Tertiary age and by one small and partly dissected olivine trachybasalt flow of probable Tertiary age.

The structure of the rocks of pre-Tertiary age is complex. Several stages of deformation, probably related to the Laramide orogeny, are recognized. These stages of deformation produced folds, low-angle thrusts, hundreds of moderate to steeply dipping normal and reverse faults, a large graben, and widespread fracture zones. Most faults, folds, and fracture zones trend northeast, although one of the major structures, the Flume Creek fault, trends north. At many places deformation caused a recrystallization of carbonate rocks, the development of slaty cleavage in argillaceous strata, and foliation and linear features in other formations which were metamorphosed to phyllite and schist. The Metaline zinc-lead district is largely contained in the outstanding structural feature of the region, a triangular-shaped graben, which is depressed 10,000–12,000 feet along its western border (Flume Creek fault) and 6,000–7,000 feet or more along its southeastern border (Slate Creek fault).

In 1869 zinc and lead deposits were reported in the Metaline district, but little ore was shipped until many years later when better transportation facilities reached the region. The first large ore bodies were found in 1928. The yearly value of the zinc and lead ore produced from 1938 to the present (1956) has never declined below $1 million. Three mines—the Pend Oreille, Grandview, and Metaline—have yielded more than 90 percent of the ore mined in the district. The ores are generally of low grade, mill heads commonly ranging from 3 to 6 percent combined zinc and lead. In the ores zinc is generally dominant over lead; only a trace of silver accompanies the lead.

By far the most widespread and the only large and productive ore bodies yet known are replacement deposits in dolomite and limestone. A few vein deposits contain minor quantities of sulfides, chiefly sphalerite and galena, and locally tetrahedrite, in a gangue of white quartz. Placer deposits, chiefly along the banks of the Pend Oreille River, have yielded a little gold.

The replacement deposits are widely distributed, although the largest known bodies are in the south-central part of the district near Metaline Falls. Nearly all are in the Metaline Limestone and range in stratigraphic position from near the base of that formation upward to within a few feet of the overlying Ledbetter Slate. However, by far the most productive replacement bodies occur in an irregular zone lying 35–200 feet below the top of the Metaline. The mineralized replacement bodies range in size from scattered sulfides extending over a distance of a few feet or less to ore bodies several hundred feet or more long. Most ore bodies in the larger mines average 15–25 feet in height; one in the Pend Oreille mine reached 115

feet. The form of most of the mineralized bodies is very irregular; some occur as poorly defined tabular bodies parallel to the bedding of the enclosing rock, whereas others are in poorly defined elongate forms that pass into the tabular and irregular bodies. The principal structural setting of the main ore bodies is in highly fractured ground in the graben between the Slate Creek and Flume Creek faults. The replacement ores generally are in irregularly shaped bodies of strongly to vaguely defined crush breccia. Some ore is concentrated along premineral fractures and faults and locally in folds, although at most places the structures that localized the ores are not evident.

The principal, and generally the only, ore minerals are sphalerite and galena, which typically are in a compact gangue of light- to dark-gray jasperoid, crystalline dolomite, and coarse calcite. Pyrite occurs locally; it is especially common in the ore at the Yellowhead mine. Barite is common in the ore at Lead Hill but is rare or absent elsewhere. Small cavities and in places large caves are locally associated with the ore deposits. A few ore bodies are enclosed in unaltered or slightly altered limestone, but most are irregularly bordered by an intricate mixture of crystalline dolomite, coarse calcite, jasperoid, and, locally, white quartz. The zone of oxidation is generally very shallow; at most places fresh sulfides are at the surface.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Metaline zinc-lead district, a wedge-shaped area of 75 square miles, is in Pend Oreille County, northeastern Washington, adjacent to British Columbia and about 15 miles west of the boundary between Washington and Idaho (fig. 1). It lies within a rectangle bounded on the north by lat 49°00′, on the south by lat 48°47′, on the east by long 117°10′, and on the west by long 117°26′30″.

The Metaline district is in a large sparsely populated region. The only 2 towns in the district are Metaline Falls and Metaline, with populations in 1955 of about 600 and 400, respectively. Metaline, the oldest

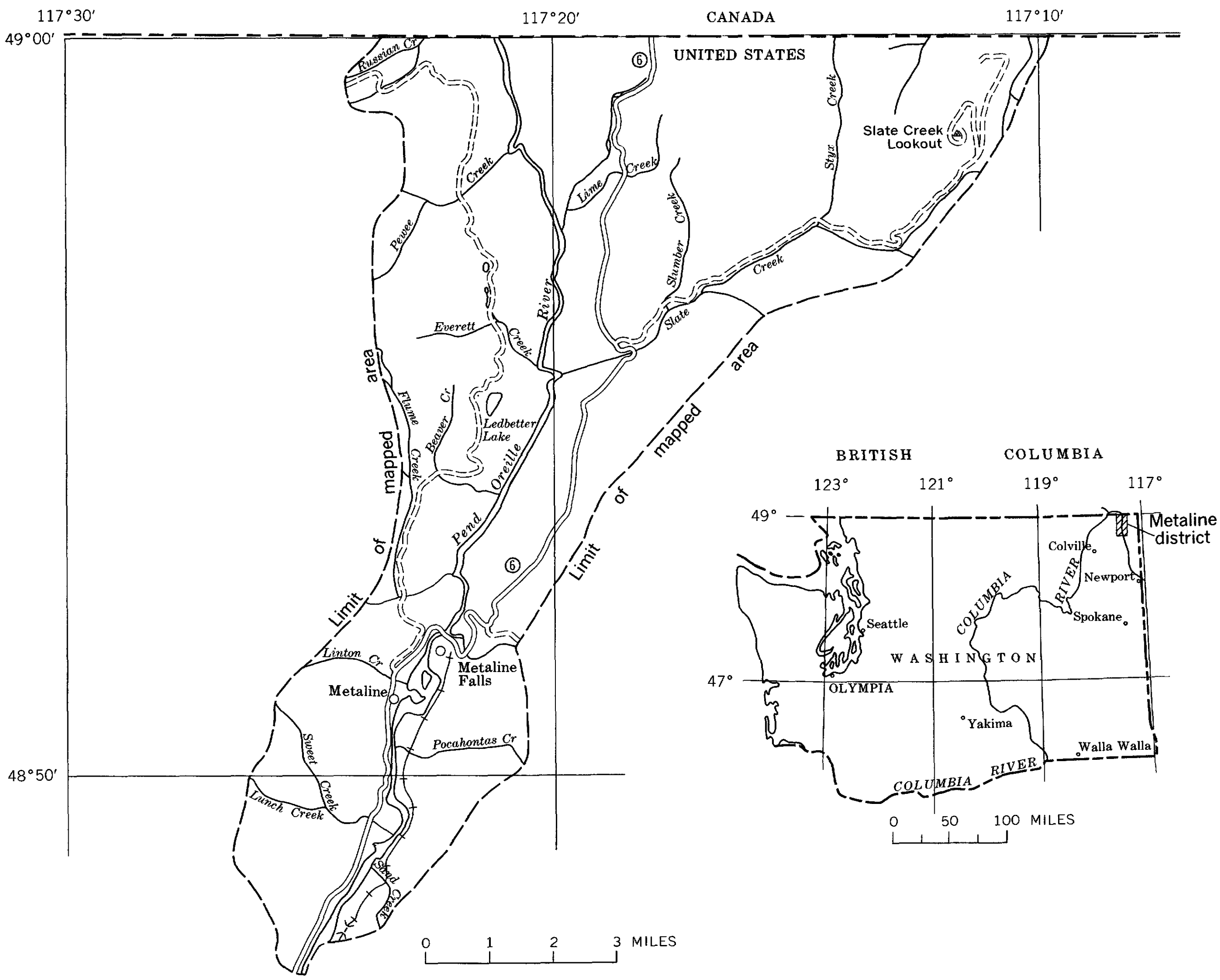

FIGURE 1.—Index map showing the location of the Metaline zinc-lead district, Washington, and limits of the region discussed in this report.

settlement in the district, is locally referred to as "Old Metaline" or "Old Town." A few hundred, or less, persons live in the outlying communities of Pend Oreille Village and Grandview Flats, both a short distance northeast of Metaline Falls (pl. 1). The population fluctuates somewhat, depending largely upon the current activity in the nearby mines. A few farms are scattered throughout the district. Metaline Falls is the northern terminus of a branch freight line from Newport of the Chicago, Milwaukee, St. Paul and Pacific R.R. Bus service is maintained to Newport and Spokane; the latter is about 100 miles from Metaline Falls.

A paved road (Washington Highway 6) from Newport and Spokane extends through the center of the district to Canada; beyond the international boundary, in British Columbia, an excellent paved road leads to Salmo where it joins a paved highway connecting Trail and Nelson. A surfaced road to Sullivan Lake leaves the main paved highway a short distance northeast of Metaline Falls at Grandview Flats. Two main gravel roads reach outlying areas in the district. One of these, east of the Pend Oreille River, leads up the valley of Slate Creek almost to the international boundary. The other road, on the west side of the Pend Oreille River, leads to the valley of Russian Creek and across the mountains into Stevens County; this road is generally in poor condition a few miles west of the district. The Pend Oreille River is bridged at Metaline Falls and 15 miles to the south near Ione; in British Columbia the nearest bridge is at Waneta—a distance of about 15 miles. Other secondary roads lead to mines, prospects, logging operations, farms, or diamond-drill sites. Except for the roads leading to the larger mines, most of these secondary roads are passable only at unpredictable intervals, depending largely upon whether individuals have removed the trees—some of which may be huge—that almost everywhere fall across the roads during the winter months. Most of the steeper or seldom-used roads are shown as trails on plate 1, although at times these may be passable in conventional vehicle or by truck or jeep. Most of the trails were cut many years ago; with very few exceptions they are in extremely poor condition, and at many places they are largely overgrown. In some areas, particularly the northeastern part of the district, long stretches of formerly good trail are virtually impossible to follow or break through. The difficulty in access to many areas is of considerable moment in detailed geologic mapping in this and adjoining regions.

LOCAL INDUSTRIES

The main industries are lead and zinc mining, cement manufacturing, and logging. The three principal mines are the Pend Oreille, Grandview, and Metaline (pl. 1); the Metaline mine has been shut down since 1950. The Pend Oreille mine is owned and operated by the Pend Oreille Mines & Metals Co. The Grandview mine is owned by Grandview Mines, Inc. and operated by the American Zinc, Lead, & Smelting Co. The Lehigh Portland Cement Co. has a large plant at Metaline Falls which is connected by an aerial tramway to their quarries on Quarry Hill, a mile to the east. Logging has been carried on for many years in this heavily timbered region where wood for matches, poles, and lumber is obtained. The Diamond Match Co. has a camp at Sullivan Lake about 8 miles east of the district, and the Ohio Match Co. formerly had a camp on Flume Creek. Some of the old flumes formerly used in logging operations remain; thus, the obvious name given to Flume Creek. Rather surprisingly there is little tourist business in this scenic country, although in the fall it is visited by a moderate number of hunters in quest of the rather abundant black bear and deer; at rare intervals grizzly bear are shot, especially in the extreme northeastern part of the district.

TOPOGRAPHY AND DRAINAGE

The Metaline district lies in a broad long belt of mountainous country that is variously referred to as the Selkirk System or Selkirk Range. Daly (1906, p. 588, 599) named the mountains near the Metaline district the Pend Oreille Mountains, although this name as well as the term "Selkirk" is rarely used locally.

The principal topographic feature of the Metaline district is the valley of the Pend Oreille River, which lies roughly in the center of the district and extends from the southern to the northern limits of the map area. The valley of the Pend Oreille is broad. Its bedrock floor is largely covered by glacial lake sediments that occur as two well-developed terraces at altitudes of 2,100 and 2,575 feet. Beyond and above the higher terrace level the bedrock rises into partly dissected highlands. West of the area shown on plate 1 the slopes are steep and culminate several miles distant in mountains, such as Abercrombie and Hooknose, that attain altitudes of more than 7,000 feet. East of the district for distances of 2 to 6 miles lies a belt of dissected hills and mountains which commonly attain altitudes of 3,500 to 4,200 feet; a litttle farther east, these rise to peaks of 6,000 to 7,300 feet on Gypsy and Crowell Ridges and on Sullivan and

Hall Mountains. (See topographic map of the Metaline quadrangle.) Within the region shown on plate 1 the highest mountains lie in the northeastern part; the highest point is Boundary Ridge, altitude 5,219 feet; the lowest point is along the banks of the northward-flowing Pend Oreille River at the international boundary, where the altitude is about 1,750 feet.

The principal drainage is by the Pend Oreille River. The Pend Oreille south of Metaline Falls is a slow-flowing river averaging 500–1,000 feet in width; east of Metaline it is nearly half a mile wide. In this area many bars and islands of silt, sand, and gravel are exposed during periods of low water level. North of Metaline Falls the river narrows greatly and flows rapidly and turbulently through a series of steep-walled gorges, many very spectacular. At a point a few thousand feet south of Z Canyon (pl. 1) the river flows between walls several hundred feet deep and only 17 feet apart at water level. This particular gorge, one of the more spectacular, is known as the Z Canyon damsite, for a dam at this locality has been proposed for many years. Another proposed damsite, known as the Boundary site, is located farther north on the Pend Oreille River at a point about 1 mile south of the international boundary (pl. 1) where the river plunges through a narrow deep gorge before widening northward as it enters Canada. About a mile north of the international boundary, in British Columbia, the Pend Oreille River swings westward and joins the southward-flowing Columbia River about 15 miles distant at Waneta, just north of the boundary. A recently constructed dam at Waneta is of sufficient height to eventually form a lake that will back water to the international boundary.

The main tributary streams east of the Pend Oreille River are Slate, Sullivan, and Sand Creeks; west of the river the principal streams are Russian, Fence, Flume, Sweet, and Lunch Creeks, all of which are smaller and shorter than those east of the Pend Oreille.

CLIMATE AND VEGETATION

Most of the precipitation falls as snow during the winter months, although it is usual to have the heaviest monthly precipitation as rain during June. Temperature and precipitation differ markedly between the highest and lowest elevations, as would be expected. The average annual precipitation at Metaline Falls over a period of about 20 years is about 26 inches. The winters are cold; temperatures of zero or below are not uncommon. The summer temperature is generally moderate, with pleasant cool days and nights, although hot days, with local thundershowers, commonly occur during a period of a few weeks in July and August. Strong winds are infrequent.

Except for a few rocky slopes and burned areas, the region is brushy and heavily forested. A wide variety of evergreen trees are found, including fir, spruce, pine, cedar, and hemlock. Birch, alder, larch, and several other trees as well as many types of shrub and bush are scatttered through the forests. Most of the district has been burned over several times. In many places large windfalls or dense growths of lodgepole pine or larch combined with fallen logs make the terrain almost impenetrable.

FIELDWORK AND ACKNOWLEDGMENTS

The principal fieldwork upon which this report is based was carried on during the summers of 1945, 1953, 1954 and 1955. The fieldwork in 1945, as explained below, was for the most part a continuation of geologic work started near the beginning of World War II. The average field season was from the middle of June through the middle of September.

Throughout most of World War II the senior author was a member of a group of geologists of the U.S. Geological Survey that was assigned to the Metaline district, principally to aid and advise the U.S. Bureau of Mines in interpreting the local and regional geology during an exploratory diamond-drilling program financed by the Bureau (Wimmler and Cole, 1949). The geologic work of the Survey at this time was under the supervision of Edward S. Sampson. Largely on account of the nature of this investigation the geologic mapping was fragmentary, both in the mines and on the surface. The lack of base maps of adequate scale necessitated mapping both topography and geology by planetable methods—a slow method in this heavily forested region. The resulting maps, which ranged widely in scale from map to map, generally showed the outline of individual croppings, the type of rock, and the known or inferred faults. Little or no attempt was made to map glacial units and bedrock pattern as determined from float fragments. About 6 months before the war ended, base maps of the district, on a scale of 1 inch equals 500 feet, became available. These maps were made by the Topographic Division of the U.S. Geological Survey by multiplex method from aerial photographs. In April 1945 Mr. Sampson was assigned to other geologic work, and M. G. Dings was placed in charge of the Metaline project. The regional mapping for the present report began early in the summer of 1945. The field party at that time consisted of V. E. Nelson, Irvin Gladstone, Adolf Pabst, and M. G. Dings. In the fall of 1945 the entire project was recessed in-

definitely, chiefly because of failure to obtain clear-cut permission from mine owners to release to the public a large part of the results of the investigations. In 1953 the situation changed, permission to publish was granted by all major mine operators in the district, and in June of that year fieldwork was resumed under the direction of Dings. Also, in June 1953, a map of a large part of the area mapped in 1945 was released for public inspection as an open-file geologic map (scale 1 in. equals 500 ft) by Dings, Nelson, Gladstone, and Pabst (1953).

It is beyond the scope of the present report to acknowledge adequately and with proper emphasis, the work of each of the many Survey geologists who took part in the fieldwork during most of the war years. Some of the geologic units, structural features, and interpretations incorporated in the present report were formulated, in part at least, from group discussions when the senior author was a member of the field party stationed in the district before June 1945. However, nearly all this early surface mapping was later reexamined, consolidated, expanded, and at many places markedly changed because of additional field data that were obtained. These maps were of great aid in the location of many croppings, and some of this early work is incorporated in the present report, as specifically credited. The main period of mapping, however, commenced in 1953, and the principal geologists who aided in this work are Donald H. Whitebread, the junior author of this report, and Robert G. Yates. Yates independently mapped several large areas during the summer of 1953 and for about 6 weeks during the summer of 1954. His work, in particular, contributed greatly to the understanding of the structure and stratigraphy of the Devonian strata in the northwestern part of the district. J. F. Robertson ably assisted Yates during the early part of the field season of 1954. The junior author did much of the office work preliminary to writing the report, but he was not available during the final writing stage; accordingly, the senior author assumes responsibility for most interpretations of text and map.

It is a pleasure to acknowledge the generous and complete cooperation of the people of the region, especially the staffs of the Pend Oreille Mines & Metals Co. and the American Zinc, Lead & Smelting Co., although many others aided in the progress of the work. Special thanks are due Loren Billings, J. C. Crampton, John Currie, E. A. Frick, John Fritts, Lynn Kinney, Donald Knowles, H. F. Mills, Cline Tedrow, and Delos Underwood. Many of the regional geologic problems were freely discussed and ideas exchanged with James T. Fyles and the late Cecil Hewlett, of the Department of Mines, British Columbia, who, during part of the present investigation, were geologically mapping nearby and adjoining areas in Canada.

PREVIOUS WORK

The references at the end of this report include all that relate directly to the Metaline district and some that deal with the main geologic features of the surrounding region. No claim of completeness is made, as there have been many articles published, especially in some of the older mining journals, which refer briefly to the district.

By far the most extensive geologic investigation that has been done previously in the Metaline region is that of Park and Cannon (1943). Their fieldwork was done during parts of 1936 and 1937, and the manuscript was published in 1943 as U.S. Geological Survey Professional Paper 202, entitled "Geology and ore deposits of the Metaline quadrangle, Washington." This excellent pioneer regional, and at many places, detailed, work is referred to frequently in the present report. Very little of the work of the U.S. Geological Survey done during the war years has been published because of the confidential nature of most of the information. Shortly after the fieldwork for the present investigation was completed, some of the preliminary maps were made available for public inspection by open-file report, pending the completion of the final manuscript and maps. These maps include one by Dings (1956).

GENERAL GEOLOGY

PRINCIPAL FEATURES

The rocks in the Metaline district range in age from Cambrian, or possibly older, to Tertiary. Quaternary deposits of surficial material mask large areas (pl. 1). The formations of Paleozoic age include, in ascending order, the Monk Formation (Cambrian?), Gypsy Quartzite (Cambrian), Maitlen Phyllite (Lower or Middle Cambrian), Metaline Limestone (Middle Cambrian), Ledbetter Slate (Ordovician), and an unnamed group of rocks, largely dark-gray to black argillite, of Silurian and Devonian ages. Small areas of poorly consolidated rock of the Tiger Formation of Tertiary age occur locally. The Quaternary deposits include silts and sands of lacustrine origin, and glacial and glaciofluvial material consisting of sand, gravel, cobbles, and boulders. Small deposits of alluvium occur at a few places. Igneous rocks are rare, although wide areas of the Kanisku batholith (chiefly quartz monzonite that grades into granodiorite) crop out a few miles distant. In the mapped area a few dark and generally narrow dikes of probable

Late Cretaceous or Early Tertiary age are widely scattered. Olivine trachybasalt occurs at one locality northwest of Ledbetter Lake as a partly dissected flow resting unconformably on Silurian or Devonian strata.

The geologic structures are generally moderately complex, although locally they are extremely complicated. Structures include folds, faults, and widespread fracture zones with prevailing northeasterly trends. The dominant structure is a wedge-shaped graben—the valley block or graben—which along its western border is marked by a fault with a stratigraphic throw of 10,000 to 12,000 feet. The stratigraphic throw of the fault that bounds the graben on the east is not precisely known, although it is locally a minimum of 6,000 to 7,000 feet. Several stages of deformation are recognized.

PALEOZOIC ROCKS

The total thickness of a complete stratigraphic section of the Paleozoic formations in the region centering around and extending outward for several miles from the Metaline zinc-lead district is about 24,000–27,000 feet. These figures are based upon thicknesses obtained during the present investigation, and they have been added to those given by Park and Cannon (1943, p. 6) for the Monk, Gypsy, and Maitlen Formations.

The Paleozoic rocks described on the following pages include only those that lie within or border the large graben. Rocks of Cambrian, Ordovician, Silurian, and Devonian ages are represented principally by limestone, dolomite, argillite, slate, phyllite, and quartzite. Fossiliferous beds are, as a whole, rare and spaced at large stratigraphic intervals. In the area mapped for this report only parts of the Monk, Gypsy and Maitlen Formations are present; consequently, these units were not studied in detail and the reader is referred to the description of Park and Cannon (1943, p. 11–17). However, detailed studies were made of the Metaline Limestone—an irregularly dolomitized formation containing the main ore bodies—the overlying Ledbetter Slate and the Silurian and Devonian rocks. Rocks of Silurian age had heretofore been unknown in this region.

CAMBRIAN(?) SYSTEM—MONK FORMATION

Rocks assigned to the Monk Formation are restricted to the southwestern border of the area mapped for plate 1 where a narrow strip is shown extending along the base of the steep slopes from Lunch Creek northeast to, and a short distance beyond, Linton Creek. The formation was first named by Daly (1912, p. 147–150) for a heterogeneous assemblage of schists, phyllites, slates, and conglomerates exposed along Monk Creek in British Columbia. The Monk Formation was redefined by Park and Cannon (1943, p. 11) to include additional strata at the top and at the bottom. The principal occurrence of the Monk near the Metaline area lies about 7 miles to the east where it forms a belt about a mile wide that extends northeast for 15 miles to the international boundary.

The Monk Formation is overlain by and grades into the Gypsy Quartzite of Cambrian age. No detailed examination was made of the limited exposures of the Monk Formation in the mapped area because the strata lie outside the main graben structure that was studied. The formation, according to Park and Cannon (1943, p. 11–13), is chiefly fine-grained phyllite that contains numerous intercalations of carbonate rock, quartzite, and grit. Rocks of the Monk Formation shown on plate 1 of the present report are chiefly phyllite, quartzite, dolomite, and sandy dolomite occurring in the upper part of the formation. The contact with the overlying Gypsy Quartzite is placed at the top of a bed of sandy dolomite marble. Park and Cannon (1943, p. 11) state that the Monk Formation has an apparent thickness of about 3,800 feet, measured west of Leola Peak along the trail that bears toward Gypsy Peak. Insofar as it is known to the authors, no fossils have been found in the Monk. In the Salmo area of British Columbia, Little (1950) shows a Proterozoic age for the Monk Formation on his accompanying geologic map. The basis for this age is not explained in the text.

CAMBRIAN SYSTEM

GYPSY QUARTZITE

The Gypsy Quartzite forms a large part of the western border of the mapped area (pl. 1). It lies west of the Flume Creek fault and for long distances it is well exposed on the steep eastward slopes of the mountains, especially in the area west of the old Sullivan glory hole. In the vicinity of Russian Creek the strata are part of an overturned anticline (pl. 1, section *B–B′*). The Gypsy Quartzite was named by Park and Cannon (1943, p. 13) for dominantly quartzitic strata typically exposed on Gypsy Ridge, about 12 miles northeast of Metaline Falls. The Gypsy Quartzite correlates in general with the Reno Formation as recognized in Canada by Fyles and Hewlett (1959, p. 21) and earlier by Mathews (1953, p. 21).

The following information concerning the Gypsy Quartzite is taken from the regional work of Park and Cannon (1943, p. 13–15), for no detailed study was made by the authors of the limited exposures of the Gypsy Quartzite which lies within the mapped area.

The Gypsy Quartzite grades conformably downward into the Monk Formation and upward into the Maitlen Phyllite. The limits of the Gypsy were placed where quartzite and grit beds predominate over beds of other types. The Gypsy ranges in thickness from 5,300 to 8,500 feet. It is composed chiefly of quartzite, grit, and phyllite. Minor amounts of conglomerate, schist, and limy beds occur locally. Many of the quartzites are crossbedded. Phyllite layers are more numerous near the top of the formation and grit near the base.

MAITLEN PHYLLITE

The Maitlen Phyllite of Lower or Middle Cambrian age is in the northern part of the district in the vicinity of Boundary Ridge; it also forms much of the eastern and western limits of the area mapped for this report (pl. 1). The Maitlen was named by Park and Cannon (1943, p. 15) for dominantly phyllitic rocks exposed along Maitlen Creek, about 8 miles south of Metaline Falls. The Maitlen extends beyond the mapped area at least 18 miles northward into Canada where it correlates, in large part at least, with the lower Pend d'Oreille Series of Walker (1934, p. 9–10) and the Laib Formation of Little (1950, p. 15–18) and Fyles and Hewlett (1959, p. 23). South of the international boundary and, in general, just east of the mapped area, the Maitlen forms a belt, locally as much as 5 miles in width, that trends southwest to Tiger—a distance of about 25 miles. (See Park and Cannon, 1943, pl. 1.)

The Maitlen Phyllite grades upward into the Metaline Limestone and downward into the Gypsy Quartzite. The upper contact is gradational and difficult to establish with certainty at most places. The lower contact with the Gypsy Quartzite was placed by Park and Cannon (1943, p. 15–16) about 100-200 feet below a band of limestone and, in general, where phyllitic rocks give way to dominantly quartzitic ones. Just north of the Metaline district, in British Columbia, Litttle (1950, p. 15) places the contact of the Laib (Maitlen) and Reno Formations at the base of the lowest extensive band of limestone above the Reno. This extensive band of limestone is very likely the same one as that used by Park and Cannon and mentioned above. No reliable stratigraphic section nor estimate of the thickness of the Maitlen Phyllite was given by Park and Cannon (1943, p. 15–17) because the phyllite is strongly sheared and distorted. These authors state that the minimum apparent thickness on the west slope of Sullivan Mountain is about 5,000 feet. In the Salmo area, Fyles and Hewlett (1959, p. 19) report an approximate thickness of 3,800 feet for the Laib in the Sheep Creek anticline south of South Salmo River.

The regional lithology and especially the megascopic features of the Maitlen Phyllite are extremely diverse (Park and Cannon, 1943, p. 16–17). The common rocks are phyllite, quartzite, sericite schist, and limestone. The most common rock type is gray-greenish fine-grained conspicuously banded phyllite. The Maitlen, or its approximately equivalent Laib Formation in Canada, is a very confusing unit regionally and has been the cause of much disagreement in correlation among workers in surrounding areas. However, the recent work of Fyles and Hewlett (1959) has done much to further an understanding of this formation. The Maitlen Phyllite in the Metaline district commonly weathers into thin small gray or greenish-gray chips. Some are dull whereas others retain a glistening surface. At places, these chips are practically indistinguishable from similar chips of the younger Ledbetter Slate.

The only fairly large area (about 2 sq mi) underlain by Maitlen Phyllite lies west of Styx Creek in the vicinity of Boundary Ridge in the north-central part of the mapped area(pl. 1). There the few exposures present are almost entirely in cuts along old logging roads on the west slope of Boundary Ridge and the ridge extending to the south. The entire area is thickly covered by timber, brush, forest mat, and some glacial till. The two most common rocks are phyllite and interbedded quartzite and phyllite. The phyllite is a dark gray to black fine-grained rock which at many places is limy, locally grading into limestone. The interbedded quartzite and phyllite consists of dark-gray to black phyllite containing light-brown layers and lenses of fine-grained quartzite. All rocks are thin bedded. They commonly contain euhedral cubes of pyrite, or pseudomorphs of limonite after pyrite, that average one-sixteenth of an inch across; some are as much as one-quarter of an inch across. In the Boundary Ridge area bedding planes were recognized at only a few places, chiefly in the interbedded quartzitic and phyllitic rock. No indication of bedding could be found in any exposures of the dark phyllite.

In general, the phyllite and limy phyllite occur in the upper part of the formation. These rocks are intermittently exposed in roadcuts on the southwest slope of Boundary Ridge and on the west slope of the ridge extending to the south. About 1,000 feet south of the Boundary Lookout, black limestone is exposed in several roadcuts, but farther south it gives way to black limy phyllite. Some black limestone was also found in the upper part of the formation on Confusion Ridge, about a mile west of Boundary Ridge (pl. 1).

Interbedded quartzite and phyllite is exposed in many roadcuts west of the Boundary Lookout. There the black phyllite layers, which range in thickness from $\frac{1}{16}$ to $\frac{3}{4}$ inch and average $\frac{1}{2}$ inch, predominate over the brown coarser grained layers, which range in thickness from paper thin to $\frac{1}{16}$ inch. The brown layers are made up chiefly of very small quartz grains. In general, the banding does not parallel the dominant foliation.

On the east slope of Boundary Ridge, and presumably lower in the section, the Maitlen is chiefly dark-gray and brown banded phyllite, but the quartzite layers are more abundant. Sparse float indicates that beds of fine-grained quartzite and limy quartzite are present. The only outcrops found on the entire east slope is near the international boundary at an altitude of 4,410 feet. The rock is a gray very fine grained phyllitic quartzite.

Microscopic examination of thin sections of the rocks in the Boundary Ridge area shows a characteristic fine grain size. The rocks are composed almost entirely of sericite, quartz, chlorite, and locally calcite. Sericite is the most abundant mineral, and with chlorite, commonly forms 50 to 95 percent of the phyllite. Quartz, which ranges in size from 0.01 mm to 0.15 mm, was found in all the thin sections examined. In the black phyllite of the upper part of the Maitlen, sericite with some chlorite forms 85–90 percent of the rock; quartz in grains ranging from 0.01 to 0.10 mm forms 10–15 percent. Quartz grains, ranging from 0.01 to 0.05 mm, make up 10–30 percent of the limestones. The most distinctive compositional difference is seen in the banded phyllite, which is lower in the section than the black phyllite and limestone. About 95 percent of the dark bands is sericite and chlorite, and about 5 percent is quartz grains averaging 0.01 mm. Quartz grains from 0.01 to 0.05 mm make up 50–75 percent of the light-colored bands. Lower in the Maitlen, the very fine grained quartzite is composed almost entirely of quartz grains which range from 0.01 to 0.15 mm and average about 0.04 mm.

A narrow band of Maitlen Phyllite is shown extending about 18 miles along the eastern border of the mapped area (pl. 1). The phyllite is in normal contact with the overlying Metaline Limestone in the central part of this belt; elsewhere, it is in fault contact with younger rocks. In the central area by far the best exposure of the upper strata of the Maitlen is in the canyon of Sullivan Creek. There continuous exposures of grayish-green to dark-gray phyllite grade upward through limy phyllite and phyllitic limestone into the lower part of the Metaline Limestone. The upper few hundred feet of the Maitlen in this area contains sparse limy layers, commonly ranging from thin partings to those one-quarter inch in thickness. Northeastward from Sullivan Creek the upper part of the Maitlen appears to become progressively more limy, although exposures normal to the strike of the beds, or even float fragments, are entirely too sparse in this area to establish a reliable section. Bedding planes are also rarely recognized in these rocks.

In the extreme northeastern part of the area mapped, near Lead Creek, the Maitlen Phyllite is in fault contact with the Ledbetter Slate. The rock is phyllite, locally containing thin sandy beds, and some limy phyllite and phyllitic limestone. Much of the rock is strongly contorted. Pyrite cubes occur locally.

West of the Flume Creek fault, the rocks of Maitlen age are much lower stratigraphically than those found elsewhere in the district. These rocks were not examined in detail, but, in general, they are more quartzitic and schistose than the others.

No fossils were found in the Maitlen Phyllite during the present investigation. Park and Cannon (1943, p. 15–17) mention "fucoids" and "burrows" near the base of the formation, but otherwise no indications of fossils were found by them. In 1948 and 1949, Little and Okulitch, who were studying the geology north of the Metaline quadrangle in British Columbia, found fossils (pleosponges) of Early Cambrian age in the 200-foot layer of limestone at the base of the Laib Group (Maitlen Phyllite of this report). These, according to Little (1950, p. 17–18), were collected from a point 1,000 feet south of the international boundary to a point nearly 5 miles to the north. Okulitch (Geol. Survey Canada, unpub. data, 1950) lists the following fossils:

Ajacicyathus osilinka Okulitch and Roots
  nevadensis Okulitch
  purcellensis Okulitch
  undulatus Okulitch
  sp.
Archaeocyathus atlanticus Billings
Archaeocyathellus sp.
  cf. *C. miniporosus* Bedford
Coscinocyathus dentocanis Okulitch
  sp.
Cambrocyathus amourensis Okulitch
  columbianus Okulitch
  cf. *C. donaldi* Okulitch
  sp.
Copleicyathus laminosis Okulitch
Ethmophyllum americanum Okulitch
  whitneyi Meek
  sp.
Eucyathus cf. *E. obliquus* Okulitch
Paracoscinus sp.
Protopharetra sp.

METALINE LIMESTONE

The Metaline Limestone of Middle Cambrian age was named by Park and Cannon (1943, p. 17) for rocks exposed near Metaline Falls. The formation consists chiefly of dolomite and limestone. It is widely distributed throughout most of the district, but is largely confined to the graben, or valley block, where it is the dominant rock (pl. 1). Two fairly extensive areas, however, are outside the graben. The largest of these lies south of Metaline Falls and extends to the southern border of the mapped area, a distance of 4 miles; the other is a relatively narrow belt of rocks in the lower part of the Metaline Limestone that lies on the east, or upthrown, side of the Slate Creek fault and extends from Sullivan Creek northeast almost to Slate Creek, a distance of 7 miles.

The Metaline Limestone when considered as a whole is poorly exposed. Large areas are totally concealed beneath a thick blanket of glaciofluvial and glacial lake deposits. Many areas shown as bedrock on the geologic map contain only a few outcrops and patches of float material that are commonly separated for long distances by a thick mat of forest growth. However, fairly continuous and lengthy exposures of the Metaline rocks do occur in four widely separated areas; namely, (1) along the steep cliffs that form the gorge of the Pend Oreille River from a point a few thousand feet south of the mouth of Slate Creek north to within half a mile of the Canadian border; these rocks are largely inaccessible for close observation; (2) on the lower part of the east slope of Timber Hill near York and Crescent Lakes in the north-central part of the mapped area; (3) in the low hills of limestone that lie east of the Lead King, Giant, and Cliff mines in the northwest part of the area mapped; and (4) along roads and in the quarries on the upper part of Quarry Hill southeast of Metaline Falls. Besides these areas, the upper few hundred feet of the Metaline Limestone is well exposed in the Pend Oreille, Grandview, and Metaline mines, and hundreds of drill holes in the mine areas furnish additional information regarding the upper part of the formation; a few drill holes have penetrated 1,000 feet or more into the formation, but most of them do not go below the upper 300 feet.

The topography of most of the limestone and dolomite areas is rough, and the surface of the rocks are pitted; locally, they are grooved and channeled. Some steeply dipping beds, such as those making up the long belt east of the Slate Creek fault, form sharp strike ridges and narrow valleys. Some dip-slope surfaces of limestone are relatively smooth, as can be seen in the hills east of Hoage and Beatty Lakes, along the northern part of the western slope of Confusion Ridge, and in the limestone area high on the hill northeast of Z Canyon and about 1,000 feet west of the Scandinavian prospect. At some places, particularly on the low knob west of the Grandview glory hole, the carbonate rock is smooth and locally is striated owing to glacial erosion. Cliffs of limestone and dolomite a hundred feet or more high are largely confined to parts of the gorge of the Pend Oreille River that lie north of Metaline Falls.

REGIONAL DISTRIBUTION

The Metaline Limestone for this report is part of a belt of this formation that trends north-northeast for about 23 miles. The Metaline Limestone extends 4 miles north and 4½ miles south beyond the area shown on plate 1. To the north, in Canada, the Metaline Limestone is known as the Nelway Formation (Little, 1950). South of the mapped area the Metaline Limestone is exposed as far as Ione (Park and Cannon, 1943, p. 1), where it passes beneath a thick covering of glacial material and patches of the Tiger Formation (Tertiary). The maximum extent of the Metaline Limestone in Washington is not known. Rocks that unquestionably correlate with the Metaline are recognized in the Leadpoint quadrangle (Yates and Robertson, 1958) about 15 miles northwest of Metaline Falls. Deiss (1955, p. 122) tentatively correlates dolomite beds near Marble, 21 miles west of Metaline Falls, with Metaline Limestone. These beds, according to Deiss, lie within part of the Northport Limestone as mapped by Weaver (1920, pl. 1). Campbell (1947, pl. 1) recognized the Metaline Limestone at many places in Stevens County, some as far west as Northport. Rocks that are definitely correlated with the Metaline Limestone have also been recognized by W. A. G. Bennett (oral commun., 1955) at many places farther south in Stevens County. The southernmost of these exposures is a few miles northeast of Colville in cuts along the road to Aladdin. These rocks are about 27 miles southwest of Metaline Falls. No other rocks of certain correlation with the Metaline Limestone are known to the authors to be more distant from Metaline Falls than these, although a continuation of detailed mapping in this region may show that some of the carbonate units on the older maps are in part Metaline.

THICKNESS

During the present investigation particular effort was made to establish reliable subdivisions in the Metaline Limestone and, in turn, to arrive at the thickness of the formation at various places throughout the mapped area. The subdivisions that are recognized, and which vary greatly in thickness, are described in a subsequent section. The only published estimate of the total thickness of the Metaline Limestone in the district is that of Park and Cannon (1943, p. 17–18). They assigned a total thickness of 3,000 feet to the Metaline in a section east of Metaline Falls. This section is obviously incomplete, because the Slate Creek fault cuts out strata between the middle and upper parts of the formation (pl. 1). Work of the present investigation indicates that the Metaline Limestone attains a total thickness of about 5,500 feet. Yates and Robertson (1958) assign a maximum thickness of about 5,400 feet to the Metaline in the Leadpoint quadrangle, about 8 miles to the west. Just north of the Metaline district in the Salmo lead-zinc area Fyles and Hewlett (1959, p. 30) estimate a total thickness of 4,500–5,000 feet for the Nelway (Metaline) Formation.

MAIN LITHOLOGIC UNITS

The Metaline Limestone in this report is divided into three main lithologic units: an upper gray massive limestone, an intermediate light-gray bedded dolomite, and a lower thin-bedded limestone-shale sequence. These units correspond in general to those recognized by Park and Cannon (1943, p. 18) in the section near Metaline Falls; the gray massive limestone unit corresponding to the upper 600 feet of their section, the light-gray bedded dolomite unit corresponding to part of their middle 1,200 feet of fine-grained dolomite, and the thin-bedded limestone and shale unit corresponding to their lowermost 1,200 feet of interbedded limestone and limy shales.

The intermediate light-gray bedded dolomite unit of the present report is believed by the authors to have attained its dolomite composition diagenetically, that is, during or shortly after deposition in Cambrian time, and accordingly is considered a primary stratigraphic unit. The boundaries between the bedded dolomite and both the overlying and underlying limestone are generally fairly sharp, and locally very irregular. However, a few lenses of limestone lithologically identical to the upper gray massive limestone appear in the dolomite, as do a few lenses of limestone and shale identical to the rocks in the lower thin-bedded limestone and shale unit (pl. 1). In addition, lenses, tongues, and some large irregular masses of bedded dolomite occur in both the upper and lower units. At many places, especially in the upper strata, these relations are furthermore complicated by a hydrothermal dolomitization that produced dolomite (crystalline dolomite of this report) of a much younger age in all three of the main units. Locally, some of these younger dolomites are indistinguishable from the older dolomite.

In the ensuing descriptions of the main units of the Metaline Limestone it should be clearly kept in mind that they are lithologic units rather than members of the formation having definite time significances and stratigraphic positions. This is due to the fact that the diagenetic bedded dolomite may transgress bedding for hundreds of feet into both the upper gray massive limestone and the lower bedded limestone and shale, and therefore the great ranges in thickness of the units given on the following pages is believed to largely reflect the irregularity of this dolomitization rather than pronounced thinning or thickening of the units.

On the following pages the lithologic units are described from bottom to top according to their principal stratigraphic positions. Largely for the sake of brevity the units are hereafter referred to as bedded limestone (for the lower thin-bedded limestone and shale), bedded dolomite (for the intermediate light-gray bedded dolomite), and gray limestone (for the upper gray massive limestone). These brief lithologic terms are commonly used by workers in the district, although the bedded limestone is also referred to as the lower limestone and the bedded dolomite as the lower dolomite.

Bedded limestone

The rocks composing the bedded limestone unit crop out chiefly in the following five areas: (1) Quarry Hill east of Metaline Falls, (2) a long narrow belt that extends from Sullivan Creek northeast to Uncas Gulch, (3) the southern slopes of Divide Peak, (4) the area extending from the southern part of Boundary Ridge northwest across Confusion Ridge to the lower slopes of Forest Mountain, and (5) the area from Hornet Gulch and Desolation Mountain northeast to the Canadian border. The southernmost croppings found in the mapped area lie on the lower eastern slopes of the high hill south of Wolf Creek, about 2½ miles southwest of Quarry Hill. The only exposure of bedded limestone west of the Pend Oreille River is at the top of a high roadcut on the main paved highway about 1,300 feet south of the bridge at Metaline Falls. Here a small patch of thin-bedded limestone, about 10 feet long and a few feet thick, rests on dolomite. This outcrop, which is too small to show on the geologic map, is in a strongly and complexly faulted area near the intersection of the Washington Rock thrust and a northwestward-trending fault (pl. 1). The only diamond-drill holes that have cut rocks of the bedded limestone unit in the valley graben are those put down near Washington Rock. Two holes, as described in the section on the Washington Rock thrust (p. 37) cut thin-bedded dark-gray phyllitic limestone beneath thrust plates of dolomite and Ledbetter Slate.

By far the best locality for many miles around to study the bedded limestone is on Quarry Hill, where the rocks are exposed in roadcuts, quarry excavations, and croppings. There, as can be noted on plate 1, a relatively small area centering around the upper quarry diggings is apparently free from major faults and folds, and, above all, the obliterating effects of dolomitization. Unfortunately, there, as well as at all other localities mapped for this report, the lowermost strata that grade into the Maitlen Phyllite are very poorly exposed, although those a few hundred feet stratigraphically above the Maitlen Phyllite are unusually well-exposed in the small upper quarry known as the Shale quarry (pl. 1). The section given below was measured north of the southern end of the Main Lehigh quarry and above the last sharp switchback on the road from Metaline Falls to the Main Lehigh quarry.

The belt of bedded limestone that extends for nearly 8 miles from Sullivan Creek to a point a short distance beyond Uncas Gulch is underlain by the Maitlen Phyllite on the southeast and is in fault contact (Slate Creek fault) with the Ledbetter Slate on the northwest. In general, the limestone strata dip moderately to steeply northwest. Locally, the beds are overturned and cut by transverse faults; in the northern part they are strongly folded. The rocks are irregularly dolomitized, especially in the northern and southern parts of the belt (pl. 1). There are many outcrops along this belt; most are confined to the upper slopes and crests of the sharp ridges that trend parallel to the strike of the strata. Individual outcrops rarely expose as much as 50 feet of section, although some beds can be traced along strike for 500-1,000 feet. The rock exposed in this area is chiefly thin-bedded dark-gray limestone with scattered croppings of gray massive limestone. The stratigraphically lowermost 500 feet of the rocks of the northern third of this belt contain a larger quantity of limy phyllite beds and lenses than farther south, although exposures are too widely separated in this area to furnish a reliable stratigraphic section to compare with the rocks of Quarry Hill. Lenses of phyllitic limestone and limy phyllite are especially common in the area 2,500 feet southeast of the cabin at the southwest end of Bluebird Ridge (pl. 1).

The rocks of the bedded limestone unit that lie north of Slate Creek are, in general, more strongly deformed than the rocks of the same stratigraphic position on Quarry Hill. As a result, part of the rock north of Slate Creek is a light- to medium-gray streaky fractured limestone; locally, it resembles a schist, particularly the rock exposed at the end of the secondary

Section of the bedded limestone unit of the Metaline Limestone on Quarry Hill

Top.

Dolomite: Chiefly light-gray, fine- to medium-grained; locally black and medium-grained. Well bedded.

Subunits:	Feet
1. Thin-bedded subunit: Interbedded limestone, shale, and limy shale. Limestone constitutes about 90–95 percent. Chiefly papery to platy dark-gray to black limestone beds, ¼–6 in. thick, alternating with black shale and limy shale beds and partings commonly less than a quarter of an inch thick. Very thin beds predominate in the upper part, whereas in the lower part some beds of limestone and limy shale reach 3 ft thick. Locally grades into phyllitic limestone. Limestone weathers light to medium gray; some shale to reddish brown. In lowermost 25 ft of subunit in Main Lehigh quarry are 2 beds, 1–2 ft thick, of light-brown-weathering limy shale that locally contain abundant trilobites	385
2. Quarry subunit: Light-gray to gray mottled limestone locally grading along strike into dark-gray limestone. Beds range in thickness from a few inches to 20 ft. Calcite flecks, stringers, and veinlets locally abundant. Many chemical analyses show that rock grades irregularly from nearly pure limestone to limy dolomite. Principal quarry beds	65
3. Algal and oolitic subunit: Interbedded dark-bluish-gray limestone and dark-gray shaly limestone. Beds 1–4 in. thick. Limestone constitutes 80–90 percent of subunit. Limestone separated by partings, wavy streaks, and thin beds of the shaly limestone which locally join and leave "eyes" of limestone. Shaly limestone weathers a pronounced reddish brown. About 75 ft below top of subunit is a bed 5± ft thick that locally contains algae. About 25 ft below the algal bed is a poorly exposed bed, 1–2 ft thick, of black oolitic limestone. Rocks of the subunit become progressively thinner bedded and more phyllitic from top to bottom	125
4. Phyllitic limestone subunit: Dark-gray to black, thin-bedded to very thin bedded phyllitic limestone interbedded and intergrading with dark-gray to black limy phyllite and some phyllite. Limy phyllite and phyllite become progressively more abundant toward base. Fresh surfaces break along phyllitic partings that are greenish gray and glistening. Weathers into brownish and greenish-gray chips and thin plates. Lower half of subunit very poorly exposed and based largely upon chips of weathered rock. Grades indistinctly downward into Maitlen Phyllite	375
Total	950

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road shown leaving the main paved highway at a point 1,000 feet south of the southern bank of Boundary Lake (pl. 1). However, most of the rock northwest of Desolation Mountain and south of Divide Peak consists of relatively underformed strata of thin-bedded dark-gray to black limestone with partings of phyllite or black shale. Scattered throughout the region north of Slate Creek are a few croppings of reddish-brown weathered shaly limestone similar to rocks found in subunits 1 and 3 of the Quarry Hill section.

Nearly everywhere north of Slate Creek, the contact between the bedded limestone and the underlying Maitlen Phyllite is very poorly exposed over a stratigraphic distance of several hundred feet or more, and commonly it is in a zone of considerable structural complexity. The longest (1½ miles) unfaulted part of the contact in this region lies on the northern and eastern slopes of Confusion Ridge (pl. 1) where limited exposures and float fragments indicate a progressive but irregular change downward from dominantly thin-bedded phyllite limestone of the Metaline Limestone to phyllite and limy phyllite of the Maitlen Phyllite. This gradational contact is similar, in general, to that found in the Quarry Hill section (p. 11). At all places in the district the Maitlen-Metaline contact is placed where phyllite and limy phyllite predominate over limestone and phyllitic limestones.

The upper contact of the bedded limestone with bedded dolomite is marked in a few places by an irregular band of black crystalline dolomite; elsewhere, the dolomite is fine grained and light gray. In places the dolomite is concordant with the bedding of the limestone over long distances, but at many other places it is highly crosscutting.

About 2,000 feet south of the Main Lehigh quarry, east of Metaline Falls, a lobe of bedded dolomite extends about 2,000 feet into the lower bedded limestone unit (pl. 1). The contact here between dolomite and limestone appears on the surface to be fairly sharp although coarse calcite is irregularly distributed over a distance of a foot or less on each side of the contact. To obtain general information on the composition of the rock in this area four specimens were collected near the contact—two in the dolomite and two in the limestone to the north. The results of the analyses, shown in table 1, indicate that the rocks 5 feet from the contact in this area are virtually of the same composition as those 45 feet farther away. Many analyses made by the Lehigh chemists of carbonate rock found north of the dolomite lobe in the vicinity of the quarry workings indicate a marked irregularity in magnesium content in the bedded limestone, although the main quarry zone, or "bed," locally extends as a very pure limestone over long distances. These analyses confirm observations made in the field by crude acid tests and show that the main bodies of dolomite as mapped are fairly sharply defined and grade rather abruptly into limy rock, although minor, and at a few places moderate, amounts of magnesium are widely and irregularly distributed in the lower strata.

TABLE 1.—*Chemical analyses of carbonate rock sampled normal to the contact of bedded dolomite and bedded limestone, south slope of Quarry Hill*

[Analyst: C. M. Collins, Metaline Falls, Wash.]

Laboratory No.	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3	Fe_2O_3	Total
A 18	96.87	1.55	0.49	1.00	0.09	100.00
A 19	96.76	1.39	.65	1.12	.09	100.01
A 20	56.69	41.76	.75	.42	.39	100.01
A 21	55.96	41.74	.54	.31	.36	98.91

A 18. Collected about 1,950 ft south of the southern end of Main Lehigh quarry 50 ft north of the contact between limestone and dolomite.
A 19. Collected 45 ft S. 30° W. of A 18, 5 ft north of contact between limestone and dolomite as shown on pl. 1.
A 20. Collected 10 ft S. 30° W. of A 19, 5 ft south of contact between limestone and dolomite.
A 21. Collected 45 ft S. 30° W. of A 20, 50 ft south of contact between limestone and dolomite.

Bedded dolomite

Rocks included in the bedded dolomite unit are widely distributed in the district (pl. 1). Bedded dolomite forms many of the hills and mountains that are contained in the large wedge-shaped area north of Slate Creek and east of the Pend Oreille River. Dolomite is the only type of rock exposed over a distance of 2½ miles in the north-central part of the mapped area from a point near the Scandinavian prospect due east across Lime Creek and Dolomite Mountain and beyond to its contact with the bedded limestone. In this area the unusually wide belt of dolomite is due to repetition by faulting. Most of the rock exposed for a distance of about 2½ miles in the gorge of the Pend Oreille River from Slate Creek north to Lime Creek is bedded dolomite. Wide belts of glacial material border both sides of this gorge, which, in general, follows the northerly strike of the strata, and much of the rock of the gorge is inaccessible to close observation, so that only a very limited amount of stratigraphic data could be obtained. In the upper Slate Creek area a prominent belt of bedded dolomite, averaging a mile in width, extends from the valley of Styx Creek northeastward to and beyond the Canadian border, and farther northwest Styx Mountain is held up by dolomite. Bedded dolomite attains a thickness of about 3,800 feet in the area extending northwest from La Sota Hill to Hornet Gulch. Elsewhere, dolomite strata unbroken by areas or patches of limestone may attain a somewhat greater thickness than 3,800 feet, especially in this same belt near the Canadian border where the beds dip more steeply than they do farther south; however, the outcrops are few and widely spaced, and the apparently greater thickness may be due to minor structures that are not evident. Little is known for certain regarding the maximum thickness of the bedded dolomite south of Metaline Falls because of the presence of major faults and the absence of recognizable bedding planes over wide areas.

The bedded dolomite unit is largely composed of a creamy-white to light-gray fine- to medium-grained dolomite that shows no recognizable stratigraphic variations over wide areas. Many thin sections examined show that most of the rock is composed entirely of interlocking grains of dolomite (figs. 2, 3). In a few thin sections several minute irregularly shaped grains of quartz were seen. Most of the rock is medium to thick bedded, although over wide areas no bedding planes are recognizable (fig. 4). Intercalated with the light-colored dolomite are some distinctive layers and irregularly shaped bodies of black crystalline dolomite that commonly contain small spots and streaks of white dolomite (figs. 5, 6). This type of dolomite will be referred to as the black and white dolomite.

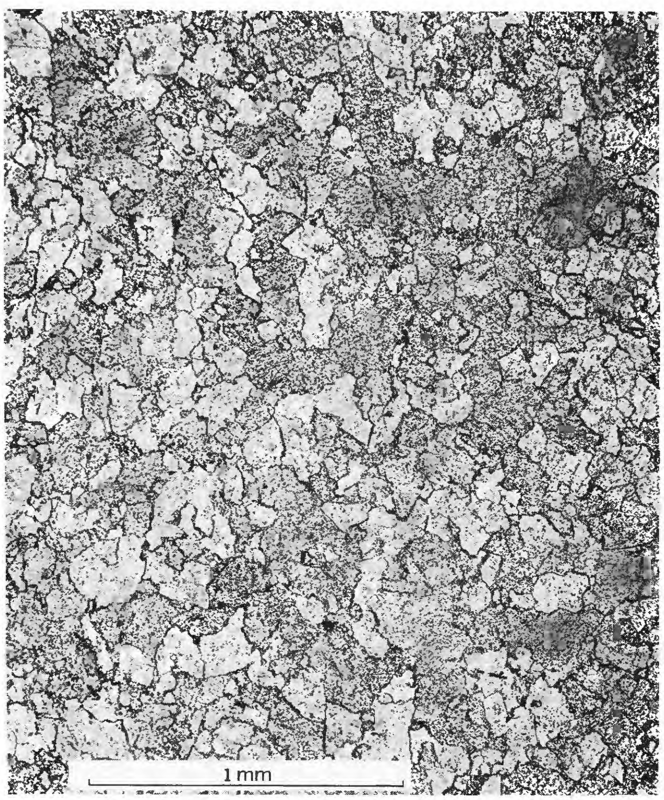

FIGURE 2.—Photomicrograph of fine-grained bedded dolomite from near mouth of Lime Creek. Consists almost entirely of interlocking fine grains of crystalline dolomite. Plane-polarized light. ×35.

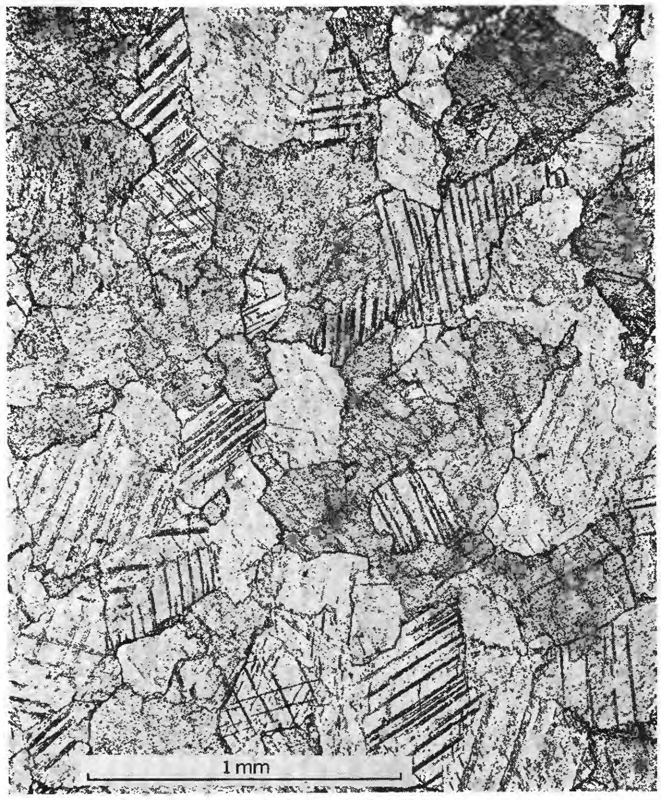

FIGURE 3.—Photomicrograph of medium- to coarse-grained bedded dolomite from outcrop 1 mile north of Slate Creek bridge. Shows interlocking medium to coarse grains of crystalline dolomite, some twinned. Rock at many places grades into fine-grained type shown in figure 2. Plane-polarized light. ×35.

FIGURE 4.—Outcrop of bedded dolomite unit of Metaline Limestone showing the typical poor physical features of the rock. Small outcrop of fine-grained and fractured dolomite. Bedding planes cannot be recognized.

Small cavities and patches of white quartz are widely scattered through all parts of the dolomite. The cavities are generally less than three-fourths inch across. They are commonly lined with small crystals of white dolomite which generally show curved crystal faces. White quartz generally occurs in patches 2 inches or less in longest dimension; some are roughly elliptical, whereas others are short stubby veinlets (fig. 7). No well-defined nodules were seen that resembled typical chert nodules, although some of the crudely elliptical ones may be crystallized and possibly deformed chert nodules. The dolomite along the sharp ridges in the southern part of the mapped area between Pocahontas and Sand Creeks (pl. 1) is cut at many places by a profusion of intersecting veinlets and small bodies of white quartz, some 10 feet or more in length. The quartz of this area may be genetically related to the Kaniksu batholith which crops out three-fourths of a mile or less to the east. (See Park and Cannon, 1943, pl. 1.)

FIGURE 5.—Black and white spotted and streaked dolomite, roadcut east of York Lake.

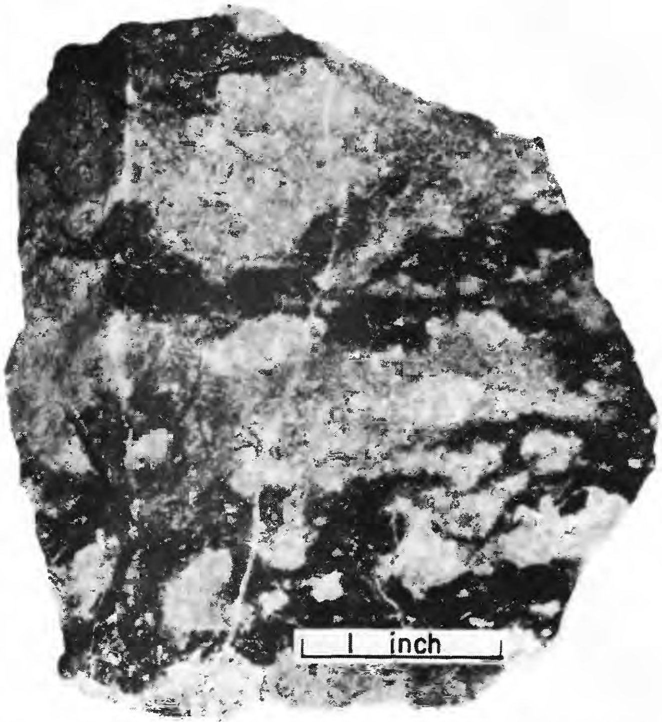

FIGURE 6.—Remnants of black dolomite in light-colored dolomite. Notice the partial alterations of the black layers.

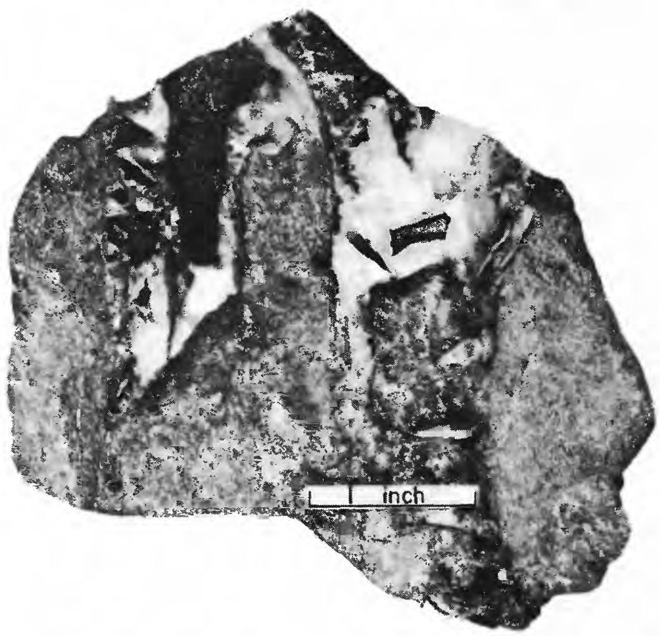

FIGURE 7.—Fine-grained light-gray dolomite containing irregularly shaped bodies of white crystalline quartz and (upper left) dark-gray jasperoid.

The main bulk of the bedded dolomite unit of this report corresponds to the rock variously referred to by Park and Cannon (1943) as either bedded, cream-colored, or fine-grained dolomite. It is virtually the rock described in their section east of Metaline Falls

(1943, p. 18) as lying between gray limestone and interbedded limestones and limy shales (bedded limestone unit of this report).

The ease of recognition of bedding planes in the dolomite varies greatly in different areas and along the strike of the beds. This variation is due to several factors which include the degree of development of stratification and parting planes, the amount of deformation of the rock, and the quality of exposure. Most of the bedded dolomite unit is strongly fractured, and parallel fracture planes, especially in small exposures, are readily mistaken for bedding planes. This confusion has not uncommonly led some workers to markedly inaccurate interpretations of structure and stratigraphy. Visitors to the district commonly obtain an erroneous impression of the typical features of most of the dolomite, for they visit the easily accessible area of dolomite that is well exposed along roadcuts and in cliffs near York and Crescent Lakes. There, bedding is unusually well developed, the rocks are relatively undisturbed, and the black and white dolomite stands out sharply from the light-colored rock. These rocks contrast markedly with the dolomite as is appears throughout a very large part of the rest of the district where small croppings of fractured rock (fig. 4) predominate. Many croppings are partly to completely covered with a layer of moss or lichen, but even where perfectly exposed, most require a thorough examination to recognize bedding planes.

Although the bedded dolomite unit cannot be divided into stratigraphic subunits, several fairly distinct varieties of dolomite occur locally or over fairly wide areas. Isolated hand specimens of these rocks differ strongly in appearance, although in the field most were seen to intergrade at places. All varieties range greatly in grain size within a distance of a few feet along strike, not uncommonly within the limits illustrated on figures 2 and 3. The most conspicuous of these types is the black and white dolomite previously mentioned. A typical hand specimen of this rock is shown on figure 5. The rock is a black fine- to medium-grained crystalline dolomite that commonly contains white spots and streaks of dolomite, generally of the same grain size. The spots are commonly less than half an inch across, and the streaks are generally less than an inch long. The black dolomite occurs as layers or irregularly shaped masses in light-colored dolomite. The layers commonly, but not everywhere, follow bedding. They are generally less than 8 feet thick, but some are as much as 20 feet thick and others are only a fraction of an inch thick. The light dolomite (including the white spots and streaks) lying along the strike of the black strata probably formed by recrystallization of the darker layers and the expulsion of the carbonaceous material, as postulated by Park and Cannon (1943, p. 18). Figure 6 shows a hand specimen of remnants of black dolomite in the lighter colored rock. Analyses (Park and Cannon, 1943, p. 42) of the light-colored and black dolomites show that these two rocks are nearly identical in composition, except for a minute quantity of carbonaceous material in the black dolomite. Movement along bedding planes of the black dolomite has locally formed zebra dolomite (fig. 8). In the northern

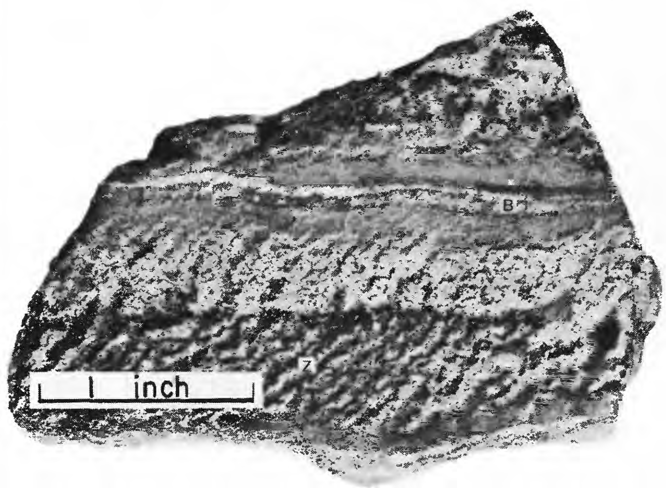

FIGURE 8.—Zebra dolomite. Zebra banding (Z) developed at a high angle to the bedding (B). Notice the coarse grain size of the bands as compared to the fine-grained dolomite showing bedding.

part of the district the black and white dolomite layers and irregular masses are most abundant in a stratigraphic zone about 2,500 feet thick, the base of which lies about 2,000 feet stratigraphically above the base of the Metaline Limestone. The black and white dolomite, even in this zone, constitutes on the average only about 1 to 3 percent of the rock mass. Minor black and white bodies, however, occur locally and very sparingly throughout the entire bedded dolomite unit; so the presence of this rock in isolated outcrop, of which there are many, does not in itself indicate that the rocks of the area are in this broad stratigraphic zone. In the southern part of the area mapped the stratigraphic position of this black and white dolomite zone is not well known because of scanty croppings. However, drill hole U.S. 24 (pl. 3, section C-C′) cut the top of a zone of black and white dolomite at a stratigraphic position about 1,400 feet below the Ledbetter Slate.

Far less widely distributed than the black and white spotted dolomite are other varieties of dolomite described briefly below. One is a gray, very fine grained, or sublithographic, dolomite which at many places is identical in appearance to the massive gray limestone. Some of this dolomite is faintly laminated. It is well exposed at several places along the old logging roads, along the cliffs west of York Lake, and also along the south slope of Dolomite Mountain. A uniformly black dolomite, ranging in grain size from medium to coarse, occurs locally, especially at or near the lower contact of the bedded dolomite unit with the bedded limestone. On Quarry Hill, black dolomite 800 feet west of the southern quarry excavations attains a stratigraphic thickness of about 200 feet, but about 1,800 feet or less to the north it gives way irregularly along strike to light-colored dolomite. Another local variety of dolomite is finely crystalline and massive, and within short distances ranges from light gray to dark gray. Bedding planes are especially difficult to recognize in this rock. At many places this dolomite can be seen irregularly replacing limestone (fig. 9). Some dolomite west of Metaline Falls is thin bedded, in contrast to the usual medium- to thick-bedded character of most of the rock of the dolomite unit.

Chemical analyses of bedded dolomite from widely separated areas are given below in table 2 and table 9 on page 101. The analyses show that most of the dolomites are very similar in chemical composition, regardless of the physical properties or areal distribution of this rock. These analyses also agree very closely with two other analyses given by Park and Cannon (1943, p. 42) of dark and light dolomites collected

FIGURE 9.—Limestone (L) partly altered to fine-grained dolomite (D), Desolation Mountain. Notice sharp and irregular contact and, in the upper part of the specimen, the small patches of unaltered limestone in dolomite.

about a foot apart in the same layer of bedded dolomite north of Crescent Lake. The relatively high percentage of insoluble material in sample A 14 (table 2), near the Yellowhead ore body, is probably due to hydrothermally introduced silica. It is noteworthy that the dolomites shown in table 2 vary only a few percent in the ratio of calcium carbonate to magnesium carbonate. All these rocks fall into the classification of dolomite (less than 10 percent calcite, more than 90 percent dolomite) as defined by Pettijohn (1957 p. 417). The mineral dolomite, if pure (which is rare), consists of 54.35 percent calcium carbonate and 45.65 percent magnesium carbonate.

Origin of the bedded dolomite.—Several possible origins have been considered for the bedded dolomites. These origins include hydrothermal replacement, alteration by ground water, direct precipitation from sea waters, and diagenesis—the theory favored by the authors.

The authors of the present report have considered the possibility that the bedded dolomite could have formed by hydrothermal alteration, which would seem to account for the irregularity of some of the bodies and their varying stratigraphic positions. The four principal reasons, however, for rejecting a hydro-

TABLE 2.—*Chemical analyses of various lithologic varieties of bedded dolomite from the Metaline Limestone*

[All samples were analyzed by C. M. Collins, Metaline Falls, Wash., except A 13 and A 14, which were analyzed by J. C. Crampton, Metaline, Wash.]

Laboratory No.	$CaCO_3$	$MgCO_3$	Insoluble	SiO_2	Al_2O_3	Fe_2O_3	Total
A 6	55.96	43.35		0.21	0.11	0.36	99.99
A 7	55.84	43.22		.47	.15	.32	100.00
A 8	55.38	44.15	0.21				99.74
A 9	55.71	44.02	.29				100.02
A 10	55.60	44.04	.23				99.87
A 11	54.58	44.86	.42				99.86
A 12	53.40	44.38	1.10				98.88
A 13	53.43	43.38	1.09				97.90
A 14	53.16	42.19	2.11				97.46
A 15	54.12	43.64		1.28	.62	.34	100.00
A 16	55.06	44.52	.35				99.93

A 6. Light-gray fine-grained dolomite from outcrop along paved highway 1,300 ft northeast of Crescent Lake.
A 7. Creamy-gray fine- to medium-grained dolomite from near top of cliff 1,000 ft southwest of Crescent Lake.
A 8. Light-gray fine-grained dolomite with faint streaks and dark-gray patches from southern part of large isolated mass of dolomite in bedded limestone at south end of Confusion Ridge.
A 9. Light-gray fine- to medium-grained dolomite from northern part of same dolomite mass as A 8.
A 10. Grayish-white fine-grained dolomite from outcrop on lower western slope of Timber Hill. Stratigraphically about 150 ft below the top of the bedded dolomite unit in this area.
A 11. Fine-grained black-and-white-streaked dolomite from northeast slope of Timber Hill. Stratigraphically about 1,200 ft below the top of the bedded dolomite unit in this area.
A 12. Light-gray sublithographic dolomite from base of cliff west of paved highway about 200 ft north of Lime Creek.
A 13. Light-gray very fine grained dolomite from western part of Yellowhead mine adit.
A 14. Light-gray fine-grained dolomite from upper part of raise in Yellowhead mine about 20 ft below the ore bodies.
A 15. Medium-gray sublithographic dolomite from prospect cut located 1,500 ft north of Josephine shaft.
A 16. Light-gray fine- to very fine grained dolomite from outcrop along west side of road to Russian Creek about 2,000 ft west of Metaline Falls.

thermal origin for the bedded dolomites of the Metaline district are listed below and briefly described:

1. On the basis of the known composition of emanations from intrusive bodies it is highly unlikely that hydrothermal solutions genetically related to a large intrusive body, such as the Kaniksu batholith, could furnish sufficient quantities of magnesium to form a section of dolomite more than 3,000 feet thick and extending over a distance of many miles.
2. The Kaniksu batholith, the logical source of any such large quantities of hydrothermal fluids, was emplaced after these bedded dolomites were formed, as indicated by the relationship of the bedded dolomites to faults and folds that formed, in part at least, before the batholith was emplaced and by the suggestion of dedolomitization effects noted by Park and Cannon (1943, p. 45) south of the area mapped for this report.
3. Of somewhat lesser importance is the absence of structures in the middle part of the Metaline Limestone which would have generally guided the hydrothermal solutions, regardless of their source, into this part of the formation.
4. The preservation of bedding planes. In areas of known hydrothermal dolomitization in the district bedding planes are almost everywhere obliterated.

Some of the irregularities in the bedded dolomite bodies, as well as the erratic distribution of dolomitic limestone and limy dolomites, may be accounted for by the altering action of underground solutions, as mentioned by Park and Cannon (1943, p. 45). This effect, however, cannot be of widespread importance, because analyses of ground water and river water show a great excess of calcium carbonate over magnesium carbonate, and therefore, according to Van Tuyl (1914, p. 399), it is unlikely that these waters could dolomitize limestone when they already contain calcium carbonate far in excess of magnesium carbonate.

The main factors that are believed by the authors of the present report to favor an origin for the bedded dolomites from sea waters are as follows:

1. The general middle stratigraphic position of the bedded dolomites in the Metaline Limestone between the gray limestone and bedded limestone units.
2. The large volume of magnesium contained in the bedded dolomites is most logically accounted for from sea water.
3. Early Paleozoic strata elsewhere, regardless of structural position and nearness to igneous bodies, contain much larger quantities of dolomite than younger strata, suggesting that the ancient seas contained a relatively large amount of magnesium.

The great thickness of nearly pure dolomite might very logically suggest that the bedded dolomite formed directly by precipitation from sea waters. However, the highly irregular upper and lower boundaries of this dolomite with limestone and the isolated areas of dolomite in limestone suggest that at least part, if not all, of the bedded dolomite formed as a result of alteration of limestone to dolomite, either before or after lithification. The authors favor replacement beneath the sea before complete lithification as proposed by many early workers and described and discussed at length by Van Tuyl (1914, p. 257–421), who termed it "marine alteration."

Future studies of dolomitization in the district supported by hundreds of chemical analyses might furnish valuable data that would aid in solving this much-discussed problem, although factors that would hinder such an exhaustive study include sparsity of large croppings, wide belts of glacial covering, the possible presence of undisclosed structures, and the difficulty of tracing individual beds more than a few hundred feet.

Gray limestone

The gray limestone unit is exposed at many places throughout the mapped area and the underground workings in the three principal mines. However, most of the original gray limestone cut in the mine workings is so intensely dolomitized that its original character is largely obscured. By far the thickest section and best exposure of gray limestone is found in the Lead King Hills (pl. 1), which is part of a wide belt of gray limestone that extends northward to Contact Mountain for a distance of about 4 miles. In the extreme northwestern part of the area shown on plate 1 near Gardner Cave and the South Fork of Russian Creek, a few low hills and knobs expose strongly metamorphosed rocks of this unit. The only exposures of unaltered gray limestone in the large area north of Slate Creek and east of the main highway to Canada lie half a mile or less north of the Lead Hill fault where they crop out at widely separated intervals from the highway to a point 3,500 feet northeast of La Sota Hill. Gray limestone, in part very irregularly altered to dolomite, is found in the cliffs along the Pend Oreille River gorge north of Washington Rock and in the area extending from the portal of the Grandview mine northwest to the Sullivan glory hole (pl. 1). Small areas of the gray limestone also occur high on the hills northwest of the portal of the Metaline mine in the vicinity of the old Blue Bucket and Bella May workings and in the area north of the West Contact raise.

Rock typical of the gray limestone unit is a light- to medium-gray irregularly mottled very fine grained soft massive limestone (fig. 10). Individual beds can rarely be recognized, but locally the attitude of the strata can be distinguished by parting planes and rarely by a faint color banding. In a few places in the Pend Oreille mine shaly partings and scattered thin shale beds can be seen. Generally these are restricted to the upper 25 feet of the unit. White to medium-gray chert is widely, but generally sparingly, distributed in the gray limestone; it is especially common in the uppermost 200 feet in the Lead Hill and Lead King Hills areas. Chert commonly occurs in small isolated patches in a wide variety of forms including spherical (rare) to angular nodules or clusters of nodules. Many nodules, as the term is loosely used in this report, are connected by irregularly shaped and roughly cylindrical stemlike forms or branches which locally pinch and swell greatly within distances of a few inches or less. The nodules, excluding connecting stems, are generally less than an inch in longest dimension, although locally they are several inches or more long. Flattened and well-shaped ellipsoids, lenses, and tabular bodies of chert are very rare. Some chert nodules are recrystallized to fine-grained white quartz; elsewhere, near the ore bodies they grade into jasperoid. Some small nodules are bordered by a rim of coarse calcite (fig. 11).

The Lead King Hills afford, at several places, nearly continuous exposures of the gray limestone unit. On the west slope of these hills the moderate westerly dip of the strata is generally masked by preferential erosion along fractures which resemble bedding planes dipping more steeply than the strata themselves. Along the crest of the hills, however, bedding is clearly seen at many places. There, bedding planes occur at 3- to

Figure 10.—Photomicrograph of gray limestone from Lead King Hills. Shows small (about 1 mm) grains of calcite in the typical sublithographic grain size of most of the rock. Plane-polarized light. ×35.

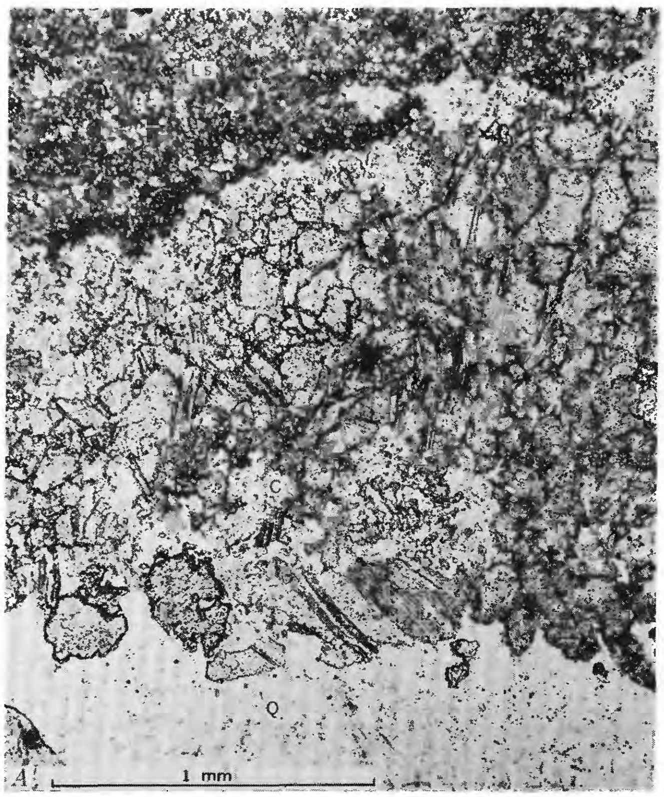

Figure 11.—Photomicrograph showing rim of coarse calcite between chert nodule and gray limestone, near Lead King mine. Part of chert nodule (Q) in gray limestone (Ls) separated by rim of recrystallized calcite (C). Plane-polarized light. ×35.

15-foot intervals, and erosion controlled by these planes has locally produced small ridges and valleys a few feet high. The lowest part of these valleys is everywhere covered by soil, and it is possible that some may conceal partings or thin beds of shale or shaly limestone, although rocks of the same general stratigraphic position where exposed elsewhere to the north in small cliffs do not contain shale. The sections given below are based upon planetable surveys along traverses that are the best exposures of the upper part of the Metaline Limestone in the district. The subunits in the two sections do not correlate; the numbers are merely for text reference.

Section of gray limestone and part of bedded dolomite units of Metaline Limestone in southern part of Lead King Hills near the Lead King mine.

	Feet
Top.	
Glacial deposits:	
Subunit:	
1. Dolomite, medium-gray to black, fine- to coarse-grained. Sparse to abundant jasperoid, quartz, calcite, sphalerite, and galena; all irregularly distributed. Grades irregularly into subunit 2	40+
2. Limestone, gray, irregularly mottled light- to dark-gray, sublithographic, soft, weakly developed thick to very thick beds, massive; weathers light gray. Contains widely distributed irregularly shaped patches, streaks, and stringers of secondary dolomite, calcite, jasperoid, and quartz commonly less than 2 in. long. Secondary products occur singly or in various combinations	250
3. Dolomite, medium-gray, coarse-grained; contains a little jasperoid, calcite, and a few specks of sphalerite. Dolomite conforms in general to the attitude of the enclosing strata but locally crosscuts bedding into the limestone	20
4. Limestone, similar to subunit 2 except for smaller quantities of the secondary products	490
5. Dolomite, chiefly medium-gray and medium-grained, but grades into minor amounts of dark-gray and fine-grained dolomite. Jasperoid common. Upper and lower contacts locally crosscut bedding planes of the limestone	25
6. Limestone, similar to subunit 4. Near middle contains 2–3 ft of gray medium-grained dolomite	65
7. Dolomite and limestone, chiefly a zone of fine- to medium-grained gray dolomite that follows and crosscuts bedding planes in gray limestone. Part of the rock is a dolomitic limestone or limy dolomite, but about 75 percent of the zone is dolomite. Lower 100 ft largely covered; lithology inferred from float fragments and rare outcrops near the line of section	300
8. Limestone, similar to subunits 4 and 6	35
9. Limestone, gray, irregularly mottled, light- to dark-gray; contains common greenish-gray shale partings, small patches and thin beds 1 in. or less thick; shale weathers reddish brown. Part of shale squeezed into irregular stringers that crosscut bedding planes. Shale constitutes less than 1 percent of the volume of this subunit	150
10. Limestone, similar to subunit 8	125
Total of gray limestone unit	1, 500
Base of the gray limestone unit.	
11. Dolomite, gray, medium-grained. Base of outcrop covered for a long distance to the east, but float fragments and rare outcrops in area indicate that all rock lower in stratigraphic position is very fine grained to medium-grained dolomite	10+
Total	1, 510±

Section of gray limestone and part of bedded dolomite units of Metaline Limestone in northern part of Lead King Hills near the Cliff mine

	Feet
Top.	
Glacial debris:	
Subunit:	
1. Limestone, gray, irregularly mottled light- to dark-gray, sublithographic, soft, weakly developed thick to very thick beds, massive. Weathers light gray. Contains widely distributed irregularly shaped patches, streaks, and stringers of secondary dolomite, calcite, jasperoid, and quartz, commonly less than 2 in. long. Secondary products occur singly or in various combinations	810+
2. Dolomite, medium-gray, coarsely crystalline, nonbedded. Contains sparse coarse grains and small patches of calcite. Most of contact follows bedding planes but locally crosscuts into limestone. Weathered surface light brown	10
3. Limestone, similar to subunit 1	80
4. Dolomite and limestone, about equal in volume. Limestone similar to subunits 1 and 3. Dolomite ranges in color from light to dark gray and in texture from very fine to coarsely crystalline. Commonly the fine-grained dolomite is irregularly overlain and underlain by coarse dolomite. Generally the contact between dolomite and limestone follows bedding planes, but locally it is markedly crosscutting. Dolomite weathers light brown, limestone light gray	75
5. Limestone, similar to subunits 1 and 3	150
6. Dolomite, medium-gray, coarsely crystalline, nonbedded. Contains sparse coarse grains and patches of calcite. Weathers light brown. Poorly exposed	35±
7. Limestone, similar to subunits 1, 3, and 5	165±
Total of gray limestone unit	1, 325+

Base of gray limestone unit:	*Feet*
8. Dolomite, chiefly medium-gray, coarsely crystalline. Common coarse calcite grains and patches. Grades locally into very finely crystalline dolomite. Poorly exposed and upper and lower contacts concealed. Weathers light brown	100±
9. Dolomite, light- to medium-gray, finely crystalline, thick-bedded. Upper 100 ft contains a few irregular patches of medium- to coarse-grained dolomite and light-gray sublithographic soft massive limestone. Weathers light brown. Weak to moderately well developed, thickly bedded. Thick covering of glacial material at base	350+
Total	1, 775±

The two sections are spaced about a mile apart. The southern, or Lead King, section was measured from a point about 150 feet north of the Lead King adit in a due easterly direction for a horizontal distance of about 3,300 feet. The northern, or Cliff, section was measured from a point about 350 feet south-southeast of the Cliff mine in a southeasterly direction (averaging S. 67° E.) for a horizontal distance of about 3,250 feet. In the Cliff section gray limestone extends through a stratigraphic range of about 1,325 feet before passing downward into dolomite, and in the Lead King section it is about 1,500 feet. In both areas part of the gray limestone is replaced by dolomite. This dolomite, as indicated in the descriptions accompanying the section, conforms in a general way to bedding, but at many places it is markedly crosscutting. The dolomite also occurs in irregularly shaped masses of varying size, some of which lie in, or a short distance from, the lines of the sections. The thickness of these dolomite units therefore varies greatly according to the line of section chosen for measurement. Most are too narrow or discontinuous to be shown on the geologic map, plate 1, although the thick zone shown as subunit 7 in the Lead King section is shown on plate 1 as a long band of dolomite that can be traced nearly 2 miles along the eastern slopes of the Lead King Hills. Insofar as could be determined, none of the dolomite subunits is a definite stratigraphic marker.

The dolomite at the top of the Lead King section is almost certainly within 50 feet stratigraphically of the Ledbetter Slate as indicated by drill holes to the west. The stratigraphic position of the limestone at the top of the Cliff section is not known with certainty because of a probable fault or faults to the west and a wide belt of glacial covering separating the outcrop from the nearest drill hole. However, meager drill-hole data and the general characteristics of the rock suggest that the upper part of the limestone of subunit 1 is 50–200 feet below the slate. It was hoped that the limestone section containing shale partings (subunit 9, Lead King section) would prove to be a reliable horizon marker, but these rocks could not be traced very far from the line of section. At several other places to the north, especially near the swamp northeast of the Hoage mine and on the hill about 1,500 feet farther northeast, narrow zones of limestone containing shale partings were found, but all are of local occurrence and lie considerably higher stratigraphically than subunit 9.

In the Lead King section, gray limestone with minor amounts of altered rock extends to a depth of 850 feet (subunits 1–4) below the slate, assuming that 50 feet of section is missing from the top, and some gray limestone is found as far as 1,550 feet below the slate (subunits 1–10, plus 50 ft added to subunit 1). On the other hand, drill holes in the area of the principal mines near Metaline Falls show a considerably thinner section of gray limestone. In the Pend Oreille and Grandview mine area, as shown on plate 3, the thickness of gray limestone cut in drill holes ranges from zero in drill hole 216, section *B–B′*, to 650 feet in drill hole U.S. 24, section *C–C′*. This great variation in thickness of the gray limestone in the two areas is believed, as mentioned on page 10, to be due largely or entirely to the irregularity of dolomitization and not to an inherently thinner section of limestone near Metaline Falls. In the Slate Creek area near La Sota Hill only a few remnants of gray limestone remain in the dolomitized rocks; farther north the dolomitization of the original gray limestone has been complete, and dolomite is overlain directly by slate (pl. 1).

In the northwestern part of the district north of the Russian Creek fault the gray limestone beds have been dynamically metamorphosed to a light- to dark-gray layered streaky limestone marble locally containing knots and lenses of dolomite. The attitude of layering in this rock is shown by a special symbol on plate 1, so that the extent of the marble can be determined closely.

Table 3 below gives chemical analyses of various limestone beds of the gray limestone unit that were collected during a planetable survey across the hill east of the Lead King mine. The top of the Metaline Limestone is fairly closely established west of this hill by numerous drill holes put down through surficial deposits and the Ledbetter Slate; thus, the references to this datum are far better established than is indicated by the position of the slate on the geologic map.

The analyses show that there is no marked difference in the composition of the limestones over a stratigraphic range of 1,100 feet. All are in effect pure limestones with compositions similar to many of the gray limestones found in some of the drill holes in the mine areas (table 4, p. 55), which contain 97–99 percent calcium carbonate and less than 1.5 percent magnesium carbonate. In the Lead King area the bulk composition of the limestones is slightly more magnesian than shown by the analyses in table 3, because the samples submitted for analysis were free from patches and stringers of dolomite that are scattered over the area.

TABLE 3.—*Chemical analyses of gray limestone unit of Metaline Limestone from hill east of Lead King mine*

[Analyzed by Tennessee Valley Authority; analyst not specified]

Laboratory No.	$CaCO_3$	$MgCO_3$	Insoluble	Total
A 1	99. 30	0. 63	0. 04	99. 97
A 2	98. 93	1. 38	. 05	100. 36
A 3	98. 39	. 90	. 55	99. 84
A 4	99. 10	. 90	. 06	100. 06
A 5	99. 10	1. 04	. 05	100. 19

A 1. Collected near top of hill 1,120 ft N. 81° E. from Lead King adit. Bed lies about 425 ft stratigraphically below the top of the Metaline Limestone.
A 2. Collected 500 ft east of A 1. Bed lies about 685 ft stratigraphically below top of Metaline Limestone.
A 3. Collected 335 ft east of A 2. Bed lies about 915 ft stratigraphically below top of Metaline Limestone.
A 4. Collected 560 ft east of A 3. Bed lies about 1,300 ft stratigraphically below top of Metaline Limestone.
A 5. Collected 270 ft east of A 4. Bed lies about 1,525 ft stratigraphically below top of Metaline Limestone.

Contact between Metaline Limestone and Ledbetter Slate.—Contacts between the Metaline Limestone and overlying Ledbetter Slate showing little or no evidence of faulting are rare in the district. No such contact is clearly exposed at the surface, and at only a few places in the mine workings can an unfaulted contact be observed. 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. Scores of diamond-drill holes have cut the slate-limestone contact, and invariably the cores indicate much faulting along the contact by their broken and deformed character, the common repetitions of slate and dolomite, and slate forced into dolomite. Thus, it is generally impossible to tell whether the slate and limestone are for the most part in depositional contact along a minor bedding or contact slip, or whether they are brought together along a fault of significant displacement which has cut out some of the strata. Moreover, no distinct and certain horizon markers have been recognized in the beds of either slate (argillite) or limestone (dolomite) near the contact. Bedding planes in the Ledbetter are generally distinguishable a short distance above the contact where the rock is commonly argillite rather than slate, but the underlying rock of the Metaline Limestone is almost everywhere so thoroughly altered by hydrothermal solutions that bedding planes can rarely be recognized. Locally, thin shaly beds and partings in the dolomite mark the attitude of the Metaline rocks, although commonly these black shaly members are so squeezed and deformed that they serve only as a general indicator of the position of the Metaline strata. No angularity was noted between the two formations at the few places where bedding planes near the contact were seen distinctly in both formations. At most places the Ledbetter rocks appear to rest conformably on the Metaline strata, although a minor erosion surface at the top of the Metaline could easily go undetected along the undulating and deformed contact where bedding planes are not recognizable in the carbonate rock. However, at one locality near the top of the hill northeast of the Giant prospect (pl. 1) there is evidence of at least a local erosion surface on the Metaline strata beneath the Ledbetter. A small erosional remnant of black graptolitic argillite was found firmly embedded in a cavity in the Metaline Limestone about a foot wide and a foot deep. The argillite dips west at approximately the same angle as the enclosing carbonate rock.

Generally during the course of mining operations the uppermost 25 feet stratigraphically of the Metaline Limestone and the lower part of the Ledbetter Slate are avoided in the stopes because of unsafe ground and the generally poor mineralization in the carbonate rock; thus, this section of the stratigraphic column is well exposed at only a few places. The best exposures are in the eastern workings of the Pend Oreille mine on the 1900 level at the incline station and on the 1700 level along the truck road near the grizzly. At these localities 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. A few thin beds, lenses, and partings of black, generally gougy, shale occur irregularly distributed through this uppermost part of the Metaline. Overlying the broadly undulating surface of the dolomite are the black thin to medium beds of argillite of the Ledbetter Slate, which locally show small drag folds along bedding planes near the contact with the dolomite.

On the east bank of the Pend Oreille River a few hundred feet north of the mouth of Slate Creek, a small area of Ledbetter Slate resting on silicified dolomite of the Metaline can be seen during low water level (pl. 6). The slate and dolomite are for the most part in depositional contact, although fractured rock at the contact indicates some slippage, probably of the reverse type, which occurred during the time of the thrusting that produced the nearby Lee thrust.

AGE

The Metaline Limestone locally contains fossils of Middle Cambrian age in the bedded limestone unit. No fossils were found in the thick overlying section of bedded dolomite, and only one fossil, a poorly preserved trilobite, has been found in the gray limestone unit (Park and Cannon, 1943, p. 19). Insofar as is known to the authors, very few fossils have been found in the Nelway (Metaline) Formation adjacent to the Metaline district in British Columbia. Little (1950, p. 21) states, "Two very poorly preserved trilobite pygidia, reported by Okulitch, and a fragment of *Conulites* are the only fossils known to have been found in the Nelway formation of the Salmo map-area."

East of Metaline Falls in the Main Lehigh quarry fossils have been found in abundance in two beds in the lower 25 feet of sub-unit 1 of the Quarry Hill section (p. 11). The exact stratigraphic interval between the two fossiliferous beds could not be determined precisely at the time the quarry was mapped because of inaccessible quarry faces and much excavation debris that concealed definite exposures, but both are in beds that lie 25 feet stratigraphically above the quarry rock. A fossiliferous bed found in the Lower quarry (pl. 1) is probably in the same general stratigraphic position as those in the Main Lehigh quarry, for the rocks are similar lithologically and lie above the main quarry bed. A gentle fold and possibly faults of minor displacements account for the apparent difference in the stratigraphic position of the rocks at the two quarries. Fossils collected by Park and Cannon (1943, p. 19) and identified by Josiah Bridge are as follows:

Elrathia kingii
Neolenus sp.
Kootenia sp.
Pagetia sp.
Acrothele sp.

Little (1950, p. 21) reports that Okulitch collected fossils in 1947 from both the upper (Main Lehigh) and lower quarries on Quarry Hill. Okulitch identified the fossils and stated that the dominant forms in the lower quarry are *Elrathia*, *Elrathiella* and *Elrathina*, and in the upper quarry *Elrathia*, *Ogygopsis* and *Neolenus*.

Neither of the two beds that contain trilobites on Quarry Hill was seen at any locality north of Sullivan Creek. Park and Cannon (1943, p. 19) found fossils similar to those in the quarry in poorly exposed limy shale on the southeast bank of Threemile Creek at an altitude of 2,800 feet. During the present investigation a diligent search was made for additional fossils from this locality but with no success; the locality is in an area that is covered by heavy timber and a thick forest mat and therefore has few exposures.

Beds of limestone and shaly limestone that contain algae similar to those illustrated by Park and Cannon (1943, pl. 9B) were found at several localities and at what are believed to be several stratigraphic positions. These algal beds are exposed at the following six localities:

1. Along the trail 2,000 feet southeast of the southern bank of Boundary Lake at an altitude of 2,975 feet, where the algal beds are 5 feet thick. These beds can be traced northeast intermittently for about 500 feet,
2. About 1,000 feet S. 45° E. from locality 1, where the beds are shown on plate 1 as dipping 33° W. Here the algal beds are well exposed over a fairly large area,
3. In a cut along the east side of the road that leads to Boundary Lookout at an altitude of 4,325 feet,
4. On the western slope of Confusion Ridge 4,400 feet N. 52° E. from the sharp summit of Dolomite Mountain,
5. About 1,000 feet S. 20° E. from locality 4,
6. On the crest of the ridge 2,300 feet N. 85° W. from the summit of Desolation Mountain where the algal beds are well exposed for a short distance, although the entire thickness of the fossiliferous beds cannot be determined because of forest covering.

ORDOVICIAN SYSTEM

LEDBETTER SLATE

The Ledbetter Slate of Early and Middle Ordovician age is widely distributed in the Metaline district (pl. 1), but it occurs mainly along the eastern and western margins of the district. The formation, which consists largely of black argillite and black slate, was named by Park and Cannon (1943, p. 20) for rocks exposed on the slope west of Ledbetter Lake. It correlates with the Active Formation in British Columbia as used by Little (1950, p. 21–23) and with the middle part of the Pend d'Oreille Group as defined many years ago by Daly (1912, p. 271–277) and also used later by Walker (1934, p. 9).

DISTRIBUTION

In the region adjoining the Metaline district, beds of Ledbetter Slate are known to extend about 2 miles farther southwest beyond the area shown on plate 1; to the northeast, the Active Formation can be traced about 20 miles into Canada to Porcupine Creek (Fyles and Hewlett, 1959, p. 34 and fig. 2). The Ledbetter extends 3½ miles farther west in the Russian Creek area than shown on plate 1 (Park and Cannon, 1943, pl. 1). To the west of the district in Stevens County the Ledbetter has been recognized with certainty by Yates and Robertson (1958) as far as 2 miles west of Leadpoint, and Campbell (1947, pl. 1) shows Ledbetter strata 8½ miles southwest of Leadpoint in an area west of Deep Creek and about 2½ miles south of Northport.

The Ledbetter Slate is best exposed in the Metaline district along the banks and steep slopes that border the larger streams. By far the longest and most readily accessible belt of exposed slate extends along the Pend Oreille River near the Pend Oreille mine northeast for about 3 miles (pl. 1). A smaller area borders the same river for about three-fourths of a mile near Z Canyon. Along the smaller streams, slate is exposed at many places from the mouth of Slate Creek east to the main highway, and in the southern part of the district along Lunch Creek for about 1½ miles. Elsewhere in the district, slate underlies or forms parts of the slopes of many hills and mountains, and generally in these areas the rock crops out very sparingly; the best exposures are commonly in cuts along logging roads. Large masses of slate are concealed beneath glacial deposits, especially along the wide belt that borders the Pend Oreille River from Slate Creek south to the Grandview and Pend Oreille mines. In this broad belt the only surface evidences of Ledbetter Slate are a few small and generally smooth outcrops and rare float chips of slate, all too small to show on the geologic map (pl. 1). Other areas of Ledbetter Slate largely concealed by glacial material are in the south in the vicinity of Sweet and Lunch Creeks and in the north from Brushy Ridge northeast to the Tom Cat and Hanley prospects (pl. 1). Park and Cannon (1943, pl. 1) show a large area of Ledbetter Slate west and northwest of Ledbetter Lake. Work of the present investigation, however, shows that much of this region is underlain by rocks of Silurian and Devonian ages as well as by two small bodies of trachybasalt. Ledbetter Slate is exposed in parts of the workings of the three principal mines (Pend Oreille, Grandview, and Metaline) and in many small cuts, pits, and short adits throughout the district. Many diamond-drill holes have been put down into or through the Ledbetter Slate in the areas surrounding the three principal mines, and considerable drilling has been done in several other areas. These include the area extending from near the main highway bridge across Slate Creek southwest to the Pend Oreille mine—the area east of Lost Lake to, and a short distance beyond, Pend Oreille River—and in the area of the lower Bluebird claims (fig. 33) which borders Slate Creek northwest of Bluebird Ridge.

THICKNESS AND GENERAL STRATIGRAPHIC RELATIONS

The apparent maximum thickness of the Ledbetter Slate is somewhere between 2,200 and 2,500 feet. A more precise estimate of the thickness cannot be given with the information available at present. Likewise, no entirely reliable stratigraphic section can be given for the Ledbetter, although some general lithologic zones, described in following paragraphs, are evident locally. The principal factors that cause these uncertainties of thickness and stratigraphy are (1) the generally poor and widely distributed croppings, (2) the strongly sheared and distorted nature of much of the rock, (3) the absence of definite horizon markers, (4) the difficulty at many places of distinguishing bedding planes from fracture cleavage, (5) the presence of many known and suspected faults and folds that are largely concealed, (6) the probable and suspected lateral gradation of rock types. and (7) the lack of adequate core from drill holes that penetrated thick sections of slate.

The contact of the Ledbetter Slate with the underlying Metaline Limestone is generally conformable (p. 21). The upper and poorly defined contact between the Ledbetter Slate and rocks of Silurian and Devonian age is everywhere concealed. The boundary between these is placed at the base of the lowermost dark-gray to black crystalline and fossiliferous limestone or associated quartzite of Silurian and Devonian age. No certainty is felt that this contact as mapped is everywhere in the same stratigraphic position because of the lenticular nature of the generally thin limestone beds and the accidents of exposure. Also it is likely that limestone deposition did not begin at the same time throughout the area. Furthermore, it is necessary at some places to assume that the quartzite bed used in mapping is the same quartzite associated with the fossiliferous limy beds found elsewhere.

It is possible that a marked erosional unconformity separates the Silurian and Devonian, and Ordovician rocks, for, at places, such as north of Ledbetter Lake, the Ledbetter appears from meager data to be much thinner than elsewhere. There is also a considerable time gap between the Middle Ordovician age of the Ledbetter and the latter part of the Early Silurian age for the oldest known rocks of Silurian and Devonian age. Likewise, the abundance of clastic rocks and limestone reefs near the base of the rocks of Silurian and Devonian age indicates deposition in shallow water.

LITHOLOGY

Exclusive of the rock near Russian Creek and some west of Ledbetter Lake, about 95 percent of the Ledbetter Slate consists of black carbonaceous fine-grained argillite and slate and minor amounts of black limy argillite and limestone. Individual grains can rarely be recognized in most of the rock; in general, it appears homogeneous, although locally a few faint compositional or color bands, generally less than one-half inch thick, can be seen. The color bands probably represent minor differences in carbonaceous content. The argillite grades gradually into slate which has a marked fracture or slaty cleavage (fig. 12); near faults or strongly deformed areas, the gradation may be fairly abrupt. Bedding planes in the slate are, at most places, difficult to recognize; in a few places graptolites, or thin beds of limestone or quartzite, or a faint color banding reveal bedding. At most places bedding in the slate and argillite is more readily recognized from a distance of several hundred feet or more than it is closer to the outcrop.

Strongly faulted or sheared argillite and slate is commonly a black and sooty mass of pulverized rock that weathers into small thin chips, some of which are elongated into hackly fragments. At some places this fractured and weathered rock is very difficult to distinguish from similarly fractured and weathered parts of the Maitlen Phyllite or the thin-bedded strata of the lower part of the Metaline Limestone. Examples of the latter can be seen in roadcuts along the main paved highway 1½ to 2½ miles northeast of the Grandview mine where slate and limestone are in fault contact along the Slate Creek fault. Fractured and weathered Ledbetter Slate and Maitlen Phyllite bordering the Slate Creek fault in the northeastern part of the district are likewise difficult to separate at many places, especially in the area about one-half mile southeast of the Slate Creek Lookout.

FIGURE 12.—Ledbetter Slate, east bank of the Pend Oreille River one-half mile north of Z Canyon. Slaty cleavage well developed; bedding planes not recognizable.

Veins of calcite occur widely distributed in the slate; they commonly range in thickness from a fraction of an inch to about 6 inches, but some, such as those exposed along the banks of the Pend Oreille River north of the Pend Oreille mine, are as much as a foot or more thick. Fine-grained pyrite is found at many different places and stratigraphic positions in the slate, although it is especially abundant in the lowermost few hundred feet of the formation. It occurs disseminated in the rock and along joint and fracture planes. Milky quartz veinlets locally cut the slate. Some slate in and bordering faulted and strongly fractured zones is silicified to a dense black rock, part of which is a silicified slate breccia.

The Ledbetter varies widely in calcium carbonate content; over wide areas it is a noncalcareous argillite or slate, but locally it contains beds and zones of dark argillaceous limestone. Many beds vary markedly in their limy content within short distances along strike. This is well seen in the strata along the banks of the Pend Oreille River north of the Pend Oreille mine, where the relatively flat-lying limy beds have been, in general, more resistant to erosion than the argillite or slate and stand out in marked relief. The black limestone beds locally attain a maximum thickness of 10 feet. The weathered surface is usually a medium gray. At many places the limestone beds, and also some beds of hard argillite and limy argillite, pinch and swell abruptly, giving the appearance of twisted lenses or huge "logs" with rounded ends. Some beds exposed along the Pend Oreille River banks can be recognized as isolated segments of broken strata. A few are tightly folded on a small scale. These lens-like and folded strata represent, in large part, relatively competent beds deformed during slippage along bedding planes or local low-angle thrusts. Commonly the rock immediately bordering these bodies is a black slate in which fracture cleavage is well developed. A few markedly limy "logs," however, occur in undisturbed strata, and these probably are the result of differential erosion of an inherently irregular limy lens.

Black thin-bedded shale, rich in graptolites, is present locally in the lower 75-foot section of the Ledbetter. Rocks of this section are well exposed on the surface above the portal of the Cascade adit of the western Pend Oreille mine workings and along the western bank of the Pend Oreille River about 450 feet south of the Yellowhead fault (pl. 1). This richly fossiliferous zone is also exposed in the lower part of the main ventilation raise in the eastern workings of the Pend Oreille mine.

Lenses and thin beds of fine-grained black and, rarely, light-gray quartzite occur in the lower half of the Ledbetter Slate and are most abundant in the interval between 1,000 and 2,000 feet above the base. This rock is prominently exposed east of the highway bridge across Slate Creek, at a locality a short distance north of the mouth of Threemile Creek, and at several places east of Lead Hill. The largest and most prominent bodies of quartzite are strongly fractured and cut by networks of white quartz veinlets. The quartzites are massive rocks, and only in a few scattered places can a faint compositional or color layering be recognized. They are mainly lenses from 10 to 50 feet thick, but a few beds ½ to 6 inches thick have been seen in drill cores. The rock consists mainly of subrounded to rounded grains of quartz from 0.1 to 0.5 mm in diameter. Interstices are filled with quartz and cloudy carbonaceous material, and locally some calcite. A few small grains of pyrite or marcasite occur locally. The black quartzites were originally muddy, and locally slightly calcareous, sandstone, probably deposited in pockets and channels on the sea floor.

Dolomite is uncommon in the Ledbetter Slate. Two long lenses of dolomite crop out on Bluebird Ridge and on the northern slope of the hill about three-fourths of a mile to the northeast (pl. 1). The rock is a highly fractured recrystallized medium- to coarse-grained gray dolomite that is locally cut by a network of quartz veinlets. The two bodies apparently lie within black slate, although the larger body is downfaulted against black quartzite on the northwest. The dolomite is probably within the upper 500 feet stratigraphically of the Ledbetter. The lens on Bluebird Ridge attains a maximum thickness of about 100-150 feet; the northern one is probably slightly less. The third occurrence of dolomite is a very small body of medium- to dark-gray, brecciated, and silicified dolomite exposed by bulldozer on the south side of the trail (old road) about 1,500 feet northeast of the northernmost Tedrow prospect shown on plate 1. This rock is similar to parts of the dolomite breccia commonly found in the upper 150-foot section of the Metaline Limestone. The rock is not part of the Metaline, however, because even though exposures are poor in the area, it is surrounded for several hundred feet by fragments of black slate, and there is no evidence of faulting in the slate-dolomite contact nearby. This lenticular body of brecciated dolomite and the two long lenses of dolomite to the south probably represent original limestone or dolomitic lenses that were dolomitized much later during the main period of hydrothermal action related to the formation of the ores. This interpretation is based on the fact that elsewhere in the district coarse recrystallized dolomite containing abundant quartz was formed by hydrothermal action. The dolomite body near the Tedrow prospects lies stratigraphically within the lower few hundred feet of the Ledbetter section.

The Ledbetter Slate in the large area extending from Beaver Creek north to Brushy Ridge (pl. 1) is somewhat different lithologically from the slate found to the east and southeast along Slate Creek and the Pend Oreille River as far south as the Grandview mine. The lower parts are similar in both areas, but the upper 900 to 1,000 feet of the Ledbetter is markedly more limy and sandy than equivalent beds along Slate Creek and the Pend Oreille River. Strata composing the lower part of the Ledbetter are exposed chiefly west and southwest of Ledbetter Lake in cuts along the road to Russian Creek, where a black fractured slate is the dominant rock type. Graptolites are found locally in these cuts, some replaced by pyrite. Bedding planes are difficult to recognize in this area, although, locally, a faint banding in the slate suggests that the beds strike about north and dip 20°-30° W. The upper part of the Ledbetter section, determined almost entirely from float fragments, consists of about 300 feet of silty, sandy, limy, and dolomitic shales which weather to dull-grayish, yellowish, and reddish shades. Some of the strongly weathered rock is very light and porous as a result of removal of the carbonate content by ground water. Overlying the shales and extending to the top of the Ledbetter are black limy argillites which at many places weather to thin light-gray plates.

It is noteworthy that the black quartzite bodies and lenses of dolomite found in the Slate Creek area do not occur in the Brushy Ridge-Beaver Creek area or in any of the stratigraphically lower beds of Ledbetter sparingly exposed for a distance of one-half mile east of the road to Russian Creek. The nearest black quartzite body is about a mile east of the road to Russian Creek on the west bank of the Pend Oreille River about three-fourths of a mile south of the mouth of Slate Creek (pl. 1). The quartzite body lies south of a strong fault, and its stratigraphic position is not known.

Ledbetter Slate in Deer Mountain area.—In the extreme southwestern part of the mapped area (pl. 1) centering around Deer Mountain, the Ledbetter Slate is sparsely exposed, chiefly in small cuts bordering old roads and along the crests of ridges. Most of the rock of the steep eastern slopes is a black argillite, commonly iron stained and in places containing graptolites. A small part of the rock is limy. Farther west and at higher stratigraphic positions the black Ledbetter rocks contain many beds of dark-gray platy-weathering limestone. Some of the limy beds are markedly silty and weather to shades of red and brown. These limy and silty strata lie within the upper 1,000 feet or less of the Ledbetter.

About 2,000 feet due north of Deer Mountain the Sullivan Mining Co. in 1947 put down an unusually deep diamond-drill hole into the slate. This hole, collared at an altitude of about 3,160 feet, bottomed in Ledbetter Slate at a depth of 2,070 feet. Most of the hole was drilled with a plug bit, although at widely spaced intervals a total of 10 sections of slate was cored. The sections cored ranged in length from 1½ to 14½ feet. The company's generalized log of the core from this hole is as follows: "Dark gray to black carbonaceous shale. Numerous faulted and gougy zones, few leached and breciatted zones. Numerous calcite stringers and considerable pyrite and pyrrhotite scattered throughout the section." A survey of the hole at depth (Carlson and Maas compasses and acid etch) showed that it drifted southwest, and from a depth of 500 feet to the bottom of the hole the inclination ranged from 45½° to 55°.

Ledbetter Slate in Russian Creek area.—In the extreme northwestern corner of the district centering around Russian Creek are black argillites. considered as belonging to the Ledbetter, that are somewhat different from those found elsewhere. The rock is typically a black sandy argillite that, although fine grained, is nevertheless much coarser grained than the argillites of the Ledbetter found elsewhere in the district. Locally, the rock grades into argillaceous sandstone. The rocks are well bedded in contrast to the common indistinct bedding of the Ledbetter elsewhere. The individual beds are about the same thickness as those farther to the south and east. The argillite of this area is exposed at many places in cuts along the main dirt road south of Russian Creek. There the road roughly parallels the strike of the beds and only a small amount of section is exposed, although the rock is typical of most of the surrounding area. Freshly broken surfaces of the rock are black and commonly show thin (5 mm or less) gray to brownish layers and laminae. Some of the weathered rock is iron stained and markedly sooty; most of it has a gritty feel. Microscopic examination of one thin section of the typical rock shows it to be a sandy argillite in which dark undetermined argillic material constitutes about 60 percent and quartz 40 percent. The rock is made up of thin layers, lenses, and laminae of very fine grained black material separating anhedral to subrounded grains of quartz or quartz and dark material. The quartz grains range in size from 0.005 to 0.15 mm and average 0.02 mm. Most of the quartz has marked undulatory extinction. The few limestone beds that were seen in the Ledbetter Slate of the Russian Creek area are poorly exposed near the international boundary where they are interbedded with black argillite. The limestone is medium grained, poorly bedded, and ranges in color from light to dark gray.

The structural position of the argillites of Russian Creek is shown on section *B-B'*, plate 1. It is postulated that a block of Ledbetter Slate has been thrust over Maitlen Phyllite and at a later time downfaulted to the north along the Day fault. Strong evidence for this interpretation is given under "Structure." In such an environment it is not surprising that the Ledbetter rocks of the Russian Creek area are, as a whole, so much more deformed than rocks of similar age found elsewhere in the district. The stratigraphic position of these rocks within the Ledbetter Slate is not known, because neither the upper nor lower stratigraphic contact is present, and the rocks of the Russian Creek area contain no fossils or distinctive lithologic zones that can be even roughly correlated with other and better known parts of the Ledbetter. The argillite may represent a sandy facies of the Ledbetter which has been thrust for a considerable distance from its original site of deposition. Folds and the probable presence of undisclosed faults prohibit any definite statement regarding the total thickness of the sandy argillites. A diamond-drill hole put down in the valley of Russian Creek about one-fourth of a mile west of the western border of the area shown on plate 1 bottomed in argillite at a depth of 1,135 feet.

AGE

Fossils, chiefly graptolites, are found at many widely distributed localities and stratigraphic positions in the Ledbetter Slate. Park and Cannon (1943, p. 21) present a list of fossils that includes 10 genera of graptolites, 1 brachiopod, and 1 crustacean. The graptolites definitely establish the Ledbetter as of Ordovician age, and according to Josiah Bridge, as reported by Park and Cannon, both Deepkill (Early Ordovician) and Normanskill (Middle Ordovician) faunas are present.

SILURIAN AND DEVONIAN SYSTEMS

Overlying the Ledbetter Slate in the northwestern part of the district is a thick sequence of black slates and argillites which contains a heterogeneous assemblage of limestone, conglomerate, sandstone, and quartzite lenses. The sequence contains fossils of both Silurian and Devonian ages. These strata form a discontinuous belt about 4½ miles long that extends from Limestone Hill on the north to the valley of Beaver Creek on the south (pl. 1). The belt attains a maximum width of 1½ miles in the area centering around Basalt Hill. Wide areas presumably underlain by these rocks are concealed by a thick covering of glacial material. The only prominent exposures are on Limestone Hill where limestone beds stand out in bold relief near the top of the hill on the eastern side; elsewhere in this belt the rocks crop out very sparingly as small and generally low patches, chiefly along ridges and on the summits of a few of the hills. By far the best exposures are along old logging roads, but even these are widely spaced and generally expose only a few feet of section. The fossils occur at a few places, but they are so widely separated and so little is known with certainty regarding the stratigraphic sequence of the area that the two ages of rocks are grouped together in this report. The rocks of this main grouping are, in general, even more poorly exposed than those of the older Ledbetter Slate, and the same factors mentioned on page 23 which prohibited a division of the slate into stratigraphic units apply to the Silurian and Devonian rocks of the area. Outcrops, exposures along roads, and patches of float fragments constitute less than 1 percent of the entire area of rocks of this unit shown on plate 1. Most of the rocks of this belt had heretofore been considered as part of the Ledbetter Slate, although Park and Cannon (1943, pl. 1 and p. 22) recognized the fossiliferous strata of Limestone Hill to be Devonian in age.

The thickness of the Silurian and Devonian unit is not known with certainty. Probably the thickest section lies in the folded and faulted area of Beaver Mountain and in the broad belt to the north centering around Basalt Hill. It is very roughly estimated that in this large area the strata attain a maximum thickness of about 2,000 feet, although exposures are very poor here and some of the few attitudes measured may be on small folds or due to drag along nearby faults; the northeast dip near the summit of Beaver Mountain could likely be the result of drag along the fault a short distance to the west.

The lithology of the bulk of the Silurian and Devonian unit is so similar to the Ledbetter Slate that a casual examination of random outcrops would fail to distinguish it from the Ledbetter; most of the unit, probably about 95 percent, consists of black carbonaceous slate and argillite that is identical to most of those of the Ledbetter. Interbedded with the black carbonaceous rocks are sparse and widely distributed beds and lenses, generally thin, of limestone, conglomerate, sandstone, and quartzite. A few of the limestone and black argillite beds are fossiliferous, some richly so, and it is largely on the basis of these fossils that the rocks are recognized and separated from the Ledbetter. The beds of conglomerate (fig. 13) are also distinctive features of the Silurian and Devonian unit, as no conglomerates are known to be present in the Ledbetter.

The black slates and argillites of the Silurian and Devonian unit are noncalcareous, in contrast to those of part of the Ledbetter Slate, which vary considerably in carbonate content. Individual beds and lenses of limestone, generally a few feet or less thick, are scattered through the unit. The thickest beds, some probably 25 feet or more, are on Limestone Hill. More precise estimates of the thickness of these particular strata cannot be made because bedding planes are very obscure and exposures are discontinuous. The limestones are commonly medium gray to dark gray. Most of the limestone, other than that on Limestone Hill, occurs as isolated lenses, rarely more than 2 feet thick. Where these lenses have not lost their original texture through recrystallization, they appear to be composed of broken fossil fragments and probably represent reef deposits.

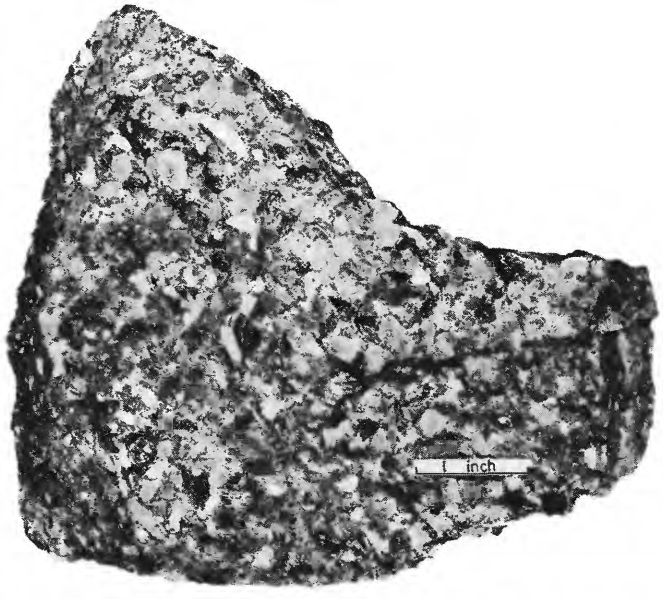

FIGURE 13.—Conglomerate from beds of Silurian(?) or Devonian age. East slope of Beaver Mountain.

Two main types of conglomerate, shown in figures 13 and 14, occur in the Silurian and Devonian unit. One of these, the limestone conglomerate, has been found at only one locality in the area mapped, where it is well exposed for a short distance in an old roadcut due east of Limestone Hill and about 200 feet west of the road to Russian Creek. The area is too small to show on the geologic map. About 8–10 feet of section is exposed in this roadcut; but the nature of the underlying and overlying strata is unknown, as glacial deposits and forest mat surround the exposure. The conglomerate consists largely of pebbles and some angular fragments of gray limestone (fig. 14), ¼ to 2 inches in length, in a matrix composed of rock ranging from limestone to limy sandstone. The sand in the matrix is composed of subrounded to well-rounded grains of medium- to coarse-grained quartz. Some of the conglomeratic rock contains dark-gray quartz, black slate, and fragments of fossils. Many pebbles contain several fossils. Segments of crinoid stems and badly weathered colonial corals are readily recognized in many specimens. Associated with the limestone conglomerate are beds of bluish-gray even-grained limestone and a thinly bedded limestone and sandy limestone that weathers into a ribbed surface (fig. 15). It should be mentioned that this limestone conglomerate, or limestone conglomerate-breccia, should not be confused with an intraformational dolomite breccia that occurs in the northwestern part of the Metaline quadrangle (Park and Cannon, 1943, pls. 1, 10*B–D*) beyond the area shown on plate 1. The intraformational breccia is markedly different in appearance from the limestone conglomerate. It is well

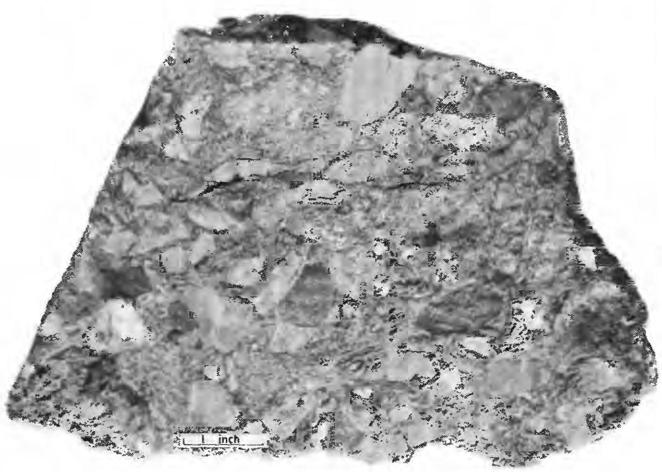

FIGURE 14.—Limestone conglomerate of Devonian age. Limestone fragments in a sandy limestone matrix. Small fragment of crinoid stem (light) can be seen in lower center part of specimen. Collected at same locality as figure 15.

FIGURE 15.—Weathered surface of interbedded limestone and sandy limestone of Devonian age. Thin sandy limestone beds stand out in relief. Collected in cut along old road (not shown on map) at easternmost edge of exposed rocks of Devonian age near Limestone Hill.

described and illustrated by Park and Cannon (1943, p. 22 and pl. 10), who tentatively assigned it to the Devonian; however, the recent work by Yates and Robertson (1958) in the Leadpoint quadrangle, west of the Metaline quadrangle, indicates that the intraformational breccias are Cambrian in age and are part of the Metaline Limestone.

The other main type of conglomerate in the Silurian and Devonian unit is widely distributed in beds and lenses a few inches to several feet thick. It is most commonly interbedded with black noncalcareous slate, although locally it is associated with thin beds of sandstone and quartzite. Float fragments and small outcrops of conglomerate are widely scattered over the slopes of Basalt Hill and the mountain to the west near Flume Creek, and, to the south, on the summit and eastern slope of Beaver Mountain. Individual beds of conglomerate and of coarse sandstone, as well as of intermediate grain sizes, were seen; although a relatively fine conglomerate, such as is illustrated in figure 13, is slightly dominant. All beds are composed of virtually the same rocks and minerals. Pebbles, fragments, and grains vary from round to angular, although the angular particles are more abundant than rounded shapes, especially in the matrix. The largest fragments are about 1 inch in length, the average is between ⅛ and ¼ inch. Some beds have approximately equidimensional grains showing all degrees of roundness and angularity. The coarse material consists of phyllite, black or gray chert, quartzite, vein quartz, sparse angular grains of fresh microcline, and some fragments of a soft dull white fine-grained rock composed of microcrystalline clay. This clayey rock may represent badly weathered slate or else rhyolite or tuff. The matrix of the conglomerates and coarse sandstones is similar in composition to the larger fragments, but it is much finer grained and contains much sericite and chalcedonic quartz as a binding material. Some specimens examined show late quartz veins and matrix material recrystallized into coarse quartz. Finely divided argillaceous or carbonaceous material gives the rock its dark-gray color on freshly broken surfaces; weathered surfaces are commonly dull grayish buff. Some beds could well be termed graywacke. A characteristic feature of the rock is a distinct planar, but not linear, orientation of grains and pebbles; the coarser the rock the more pronounced the planar structure. At many places pebbles have lengths four times their diameters, and generally the larger the pebble the more elongate the shape. Commonly, the interstitial grains are neither oriented nor lengthened.

Erosion has removed an unknown thickness of section at the top of the unit. On Basalt Hill and the hill a short distance to the southeast (pl. 1) a flat-lying trachybasalt flow of probable Tertiary age rests uncomformably on black slate containing thin beds of conglomerate. The contact between the slate and trachybasalt is everywhere concealed, but the slate beds near the southern flow body dip moderately to gently south and suggest an angular unconformity between the slate and trachybasalt (pl. 1).

Two principal localities yielded fossils, the first a Devonian assemblage in limestone and the second graptolites of unquestioned Silurian age from argillite beds. Several other localities yielded fossils, mostly of a fragmental nature, whose ages are not known with certainty, although they are believed to be of post-Ordovician age. The first main fossil locality is on Limestone Hill (pl. 1), where part of the limestone strata are richly fossiliferous, especially those that crop out on the east slope of the hill about 150 feet below the summit. It was apparently from this locality that Park and Cannon (1943, p. 22) first recognized beds of Devonian age in the Metaline quadrangle. The following list of fossils is taken from these authors; the determinations and age assignments were made by G. H. Girty, of the U.S. Geological Survey.

Favosites sp.
  limitaris?
  limitaris? or possibly *Alveolites* sp.?
A small indeterminable zaphrentoid coral
Numerous large crinoid columnals
Fragment of *Fenestella*
Small orthoid, probably *Rhipidomella*
Leptaena? or some related genus
Plicated brachiopod, with a punctate shell, suggestive of *Retzia*.
Large ostracode suggesting *Parachites*

It should be noted that no fossiliferous strata were found at lower elevations on Limestone Hill or in the area a few thousand feet to the northeast which is shown on plate 1 as part of the Silurian and Devonian unit. It is this latter area that is closely associated in space with, and probably overlies, the limestone conglomerate previously described.

In a recent article by Enbysk (1956) reference was made to fossils collected from Limestone Hill. Enbysk states,

> The faunule is probably Middle Devonian (Onondagan). Previously unreported species are: *Thurammina* sp., *Aulacophyllum princeps*, *Hexagonaria* cf. *H. alternata*, *Coenites palmata*, and *Syringopora* sp. A reef environment is suggested. What is probably a new genus of Foraminifera related to *Endothyra* was secured.

The second principal locality, which yielded fossils of Silurian age, is 500 feet northeast of the summit of Horsefly Hill (pl. 1). There black argillite is intermittently exposed for several hundred feet along and bordering an old bulldozed road; some of this rock contains abundant graptolites. Many of the fossils are poorly preserved in strongly weathered dull-white slate, but elsewhere in this area relatively fresh specimens can be obtained in black slate. The graptolites of Horsefly Hill were identified by R. J. Ross, Jr., of the U.S. Geological Survey (written commun., October 1954), who reports as follows:

> This collection is of unquestioned Silurian age, although its exact position within the Silurian is not certain. Obviously incipient foliation of the enclosing rock has deformed almost all of the specimens so that their original proportions are altered. Identification down to species, which is essential for proper zoning within the Silurian, is almost impossible. Three species of *Monograptus* appear to be present, one of these possibly assignable to the subgenus *Rastrites*. These seem to be related to species which are not older than Middle Llandovery [Early Silurian] of the British section. Paradoxically there is also present a *Diplograptus* which is very similar to *D.* (*Orthograptus*) *truncatus* var. *abbreviatus*, which is a Lower Llandovery form.

In addition to the two principal fossil localities just described, the fossils listed below were collected and identified from five other widely separated localities.

The collections were made by Robert G. Yates and the identifications by Jean M. Berdan, both of the U.S. Geological Survey.

Locality No.	Fossils	Location (see pl. 1)
1	Rostrospiroid brachiopods, crinoid columnals.	1,635 ft S. 35° E. from summit of Horsefly Hill.
2	*Heliolites* sp., *Alveolites* sp., *Cystiphyllum*? sp., crinoid debris.	1,400 ft N. 10° E. from summit of Horsefly Hill.
3	*Thamnopora* sp., *Coenites* sp.	2,900 ft N. 85° W. from summit Horsefly Hill.
4	*Favosites* sp., (small corallites), *Cystiphyllum*?, cyathophyllid corals, colonial coral aff. "*Cystostylus*" *infundibulus* Whitfield, rostrospiroid brachiopods, beyrichiid ostracodes, bryozoa.	3,600 ft S. 53° E. from summit Basalt Hill.
5	Crinoid debris	3,250 ft S. 12° W. from summit Basalt Hill.

According to Jean Berdan (written commun., 1954), nearly all genera found in the five collections listed are long-ranging types that do not serve to distinguish between Silurian and Devonian. Edwin Kirk, of the U.S. Geological Survey, had previously examined these fossils and had stated to Berdan that all are post-Ordovician and pre-Carboniferous in age.

The fossils from these five localities are in lenses of dark-gray limestone that is composed largely of detrital material, and the fragmental character of the rock suggests deposition in a reef environment. Some lenses appear to attain a thickness of 20 feet although most are only a few feet or less thick. They occur interbedded with black argillite and lenses of pebble conglomerate; sandstone and quartzite beds occur locally in close association with some of the fossiliferous limestone strata.

In summarizing the fossil evidence, it appears that the beds near the summit of Limestone Hill are of Devonian age and the argillites located 500 feet northeast of the summit of Horsefly Hill are of Silurian age—all the other localities yielded fossils that are long-ranging types that do not distinguish between Silurian and Devonian. These facts, plus the absence of definite and traceable horizon markers in this large area, make it necessary to show these rocks on the geologic map as an undivided unit of Silurian and Devonian ages.

TERTIARY SYSTEM—TIGER FORMATION

The only deposits assigned a Tertiary age are those that are similar in character to the Tiger Formation as described and named by Park and Cannon (1943, p. 23). Only two small erosional remnants of these rocks are large enough to show on the geologic map; they lie a few hundred feet north of the Hanley prospect in the northwestern part of the district where they rest unconformably on Metaline Limestone. Other croppings of the Tiger Formation, generally less than 50 feet across, were found to the south at several places; the two most conspicuous are in an old roadcut 2,000 feet northeast of the Cliff mine and on the crest of the slate-covered hill about a mile southwest of the old town of Metaline.

The maximum thickness of the Tiger is less than 50 feet, although 15 miles farther south near the town of Tiger the beds attain a maximum thickness of about 1,000 feet (Park and Cannon, 1943, p. 23).

The Tiger Formation consists of ill-defined beds of conglomerate, sandstone, clay, some lignitic material, and fragments of many other rock types. The composition of the beds changes markedly within short distances depending largely upon the underlying rock. Fragments of black slate of the Ledbetter are especially conspicuous in the rock near the Hanley prospect and on the hill southwest of Metaline. The beds were deposited in shallow water under nonmarine conditions. The crude sorting and angular to subangular shapes of the fragments, as well as the similarity of the material to the underlying country rock, indicate that the source of the material was nearby.

No fossils were found by the authors of the present report, but farther south, beyond the limits of plate 1, Park and Cannon (1943, p. 23) collected mainly poorly preserved leaves which were identified by R. W. Brown, of the U.S. Geological Survey, as *Sequoia* sp., *Quercus* sp., *Trochdendroides* sp., and *?Laurus* sp. Brown stated to Park and Cannon that this material did not lead him to any definite specific determinations or conclusions as to age. Park and Cannon, however, assigned a Tertiary age to these beds, chiefly because they are slightly deformed and considerably more consolidated than any nearby known Pleistocene strata.

QUATERNARY SYSTEM

The Quaternary sediments are mostly unconsolidated lake deposits, glaciofluvial deposits and glacial till of Pleistocene age, and alluvium of Recent age. By far the more widespread are the Pleistocene deposits. They conceal about one-fourth of the bedrock of the region, and may underlie much of the thick mat of forest debris that is present in many areas.

The tentative history of Pleistocene deposition, as disclosed in this small part of a much larger region, indicates the following sequence of main events. Till and glaciofluvial material were deposited over the area during the advance and retreat of the Cordilleran ice sheet in late Pleistocene time. As the receding glacier thinned in the Pend Oreille River valley, melt water deposited glaciofluvial sand and gravel along the ice margins. When the glacier had melted from the center of the valley, but while ice still blocked the valley somewhere north of Metaline Falls, a lake was formed between this ice and another glacier lobe in the vicinity of Newport (Flint, 1936). This glacial lake drained southwestward into the Little Spokane River (Large, 1924). At least two levels of the lake are recorded in the valley by terrace deposits of silt, sand, and some coarser material. Kettles found in all the Pleistocene deposits indicate that remnant blocks of stagnant ice were present locally; some blocks may have been carried into the lake from nearby sources. Although by far the bulk of the glaciofluvial material formed before the lake sediments were deposited, some continued to be deposited by the swift moving melt waters of local retreating masses of ice in the high regions that bordered the lake.

GLACIOFLUVIAL AND TILL DEPOSITS

Deposits of poorly sorted and unconsolidated, or slightly consolidated, glacial debris is widely distributed in the Metaline district. These glacial deposits, of which only the larger areas are shown on plate 1, lie chiefly at altitudes above the lake deposits where they commonly form wide and erratically distributed belts in the broad valleys, such as those of Styx, Slate, and Flume Creeks. The deposits consist of a wide variety of rocks that range in size from silt to large boulders, although sizes smaller than cobbles are predominant. No distinction is made on the geologic map, plate 1, between till and glaciofluvial material, although the bulk of the material is classed as glaciofluvial, for most of it shows some evidence of transportation and deposition by the melt waters from the waning glaciers. The glaciofluvial deposits are especially well exposed in an excavation for road material a short distance east of Slumber Creek on the south side of the road to Slate Creek. Many of the streams are bordered by a dissected terrace of glaciofluvial debris.

Small patches of till and boulder erratics occur on nearly all the highest mountains in the mapped area. Some boulders are 10 feet or more in length. A few depressions in the glacial debris are partly filled with silt. Park and Cannon (1943, p. 35) report finding a granitic erratic on Crowell Ridge (about 5 miles southeast of Uncas Gulch, pl. 1) at an altitude of about 6,500 feet, which is about 1,500 feet higher than any part of the area mapped during the present investigation.

LAKE DEPOSITS

Glacial lake deposits extend the entire length of the valley of the Pend Oreille River where they form a belt that is 14 miles in length and averages 1½ miles in width (pl. 1). Similar deposits extend at least several miles northward into Canada, and to the south of the Metaline district they occur as far as Newport, a total known distance, therefore, of about 75 miles. The sediments consist of poorly consolidated buff silt and fine sand that locally contain thin beds and lenses of silty clay and pebbles and at a few places cobbles and boulders. The sediments slump readily and good exposures are confined almost entirely to roadcuts. The best exposures in the district are along the main highway a mile south of Metaline, along the road to the Main Lehigh quarry, and in cuts along the first one-half mile of the road to Russian Creek after it leaves the main paved highway north of Metaline. Two well-defined terraces are developed in the lake deposits—one at an altitude of 2,100 feet and the other at 2,575 feet. The sediments rest unconformably on a marked erosion surface cut on the Metaline and Ledbetter Formations. Locally, the lake deposits interfinger with glaciofluvial material.

The lake deposits range in thickness from a thin veneer measured in inches to known thicknesses of several hundred feet. One drill hole (Grandview 308) located 1,800 feet northeast of the portal to the Grandview mine bottomed in silt at a depth of 435 feet. Several other holes in this area cut 200–300 feet of silt before reaching bedrock. Except at a few places where slump is strongly suspected, the lake beds are horizontal or else dip only a few degrees, generally toward the center of the Pend Oreille River valley.

Terraces in the lake deposits.—The two main terraces, previously mentioned as occurring at altitudes of 2,100 and 2,575 feet, are among the most conspicuous topographic features of the entire district. The town of Metaline Falls is situated on the low, or 2,100-foot, terrace. The high, or 2,575-foot, terrace is especially well preserved on the east side of the Pend Oreille River from the Grandview glory hole north to Lime Creek, a distance of 7 miles. A dissected remnant of a terrace at an altitude of about 2,425 feet occurs locally south of Pocahontas Creek. Kettles, some as much as 700 feet in length and 100 feet in depth, are scattered through the lake deposits. These kettles are especially common in the area that lies between the main highway and the mouth of Lime Creek in the northern part of the district (pl. 1). These depressions, which commonly show coarse gravel and cobbles scattered on the surface, are believed to have been formed by the melting of large stagnant ice blocks.

Little is known to the authors regarding the regional extent of the two main terraces that are found in the Metaline district. The low terrace is not recognized with certainty in the mapped area north of Metaline Falls, although at Newport, 65 miles south of Metaline Falls, Flint (1936, p. 1880) recognized a terrace at 2,100 feet altitude, which he describes as the upper limit of silt deposited in a lake dammed by ice lobes to the north and east. The high terrace extends north into Canada for at least several miles and possibly much farther. According to Park and Cannon (1943, p. 35), the high terrace is poorly defined and indistinct south of Ione. They state that this terrace ranges in altitude from 2,500 feet in the south (probably at Ione) to 2,600 feet in the north. Work of the present investigation aided by a more accurate base map indicates that the upper reaches of the high terrace in the area mapped for plate 1 maintain a fairly uniform altitude of 2,575 feet from north to south.

The present writers have little to add to the previous ideas of Park and Cannon (1943, p. 35, 36) regarding the origin of these deposits, and agree that it is difficult to explain their origin other than as a deposit in ponded water. The high-terrace deposits are older than the low-terrace deposits that Large (1924) and Flint (1936, p. 1880) believe were formed in glacial Lake Clark which had an outlet at Newport.

ALLUVIAL DEPOSITS

The more extensive alluvial deposits, which are of Recent age, are confined chiefly to the valley of the Pend Oreille River, although most of the other stream bottoms are bordered throughout parts of their courses by narrow bands or patches of silt, sand, and cobbles. Only the larger deposits are shown on the geologic map (pl. 1). The largest deposits lie south of Metaline Falls along the west bank of the Pend Oreille River, especially at the old town of Metaline, where a belt that includes the islands in the river is about three-fourths of a mile wide. North of Metaline Falls the Pend Oreille River is actively cutting into the bedrock and relatively few alluvial deposits are present. Many are very temporary deposits that are partly to completely modified by the annual spring flood waters. Some of the more persistent ones, which are commonly referred to as bars, have been periodically worked on a small scale for placer gold; examples are the Schierding and Harvey bars on the east bank of the Pend Oreille River north of the mouth of Slate Creek (pl. 1). Although most of the deposits consist largely of silt, sand, and pebbles, some contain cobbles and boulders as much as 3 feet or more in diameter. The larger size material is a heterogeneous mixture of igneous, metamorphic, and sedimentary rocks, many of which are foreign to the immediate area and probably represent debris either brought in from Canada by the ice sheet and reworked by the river waters or carried into the area along stream channels that drained southward before the main period of glaciation. A few cobbles and boulders of quartzite seen along the east bank of the Pend Oreille River near the Schierding placer show distinct percussion markings.

Other deposits of Recent age are slope wash and soil, which in places cover broad areas. Silt and sand of the lake deposits have commonly slumped and washed down many slopes to form a thin veneer that conceals the bedrock.

IGNEOUS ROCKS

Igneous rocks are very scarce in the area mapped. They consist of scattered dark mafic dikes and one flow of olivine trachybasalt (pl. 1). However, the Kaniksu batholith, which is of probable Cretaceous age and for the most part of quartz monzonitic composition, lies a few miles to the south. Outlying bodies of the batholith, are found a mile or less from Sand Creek in the southeast, and Lost Lake in the southwest. (See Park and Cannon, 1943, pl. 1.) About 4 miles north of the Metaline district, in Canada, 2 fairly large granitic stocks crop out in the areas centering around Swift and Lost Creeks (Little, 1950, geologic map; Fyles and Hewlett, 1959, fig. 2). Little assigns these stocks to the Nelson intrusions of Cretaceous(?) age. Fyles and Hewlett (1959, p. 42), although making no attempt at regional correlations, state, "Most of the granitic rocks are regarded traditionally as part of the Nelson intrusions, which, from relationships outside the Salmo Area, are post-Lower Jurassic and pre-Upper Cretaceous in age."

DIKES

Lamprophyre dikes are widely, but very sparingly, exposed throughout the district from Lunch Creek in the south to Boundary Lake in the north. Numerous drill holes, likewise widely distributed, have cut dark rock at varying depths. The dikes that are exposed range in thickness from 1 inch to about 10 feet, averaging 2–3 feet. One dike on Boundary Ridge (pl. 1) is known to have a length of about 2,000 feet, although most dikes are believed to be less than 1,000 feet. The widespread forest mat and glacial covering may be largely responsible for the apparent shortness of many dikes, as they can rarely be traced by outcrop and float fragments for more than a few hundred feet.

Insofar as it could be determined, most dikes are steeply dipping bodies that strike northeast roughly parallel to the prominent regional trend of the fractures and many of the faults (pl. 1). A northward-striking dike, 1,100 feet south of the Lucky Strike mine near the mouth of Slate Creek, has clearly been emplaced along an older fault (pl. 1). The walls of the dikes are sharp, and chilled borders are rare. Some dikes are offset a few feet by faults, whereas in others, movement along the dike walls is shown locally by disturbed zones a few inches wide in Ledbetter Slate.

The dikes cut both Ledbetter Slate and Metaline Limestone, but they are more abundant in the slate. The greater relative abundance in the slate is believed by the authors to be largely a matter of happenstance of exposures rather than signifying any difference in the two host rocks that might cause a greater abundance of dikes to form in the slate rather than in the carbonate rock.

The dikes vary somewhat in color, although most are a medium to dark greenish gray; weathered surfaces are shades of dull green, commonly stained with iron hydroxides. Many are fairly uniformly fine grained; some, however, are markedly porphyritic. One dike near the Sanborn prospect in the northeastern part of the district has a fairly uniform medium-grained granitoid texture. Thin sections of a few dikes show that the rocks consists chiefly of altered plagioclase, augite, biotite, and magnetite. Olivine and hornblende occur in some dikes. Secondary minerals, which may be abundant locally, include chlorite, epidote, serpentine, and calcite. A fibrous zeolite, probably thomsonite, is found in the dike near the Sanborn prospect. Minor constituents are quartz, white mica, pyrite, and apatite. Several dikes contain abundant phenocrysts of fresh shiny biotite; a few others contain phenocrysts of olivine, augite, or hornblende.

OLIVINE TRACHYBASALT FLOW

Erosional remnants of an olivine trachybasalt flow cap Silurian and Devonian rocks on Basalt Hill and the hill a few hundred feet to the southeast in the area a mile northwest of Ledbetter Lake. These flat to gently dipping bodies trend northwest for a distance of 3,000 feet and apparently rest unconformably on southward-dipping beds of the Silurian and Devonian rocks, although the contact between the 2 units is everywhere concealed by talus. The maximum thickness of the flow is about 200 feet.

The rock is typically aphanitic to fine grained and dark grayish green to black. In places, weathered surfaces are dull brown. Vesicles occur in a part of the rock at the northern end of the larger body on Basalt Hill. A thin section of the typical rock from the south hill shows very small crystals of clinopyroxene, olivine, and sodic plagioclase set in a matrix of glass, palagonite, and orthoclase. Clinopyroxene—probably augite—and olivine constitute nearly one-third of the rock, although clinopyroxene is far in excess of olivine. Sodic plagioclase in small (0.1–0.2 mm) laths constitutes about 22 percent of the volume of the rock. About 16 percent is glass, 13 percent palagonite, and 12 percent is orthoclase occurring interstitially or poikilitically enclosing placioclase and clinopyroxene. The remaining few percent consists of magnetite and (or) ilmenite, apatite, biotite, and limonite.

The trachybasalt probably represents a partially eroded flow of local origin that was emplaced along a northwest-trending zone of weakness related to the faults of similar trend that lie to the west, although exposures in the underlying slate are too sparse to definitely substantiate such a zone of weakness. However, the absence of bodies of trachybasalt in the higher hills to the west and elsewhere in the district suggests a local origin for these bodies rather than that the rocks are remnants of a widespread flow that formerly covered a much larger part of the district.

AGES OF DIKES AND FLOW

The precise age or ages of the dikes and flow are not known. The dikes are definitely younger than the Ordovician Ledbetter Slate which they cut. Park and Cannon (1943, p. 27) report that a few dark dikes cut the Kaniksu batholith of probable Late Cretaceous age. The dikes are tentatively assigned to the Late Cretaceous(?) or Paleocene(?) on the assumption that they formed shortly after the batholith solidified. The olivine trachybasalt is post-Devonian in age and probably is Tertiary.

STRUCTURE

General features.—The structure of the rocks of the Metaline district is complex. Several stages or pulses of deformation occurred which produced folds, thrusts, many moderate to steeply dipping normal and reverse faults, a large wedge-shaped graben, and intense local fracturing. The geologic map (pl. 1), reveals the pronounced northeast trend of most of the faults and folds. At many places deformation caused a recrystallization of the carbonate rock and the development of slaty cleavage in the argillaceous slate of the Ledbetter and of phyllite and schist in other formations. Additional structures, some perhaps of major significance, may be concealed beneath the widespread surficial deposits or obscured in some areas of scanty outcrops and heavy forest mat. Scores of minor faults are not shown on plate 1 because of scale limitation. Furthermore, at the time the district was mapped, long stretches of the gorge of the Pend Orville River were inaccessible to close observation, and some unmapped folds or faults may be present in these places. Nevertheless, the authors believe that most of the major structures have been brought out as a result of the district mapping. The area in which unrecognized major structures are most likely to be present is that covered by the broad belt of glacial deposits along the Pend Oreille River from Washington Rock south to Wolf Creek (pl. 1). In this area the few exposures indicate an excessively thick section of bedded dolomite that may be the result of repetition of strata by folds or faults or both; it is not unlikely that thrust faults related to those exposed in the Metaline mine are present in this area.

Major structures in the Metaline district and adjoining areas.—The outstanding structure of the Metaline district is a wedge-shaped graben bounded by the Flume Creek-Russian Creek faults on the west and the Slate Creek fault on the southeast (pl. 1). Within the graben the major structures include broad northeasterly trending and gently plunging folds and low-angle thrusts. These folds and thrusts are cut at many places by steeply dipping normal and reverse faults.

The major structures in the areas adjoining the Metaline zinc-lead district on the east, west, and south are shown on the geologic map and accompanying sections of Park and Cannon (1943, pl. 1). The strata, in general, strike northeast and dip moderately northwest. The larger folds, such as the Hooknose anticline and the syncline a few miles to the south, lie chiefly west of the Metaline mining district and show dominant northeasterly trends. Most of the faults strike either northeast or northwest. The Harvey fault, which is apparently the dominant fault of the region adjoining the Metaline district on the east, is a normal fault striking north to northeast, and has an apparent minimum stratigraphic throw of many thousand feet, because the Monk Formation and Gypsy Quartzite are cut out. The geologic map of Yates and Robertson (1958) shows the highly faulted character of the Leadpoint area, which adjoins the Metaline quadrangle on the northwest. It also shows the southwestward continuation of such major structures as the Russian Creek and Ridge faults and the Hooknose anticline. In Canada north of, and adjacent to, the Metaline district the work of Fyles and Hewlett (1959) indicates the dominant northeasterly trend of the major folds and faults. These regional maps show that an intensely deformed zone extends from the Leadpoint quadrangle northeast through the extreme northwestern part of the area shown on plate 1 and beyond into Canada for a total distance of at least 15 miles.

FOLDS

The pre-Tertiary rocks of the Metaline district are folded into a series of anticlines and synclines that range in size from a few feet or less to several miles across. The geologic map and accompanying sections show clearly that the dominant folds within the graben, or valley block, are broad and symmetrical, whereas some folds outside the graben and adjacent to the Slate Creek and Flume Creek-Russian Creek faults are tight and, in places, overturned. Within the graben most of the large folds and many of the smaller ones are cut, offset, and dragged along faults, and consequently fold axes are commonly discontinuous and difficult to locate precisely, especially in areas of sparse croppings or where bedding planes have been obliterated by alteration, recrystallization, and shearing. Undoubtedly, many more folds measuring a hundred to several hundred feet across are present than are shown on the geologic map; they are even more difficult to recognize than the major folds because of the rarity of local horizon markers in addition to the reasons just mentioned. Moreover, no certain criteria could be found for recognizing overturned beds other than the general stratigraphic relations. Where field evidence seemed to indicate that a structure could be interpreted equally well as a fold or as a fault, the authors have favored a fault because the number of faults that have been observed overwhelmingly outnumber the recognized folds.

Most of the major folds are in the large area extending from the international boundary south to Slate Creek and Beaver Mountain. There a series of anticlines and synclines plunge 20°–30° SW. Among this group are the Styx Mountain and Boundary anticlines and the Z Canyon and Beaver Mountain synclines (pl. 1). Both the Styx Mountain and Boundary anticlines are part of the large Sheep Creek anticlinal structure recognized north of the international boundary (Fyles and Hewlett, 1959, fig. 2).

A northeast-plunging anticline and syncline are known to be present under the glacial deposits north of the Grandview mine in the south central part of the Metaline district. These folds, both cut by many later faults, are recognized in the Grandview and eastern Pend Oreille mine workings and in many diamond-drill holes that were put down adjacent to the mines and also to the northeast for about 2 miles. Plate 2 and plate 3 clearly show the southern and better known parts of these structures, which plunge on the average about 10°–12° NE. The anticline, herein named the Grandview anticline, is known to plunge northeast as far as Threemile Creek. Incomplete data obtained from a few drill holes located north of this creek indicate that the anticline begins to rise gently to the northeast. A faulted syncline probably lies beneath the glacial covering west of the Chickahominy fault in the lower reaches of Beaver Creek (pl. 1, section *D–D′*), although this area is virtually unexplored by drill except at a few places along the borders. The steep westerly dip of the beds along the west bank of the Pend Oreille River in this area is probably the result of drag along the Chickahominy fault.

In the southern part of the district several broad and probably southwestward-plunging anticlines and synclines are indicated in the workings of the Metaline mine (pl. 4, section *A–A′*), although nearly all of these once fairly large folded structures have been so broken by later thrusts and high-angle faults that only a general pattern of the folds remains.

Only a casual examination was made of the many small folds seen in the narrow belt of Maitlen Phyllite bordering the mapped area and in the large area on Boundary Ridge where this rock crops out very sparingly. The Maitlen consists chiefly of phyllite, phyllitic limestone, schist, and thinly interbedded phyllite and quartzite which are commonly strongly contorted.

At many places the Ledbetter rocks have been deformed into either tight or open folds which are especially well seen in the mines and along the banks of the Pend Oreille River from the Pend Oreille mine north almost to Slate Creek. Some folds are recumbent and have been cut and offset by later faults. Drag folds that indicate movement along bedding planes occur locally, especially in the lower strata near or adjacent to the Metaline Limestone.

The beds of Ledbetter Slate in the Russian Creek area are highly deformed, locally being arranged in complex systems of folds ranging in size from less than an inch from crest to crest to many feet across. According to Robert Yates, of the Geological Survey, who mapped and studied this area, it is possible that folds hundreds of feet across may also exist, although the small area mapped and the scarcity of continuous exposures did not establish these large folds with certainty. Many folds are overturned isoclinal structures with pronounced plunge. The axial planes appear to have no systematic arrangement, which may be inherent or due to lack of sufficient data, but most fold axes trend northeast. North of Russian Creek most fold axes plunge to the northeast; south of the creek most of them plunge to the southwest. The plunges are gentle to moderately steep. Coinciding with this change in the direction of plunge is a change in the direction of dip of bedding. In general, dips of beds south of Russian Creek are toward the southeast; those north of the creek are toward the northwest.

Several folds were recognized in the narrow belt of rocks mapped east of the limits of the graben. A sharp syncline that can be traced for about 2 miles lies southeast of the Slate Creek fault in the area of Bluebird Ridge (Pl. 1, section *C–C′*). Southwest beyond this syncline for about 4 miles, the moderately to steeply northwestward-dipping strata that lie east of the Slate Creek fault are locally overturned. In places, these beds have been overturned by drag along some of the many faults in this area, but elsewhere, as indicated in section *D–D′*, plate 1, they are in an older and slightly overturned syncline which has been cut by the later Slate Creek fault. In the extreme northwestern part of the mapped area, the Hooknose anticline of Park and Cannon (1943, p. 29, and pl. 1) was recognized in the Gypsy Quartzite on the lower slopes of Russian Ridge. This anticline, which is overturned to the northwest and plunges southwest, can be traced southwest for about 8 miles into the Leadpoint quadrangle where it has been recognized by Yates and Robertson (1958) in the Gladstone Mountain area. Their map indicates a southwestward plunge of about 20°–25°.

FAULTS

Faults are abundant and widely distributed in the Metaline mining district. They range in length from 10 feet or less to many miles (Flume Creek and Slate Creek faults); most faults are moderately to steeply dipping, but a few are nearly horizontal. Their throw ranges from a few inches or less to 10,000 feet or more on the Flume Creek fault. Faults are especially abundant in the mine workings, as can readily be observed by reference to plate 5 and figures 17 and 37 of this report and plates 31 and 33 of Park and Cannon (1943). This apparent abundance is partly the result of good exposures in the mine workings and also is due partly to the more intense shattering and faulting of the rocks in the mineralized areas. Some further idea of this shattering can be realized from the fact that 42 distinct faults and breccia zones were observed in the core from drill hole U.S. 24 (pl. 3, section *C–C′*) over a vertical distance of 1,361 feet. Moreover, other faults are likely present in parts of the hole that did not yield core.

Many faults have smooth and slick surfaces either with or without striae or grooves; others have two or more surfaces separated by a filling of gouge or breccia or a mixture of the two. At many places movement is indicated by an irregularly bounded zone of breccia, or breccia and gouge. Only vague and generally unreliable relationships exist between the magnitude of displacement along faults and the degree of brecciation, grooving, and polishing. The presence of slate squeezed into a fault zone commonly, but certainly not everywhere, indicates moderate displacement, as determined from many such faults found in the mines. However, many weak-appearing faults, such as the Chickahominy fault where exposed on the 1700 level of the Pend Oreille mine (pl. 2), have fairly large displacements. Many faults are tight and are bordered by firm rock or compact breccia fragments; others have soft and porous rock along their borders, some of which serve as channelways for migrating surface waters, especially in carbonate rock near the surface where solution cavities are locally present. Mineralized cavities and caves, described on pages 49–51, are along some faults.

Only the principal faults are shown on the geologic map (pl. 1). Many of these are based upon anomalous stratigraphic relations or offsets; only rarely are fault surfaces exposed. Largely for convenience of description the faults are divided into five groups: thrust faults; faults that delineate the graben; principal faults within the graben; major faults in the Metaline, Grandview, and Pend Oreille mines; and faults in the area south of Wolf and Sweet Creeks.

THRUST FAULTS

METALINE THRUST

The Metaline thrust, named from the Metaline mine in which it is well exposed, is a low-angle fault along which Metaline Limestone has been thrust over Ledbetter Slate. This fault, which formed at a relatively early period in the structural history of the region, is cut by many younger faults as clearly shown on plates 4 and 5 and in section *A–A′* on plate 4. The Metaline thrust is entirely concealed at the surface under a thick covering of lake silts, although the upper part of one overthrust plate of limestone protrudes through the surficial deposits east of the Blue Bucket shaft (pl. 1).

In the Metaline mine, faulted segments of the Metaline thrust are distributed over a distance of 3,100 feet in a northwesterly direction from the Blue Bucket fault to drill hole 52; in a southwesterly direction the fault is indicated at many places over a distance of about 1,700 feet from the upper Blue Bucket workings to the workings off the South crosscut (pl. 4). The Metaline thrust is especially well exposed along the main haulage level a few hundred feet northwest of 56 raise (pl. 5). There the gentle and variable westerly dip of the thrust can be seen along the sides of the drift, and in places the fault plane, or sole of the thrust plate, is strikingly exposed in the roof of the tunnel where, locally, grooves that bear northwest are readily seen. A study of the markings and pits along the grooves failed however to show clearly whether the overlying limestone plate had moved northwest or southeast relative to the underlying black slate. Many diamond-drill holes, drilled from within the mine workings, show that the Metaline thrust has produced a highly complex fault zone at many places, especially in the South crosscut workings. Here sharp folds, repetition of strata, and wide zones of gouge and fractures are common. Some of the limestone beds in the South crosscut workings and also in the higher Blue Bucket workings to the north are streaked and banded by shearing action of the thrust (fig. 16).

The original areal extent and the initial attitude of the Metaline thrust are not known. Erosion has likely removed many segments in bordering areas, and the mine workings or drill holes disclose merely discontinuous parts of this fault, whose various strikes and dips probably do not indicate the original attitude of the thrust, but rather have resulted from movement

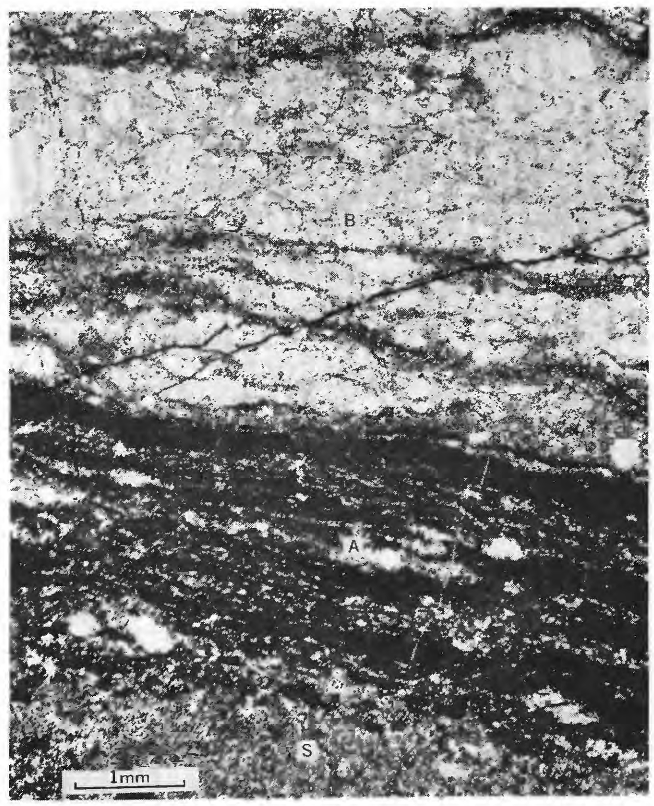

FIGURE 16.—Photomicrograph of zinc ore in thrust plate, Blue Bucket workings, Metaline mine. Very fine grained sphalerite (S) bordering and partly replacing layer of light- and dark-gray sheared limestone (A). Layer B is chiefly light-gray sheared limestone devoid of ore. Reflected light. × 12.

along the younger faults that have displaced the thrust. Moreover, the bearing of the few grooves seen along the Metaline thrust are probably of no major structural significance because of the likelihood that the individual fault blocks were rotated during the later period of deformation that produced the various segments. It is also probable that some segments of the thrust have not been recognized where older beds of Ledbetter Slate have been brought in fault contact with younger beds of the same formation.

The relation of the Metaline thrust to other faults of the region and to the ore deposits is discussed on pages 45 and 66, respectively.

WASHINGTON ROCK THRUST

The Washington Rock thrust can be seen or traced along both banks of the Pend Oreille River in the area east of Washington Rock and a short distance north of Metaline Falls (pl. 1). The thrust surface is exposed at one place on the east bank of the river where dolomite of the Metaline Limestone lies above, and in fault contact with, Ledbetter Slate. However, some of the main characteristics of this complex fault zone, described in more detail below, are best disclosed in drill holes put down in this area (fig. 17). The drill holes show two major thrust faults, one at the top and the other at the base of a wedge or layer of slate that lies in fault contact with Metaline Limestone.

Surface indications of the thrust.—The upper thrust is exposed during periods of low water level on the east bank of the Pend Oreille River 1,700 feet northeast of the mouth of Sullivan Creek. There, for a few feet, the nearly horizontal and undulating fault surface separates fractured dolomite from the underlying black and fractured graptolite-bearing slate of the Ledbetter. Surficial deposits extend far to the east from this cropping, and to the south they conceal bedrock for about 500 feet to the bluffs of dolomite along the riverbank. On the west bank of the river 3 small croppings of black slate occur over a distance of about 1,200 feet below bluffs of Metaline Limestone.

Drill holes that indicate the thrust.—The thrust has been cut by several diamond-drill holes in the area extending from a point near the highway bridge northeast to the exposure of the fault on the east bank of the Pend Oreille River. Many years ago short diamond-drill holes, put down from within the adit shown on plate 1 on the west side of the river a few hundred feet east of the bridge, cut the thrust at an altitude of about 1,985 feet. Likewise, the thrust was cut in drill holes put down from the bottom of the old Metaline Lode shaft (not shown on pl. 1), which is on the east side of the river about 400 feet southwest of where the fault is exposed at low water level. There the drill holes, which are relatively short, showed dolomite in fault contact with the underlying Ledbetter Slate at an altitude of about 1,815 feet. The principal structural data, however, relating to the Washington Rock thrust have been obtained from three fairly deep diamond-drill holes (U.S. 20, 21, and 22) that were put down in this area by the U.S. Bureau of Mines in 1944, a rotary hole (CS 12) drilled by the city of Seattle in 1958, and a churn-drill hole (W 15) on the Grandview property. (See fig. 17.) All holes were drilled vertically from surface locations. Drill hole U.S. 20 is about 25 feet south of where the thrust is exposed on the east bank of the river at low water level; drill hole U.S. 21 is at the portal of the Washington tunnel; drill hole U.S. 22 is collared on the north bank of Sullivan Creek 1,315 feet S. 80° E. of drill hole 21; and the other two holes (CS 12 and W 15) were drilled from much higher altitudes to the northeast. The main rock units cut by these holes are shown in sections *A–A′* and *A–B′*, fig. 17. The Washington Rock thrust extends northward to drill hole CS 12; beyond this point the thrust is shown dipping steeply beneath the Grandview mine. This northernmost projection is based entirely upon a driller's description of rock found in a churn-drill hole—Grandview W 15—drilled many years ago. The description, summarized below, admittedly leaves much to be desired. The hole collared at an altitude of about 2,525 feet and was drilled to a depth of 1,480 feet. It was in carbonate rock to a depth of 1,300 feet, where a gouge zone was cut. The remaining 180 feet of hole below the gouge zone was in dark-gray to black rock described as shale, shaly limestone, and calcareous shale, in part carbonaceous. This rock below the gouge zone is either Ledbetter Slate or the bedded limestone unit of the Metaline Limestone. The authors believe that it is Ledbetter Slate, because the dark color and carbonaceous character of the rock is far more characteristic of the Ledbetter than of the Metaline.

The drill hole records clearly show that a wedge of Ordovician Ledbetter Slate lies in fault contact with the overlying Cambrian dolomite and the underlying Cambrian phyllitic limestone and dolomite. They bring out the fact that the Washington Rock fault is not a simple thrust block of dolomite over slate as indicated by surface exposures, but is instead a highly complex fault zone, perhaps characterized by a series of imbricate faults far more complicated than is shown in the structure sections of figure 17. It is significant that the lower of the two thrusts locally brings younger strata over older. This relationship is in marked contrast to the upper thrust which brings the older rock over younger. These data suggest that the fault at the

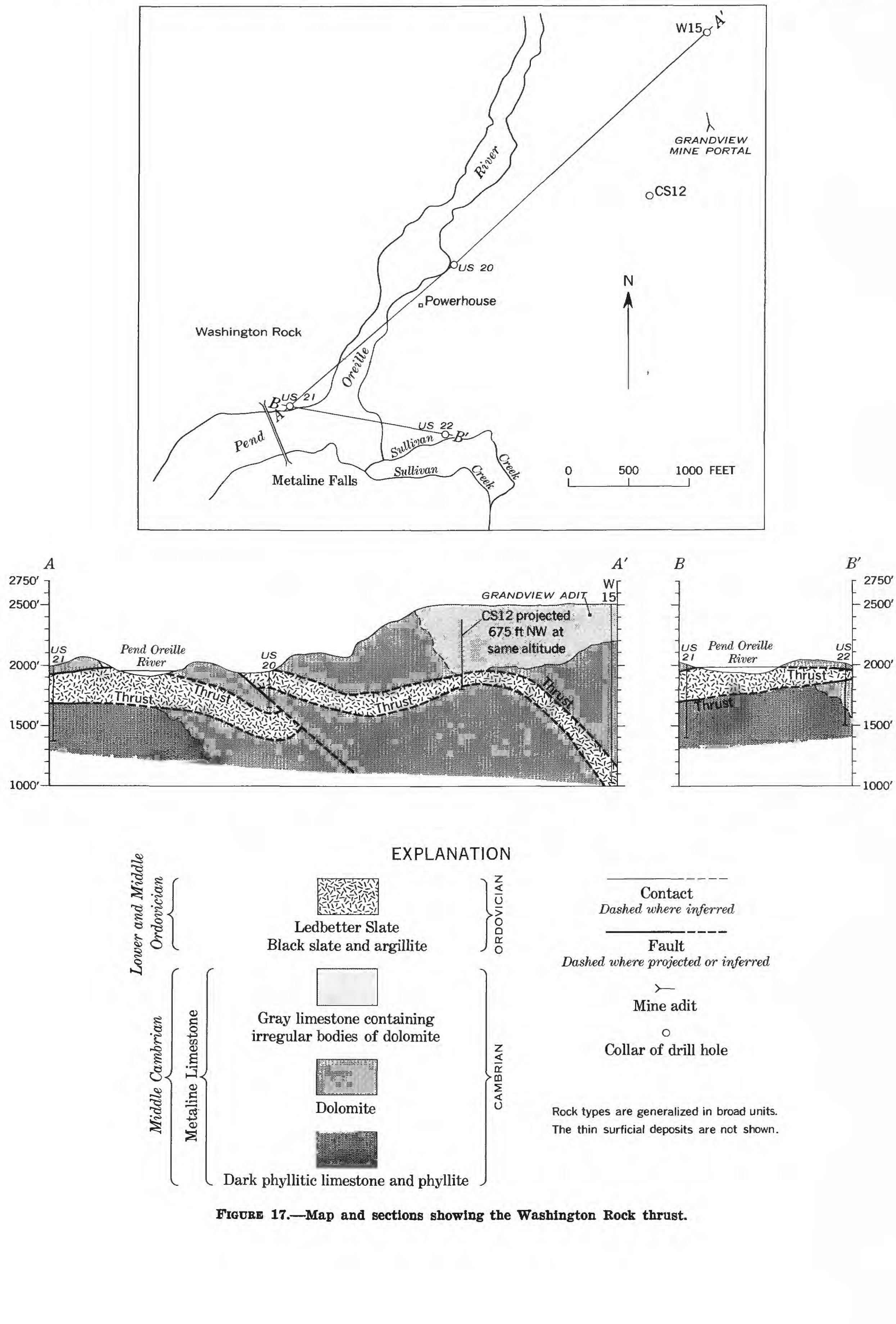

FIGURE 17.—Map and sections showing the Washington Rock thrust.

base of the slate wedge was initially a low-angle thrust that cut moderately to steeply dipping strata, perhaps beds that were tightly folded.

Southward extension of the thrust.—The extension of the Washington Rock thrust to the south beyond drill holes U.S. 21 and 22 is even more problematical than that to the north. Plate 1 shows the thrust projected southwest under the Pend Oreille River and the surficial deposits to a northwestwardly-trending fault where it is presumably cut off. The thrust may be offset to the south along this fault, although there is no certainty of this because of the wide and long belt of surficial deposits in this area. The rocks near the junction of the projected thrust and the northwestward-trending fault are exposed for several hundred feet in a deep roadcut. The rock is highly fractured and brecciated dolomite characteristic of a strong shear zone. No definite strike or dip could be determined for this wide shear zone, although a vague northwesterly trend appears dominant. At one place at the top of the roadcut, and inaccessible to close observation, a small patch of thin-bedded phyllitic limestone was seen in fault(?) contact with underlying dolomite. This unusual relation of phyllitic limestone above dolomite is probably a local expression of the complexities of structure near the junction of the two faults.

LEE THRUST

The Lee thrust, named from the prospect nearby, is exposed in the cliffs along the Pend Oreille River near the mouth of Slate Creek (pls. 1, 6). This fault, which dips gently to moderately south, brings Metaline limestone and dolomite over Ledbetter Slate. On the west side of the Pend Oreille River the upper plate of Metaline caps a conspicuous knob that rises nearly 500 feet above the river. Northwestward beyond the knob the thrust is traced with difficulty by scattered croppings and patches of float to where it passes beneath the glacial lake deposits. On the high knob about 950 feet southwest of the mouth of Slate Creek, drill hole CS 2 (not shown on map), collared at 2,208 feet, cut the fault at an altitude of 1,433 feet (depth 775 ft) passing from dolomite into Ledbetter Slate. Several northeastward-striking faults have deformed and offset the older thrust; the most prominent of these is the Ledbetter Lake fault (pls. 1, 6). On the east side of the Pend Oreille River the Lee thrust trends eastward up the steep slope for about 900 feet before it is concealed beneath a thick mantle of silt. Beyond this point the thrust probably swings to the northeast and crosses Slate Creek at one of the many places where bedrock is concealed. This tentative projection to the northeast is based upon a fractured zone and an abrupt change in the dip of the slate as seen in the core from a deep drill hole (U.S. 20) put down near Slate Creek Bridge. Under such an interpretation, older strata of slate are thrust over younger beds of slate in this area. Although data are very meager and inconclusive, it is possible that the Lee thrust is represented much farther to the northeast by the fault shown on plate 1 in the small area of exposures at the junction of Slumber and Slate Creeks. Nearby drilling has shown that this fault is a reverse rather than normal fault, but not enough data are available to determine the angle of dip of the fault plane in this area.

The maximum horizontal displacement and southward extension at depth of the Lee thrust are not known. It is possible, but the authors think unlikely, that the Lee thrust is the northern expression of a large folded and faulted thrust plate preserved in the graben and exposed 4 miles to the south as the Washington Rock thrust.

ARGILLITE FAULT

The Argillite fault, a thrust dipping gently (15°±) southward, is recognized a short distance north of Russian Creek in British Columbia (Fyles and Hewlett, 1959, p. 56–58, and fig. 2). This major fault is not exposed in the Metaline district, although as shown in section *B–B′*, plate 1, it is projected into the Russian Creek area where Ledbetter Slate is shown thrust over Maitlen Phyllite.

FAULTS THAT DELINEATE THE GRABEN

The large downdropped valley block, or graben, is delineated by the Flume Creek, Russian Creek, and Slate Creek—Blue Bucket faults (pl. 1).

FLUME CREEK FAULT

The Flume Creek fault, which forms a large part of the western boundary of the graben, has the largest known displacement of any fault in this area. The fault is everywhere concealed beneath surficial deposits, but its position can be fairly well established at many places by closely limiting croppings in both the hanging and footwall sides of the fault. The fault, as shown on the geologic map (pl. 1), follows a sinuous northerly trend from Lost Lake to the Gorge fault, a distance of about 12 miles. Park and Cannon (1943, pl. 1) show it extending 5 miles south beyond Lost Lake to about 1½ miles west of Ione. South of Ione the fault is probably cut off by the younger Kaniksu batholith. In the northern part of the district the Flume Creek fault is offset by the Gorge fault, and its northerly extension is know as the Russian Creek fault, described separately on pages 40–41.

The Flume Creek fault, which is downthrown on the east, brings strata of the Gypsy, Maitlen, and the upper part of the Monk Formations on the west against strata of the Metaline, Ledbetter, and probably the Silurian and Devonian on the east. In general, the strata west of the fault are very well exposed in steep and abrupt slopes, whereas the formations east of the fault are relatively poorly exposed in subdued topographic forms. This sharp break in topography can be especially well viewed from the Sullivan glory hole where westward-dipping beds of Gypsy Quartzite rise abruptly from the valley of Flume Creek.

The Flume Creek fault west of Horsefly Hill, although concealed by a belt of glacial material 1,200–1,900 feet wide, probably brings Gypsy Quartzite on the west against rocks of Silurian and Devonian age on the east, thus indicating an apparent stratigraphic throw along the fault of at least 12,000 feet, as all the Maitlen, Metaline, and Ledbetter Formations are faulted out. Just south of this area and extending for 2 or 3 miles to and beyond Beaver Creek are several faults roughly parallel to the Flume Creek fault. They are likewise downthrown to the east and are structurally related to the large downward movement along the Flume Creek fault.

Three diamond-drill holes (U.S. 43, 44, 45) located in a general northwesterly direction from the northwest bank of the pond 1,300 feet southwest of the Sullivan glory hole (pl. 1) furnish the only data available concerning the dip of the Flume Creek fault, for the fault plane is not exposed on the surface nor is it cut in any of the mine workings. These drill holes show that at this locality the Flume Creek is a normal fault with an eastward dip of somewhere between 40° and 85°. Wimmler and Cole (1949, p. 17, 18, and fig. 11) furnish the interested reader generalized information concerning the location and logs of these holes and offer an interpretation of the possible range of dip (40°–70°) of the fault plane. The authors of the present report believe, however, that a dip of as much as 85° is possible, and that it is probably about 75°–80° because of the long (180 ft.) brecciated zone disclosed in the core of hole 45. This brecciated zone strongly suggests that the course of the drill hole in the bedrock nearly parallels the fault even in its upper reaches.

RUSSIAN CREEK FAULT

The Russian Creek fault, which is believed to be, in part at least, the extension of the Flume Creek fault, lies in the northwestern part of the district in the vicinity of Russian Creek (pl. 1). This fault and the bordering belt of rocks have been studied in somewhat more detail than most other faulted areas in the district, except those in the mines, because of the rather unusual sharp bend in the trend of the fault and the metamorphosed nature of the Metaline Limestone in this region. A mild suspicion was held at the start of the geologic work in this particular area that the Russian Creek fault was an eastward- to northeastward-striking fault that merged with the Flume Creek fault somewhere under the glacial debris near the Canadian border on the west side of the Pend Oreille River. However, the present study, which was largely made by R. G. Yates and J. F. Robertson, of the U.S. Geological Survey, during their work in the district, shows that the Russian Creek fault trends sharply around the northeast end of Russian Ridge and, in general, follows the course previously shown by Park and Cannon (1943, pl. 1). It is virtually impossible structurally to project either the Russian Creek or Flume Creek faults, which have displacements measured in thousands of feet, northeast to and beyond the Canadian border, because the southward-dipping contact between the gray limestone and underlying dolomite of the Metaline Limestone trends with only a possible minor stratigraphic offset up the slope west of the river (pl. 1); no fault of such magnitude could cut through this area without offsetting the trace of this contact.

The Russian Creek fault can be traced west and southwest about 6½ miles beyond the mapped area into the Leadpoint quadrangle (Yates and Robertson, 1958). East of Russian Ridge the fault is shown trending southward for about three-fourths of a mile to a point where it is cut off by the Gorge fault, although a reference to plate 1 shows the wide and long belt of surficial deposits through which both the Russian Creek and Gorge faults are projected in this area. Probably in this area overturned beds of Gypsy Quartzite on the west are faulted against southwestward-dipping beds of Ledbetter Slate on the east. To the north around the nose of Russian Ridge and westward to the limits of the geologic map, overturned beds of Maitlen Phyllite are in fault contact with layered marble of the upper part (gray limestone unit) of the Metaline Limestone. The position of the fault in this northern area has been delineated largely by scanty croppings and float fragments near the fault, although at one locality, 1,100 feet S. 60° W. of the junction of the Russian Creek and Gardner Cave roads, only a few feet of covering separates the rocks on each side of the fault.

The structural relation between the Russian Creek, Flume Creek, and Gorge faults, and the tectonic forces necessary to produce these, are given under "Structural History." The geologic map and section B–B′

(pl. 1) show a postulated southerly dip to the Russian Creek fault as well as the relation of the fault to the Gorge and Flume Creek faults to the south.

SLATE CREEK FAULT

The Slate Creek fault, one of the major faults of the region, can be intermittently traced for about 16 miles from the Metaline mine northeastward to the international boundary (pl. 1). The southern part of the Slate Creek fault is locally known as the Blue Bucket fault because it is exposed in the Blue Bucket workings of the Metaline mine. The Slate Creek fault extends north into Canada for 2 miles, where it is apparently cut off by the Ripple Creek fault (Little, 1950, prelim. map). Diamond-drill holes indicate that the Slate Creek (Blue Bucket) fault extends half a mile south of the Metaline mine where it strikes north, but beyond this point the position of the fault under the thick mantle of lake silts is unknown. The steeply dipping beds of Metaline Limestone that lie east of the Slate Creek fault from Sullivan Creek northward for 2 miles form a conspicuous series of sharp ridges that trend roughly parallel to the fault and to the strike of the limestone strata. These ridges can be seen strikingly from the Shale quarry on Quarry Hill east of Metaline Falls. Elsewhere along its trend to the north there is no topographic expression of this major fault.

The Slate Creek fault strikes northeast and is downthrown on the northwest. In the Slate Creek area, Maitlen Phyllite on the southeast is faulted against Ledbetter Slate on the northwest, but from Uncas Gulch south to the area east of the Grandview mine the slate is against irregularly dolomitized beds of the lower unit of the Metaline Limestone (pl. 1). The Blue Bucket fault, which is well exposed in the Metaline mine, brings bedded dolomite of the Metaline on the east against Ledbetter Slate on the west; the slate west of the fault, in turn, is overlain by an older thrust plate of Metaline Limestone (pls. 4, 5). The minimum stratigraphic throw of the Slate Creek fault is about 7,000 feet near the Lead Hill mine (section *A–A′*, pl. 1). The throw apparently decreases somewhat to the southwest, as slate is faulted against stratigraphically higher beds in the Metaline mine. More precise statements on the throw of the fault cannot be made with the data at hand because the total thickness of the Metaline Limestone is not known for certain in the southern area; in the north, the precise stratigraphic position of the phyllite beds in the Maitlen Phyllite east of the fault has not been determined.

The Slate Creek fault throughout its long course is exposed at only two places, both along the main haulage level of the Metaline mine where dips range from 65° to 90° W. (pls. 4, 5). A calculated dip of about 80° NW. was obtained from a drill hole and a series of closely limiting surface croppings northeast of the Grandview mine. Throughout most of its course the fault probably dips steeply to the west. However, the trace of the fault in relation to the topography in the area extending about 3 miles and centering around Styx Creek vaguely suggests that the fault dips to the south and is therefore a reverse fault as postulated in section *C–C′*, plate 1.

PRINCIPAL FAULTS WITHIN THE GRABEN

The principal faults within the graben are described below. In general, the faults, or group of faults, are given from east to west, starting in the northern part of the district.

LEAD HILL FAULT

The Lead Hill fault, in the northern part of the district, extends from near the mouth of Slate Creek northeast to and beyond Lead Hill, a distance of 10 miles (pl. 1). It is a normal fault that dips 70°–85° SE. and throughout most of its extension brings Ledbetter Slate on the southeast against Metaline Limestone on the northwest. The fault plane is exposed at several places in adits and excavations but not in croppings. The fault is concealed for long distances beneath younger deposits of glaciofluvial material and lake silts from near the Whoopie prospect southwest to within a few thousand feet of the mouth of Slate Creek. The Lead Hill fault is offset a few hundred feet or less by several northward-trending faults and the westward trending fault east of the Slate Creek-Lookout on Lead Hill. In the vicinity of the Bunker Hill adit the fault has a minimum stratigraphic throw of 700 feet, which was determined by drill holes that bottomed in slate from surface locations southeast of the fault. The Lead Hill and Slate Creek faults bound a narrow graben, in places only 1,000 feet wide at the surface, that extends within the Metaline district from Lead Hill southwest for about 7 miles to the highway bridge across Slate Creek.

STYX CREEK FAULT

The Styx Creek fault, in the northeastern part of the district, is a major structure that roughly follows the northerly course of Styx Creek throughout most of its projected length of 3½ miles (pl. 1). In the Metaline district the fault is everywhere concealed under glacial deposits. In Canada it has been traced northward for 3 miles by Fyles and Hewlett (1959, figs. 2, 3, and p. 62). The Styx Creek fault is downthrown on the east; the dip is not known, but its straight course suggests a steep dip. Near the mouth of Styx Creek the fault brings younger beds of Metaline Limestone on the east against older beds of the same formation on the west, but farther north near the international boundary the throw of the fault increases greatly and Metaline bedded dolomite of the Styx Creek anticline on the east is faulted against Maitlen Phyllite on the west. In this area the stratigraphic throw of the fault is about 5,000 feet because the Maitlen strata on the west are several thousand feet below the top of the formation, and the bedded dolomite strata on the east are probably several thousand feet stratigraphically above the base of the Metaline Limestone.

DIVIDE FAULT

The Divide fault, in the north-central part of the district centering around Divide Peak (pl. 1), is an east-trending to northeastward-trending fault that can be traced westward about 4 miles from the valley of Styx Creek almost to the paved highway west of Slumber Peak. It is downthrown to the north, and throughout most of its extension Maitlen Phyllite and the lower bedded limestone unit of the Metaline Limestone on the south are in fault contact with Metaline bedded dolomite on the north. South of the fault on the long southern slopes of Divide Peak the steeply dipping bedded limestones are folded and cut by several northeastward-trending faults that branch from the main Divide fault. On Slumber Peak the western part of the fault branches and is offset by northward-trending faults.

The fault plane is nowhere exposed, but the approximate position of the fault is commonly marked by brecciated rock, shear zones, fractures, and coarse calcite in the bordering rocks as well as sharp changes in the attitude of the beds, and in stratigraphic offsets. The relatively straight course of the fault indicates a steep dip. The Divide fault cuts across and has markedly deformed, and in places obliterated, the southwestward-plunging Boundary anticline. The maximum displacement along the Divide fault is not known, although it is probably somewhere between 1,500 and 2,000 feet in the area of Slumber Creek. Section *C–C′*, plate 1, arbitrarily shows a stratigraphic throw of 1,200 feet to the fault on the western slope of Slumber Peak.

FAULTS OF THE DESOLATION MOUNTAIN AREA

Several northeast-trending faults cut dolomite and the lower bedded limestone unit of the Metaline Limestone over an area of several square miles centering around Desolation Mountain in the northeastern part of the district (pl. 1). The Desolation Mountain fault and the other two faults shown to the northwest are probably branches of the major Wilderness fault which, in general, brings bedded limestone on the southeast against dolomite on the northwest. The bedded limestone adjacent to the Wilderness fault is probably near the base of the Metaline Limestone. The dolomite on the northwest side of the fault lies at least 1,000 feet stratigraphically above the bedded limestone unit, and therefore the throw of the Wilderness fault is at least of that order of magnitude. No fault planes or brecciated zones are exposed along any of the faults of this area, and most of the structural interpretations have been made on the basis of abrupt stratigraphic changes and offsets of rock types.

FAULTS OF THE CONFUSION RIDGE-DOLOMITE MOUNTAIN AREA

A series of northeastward-trending faults is present in the northern part of the district in the area extending from Boundary Lake southeast to Confusion Ridge and Dolomite Mountain (pl. 1). The faults offset westward-dipping strata of the bedded dolomite and bedded limestone units of the Metaline Limestone. The main faults of this group are downthrown to the southeast, and as a result they account, by repetition of beds, for the unusually wide belt of the dolomite unit which extends eastward from Timber Hill 2½ miles to the southwestern slope of Confusion Ridge. Two of the faults in this group are shown in section *A–A′*, plate 1, where it is inferred that the stratigraphic throw of the western fault is 1,000 feet and the one to the east is 500 feet. None of the major faults is sufficiently well exposed to obtain the dip of the fault plane, although the generally straight trends as related to topography suggest steep or vertical dips. Strongly brecciated and fractured zones, some filled with coarse calcite, are present along some of the faults. The small group of northeastward-trending faults east of Boundary Lake show much evidence of tight shearing movement between individual faults. Although it is believed that the amount of displacement along these faults is small, they have nevertheless produced marked drag effects in the bedded limestone as the gentle southwestward-dipping strata to the east were dragged into steeply dipping northeastward-striking positions. (See pl. 1.) Some limestone beds found on the hillside about 1,200 feet south-southeast of Boundary Lake are so strongly sheared that they resemble schist.

KNOB FAULT

A fault that may be of considerable structural significance crosses the south side of a conspicuous knob 1,000 feet west of the paved highway and 2,000 feet south of Lime Creek in the north-central part of the district (pl. 1). This fault, herein named the Knob fault, is an isolated structural feature exposed for only about 1,400 feet along the strike; its continuations are masked by glacial deposits. The fault, or fault zone, brings a block of gently dipping gray limestone between dolomite as shown in section *C–C′*, plate 1. The principal displacement is down to the south on this eastward-striking and probably steeply dipping fault. The fault, although its surface is concealed under soil on the knob, is recognized by bordering brecciated and folded rock, a sharp ridge trending west from the knob, and the abnormal stratigraphic position of the limestone in this area of otherwise westward-dipping beds of dolomite. The displacement of the Knob fault may be far greater or somewhat less than that shown in the section, because the precise stratigraphic position of the gray limestone is not known for certain. The limestone is probably one of the lowermost beds in the gray limestone unit; it may perhaps be a relatively thin section of limestone of abnormally low stratigraphic position that escaped dolomitization, in which case the vertical displacement of the Knob fault would be less than that indicated in section *C–C′*.

Z CANYON FAULT

The Z Canyon fault, in the northwestern part of the district, can be traced and projected from Z Canyon northeast to the international boundary (pl. 1). Southwest of Z Canyon, the fault is projected under the glacial deposits for about 1½ miles beyond Pewee Falls, for the Silurian and Devonian strata on Limestone Hill northwest of the fault are in a downfaulted syncline bounded by the Z Canyon and Gorge faults.

The Z Canyon fault is exposed in a shallow cut near the sharp switchback on the road to the Z Canyon mine at a point about 1,300 feet northeast of the mine portal. There Ledbetter Slate on the west is faulted against Metaline dolomite on the east. A few square inches of the fault plane, dipping 75° SE., was exposed when visited. This very small surface is the only exposure of the fault plane in the entire region. West of the Z Canyon mine, the steep fractured overhanging cliff of dolomite along the riverbank also suggests a steep southeasterly dip, but no fault contact is exposed here between slate and dolomite. Southwest of the Pend Oreille River, slate is present on both sides of the fault. To the northeast on Forest Mountain near the Canadian border, the Z Canyon fault brings bedded dolomite of the Metaline Limestone on the east in fault contact with gray limestone of the Metaline on the west—a large section of bedded dolomite and the lower part of the gray limestone are faulted out in this area.

The precise throw of the part of the fault west of the Z Canyon mine is not known because the thickness of the slate section west of the fault is unknown; the dolomite and limestone on the east, or upthrown, side of the fault probably lie stratigraphically within the upper 200 feet of the Metaline Limestone. Section *A–A′*, plate 1, arbitrarily shows the slate-limestone contact on the downthrown side of the fault at a depth of about 350 feet below the river.

Considerable horizontal movement along the Z Canyon and especially the associated transverse faults is indicated by the offset patches of Ledbetter Slate in the embayment and ravines 600 feet south of the Z Canyon mine. There a small isolated patch of slate (pl. 1) is exposed on the riverbank; to the north slate is present in deep and narrow ravines eroded in sheared and partially recrystallized limestone. The offset movement along the faults produced the Z shape of the canyon in this area, as erosion of the canyon was guided by the faults.

MONUMENT FAULT

The Monument fault, which lies a short distance west of the Pend Oreille River near the Canadian border (pl. 1), displaces the contact of the gray limestone and bedded dolomite units of the Metaline Limestone several hundred feet or more in a small area of exposures near the south end of the fault. The fault is projected northward from this point under the glacial material to join a fault known to be present in Canada (Fyles and Hewlett, 1959, fig. 2) where, for about a mile, Ledbetter Slate (Active Formation) on the west is in fault contact with Metaline (Nelway) strata on the east. Several hundred feet north of Monument 187 the fault is marked by a zone of brecciated dolomite as much as 500 feet wide (1959, p. 61).

DAY FAULT

The Day fault, named from the Day prospect which is a short distance north of the international boundary (Fyles and Hewlett, 1959, fig. 3 and p. 61), is in the Russian Creek area in the northwestern part of the district (pl. 1). The fault trends northeast for a known distance of about 2½ miles. The Day fault is not exposed and is projected under glacial debris for most of its known length. The dip of the fault is unknown; it is shown as vertical in section *B–B′*, plate 1. This fault, as shown in section *B–B′*, plate 1, brings marbleized Metaline Limestone on the southeast against an overthrust block of Ledbetter Slate on the northwest. Data are too meager to postulate the throw of the fault, which is probably at least 1,500 feet.

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MAJOR FAULTS IN THE METALINE, GRANDVIEW, AND PEND OREILLE MINES

The major faults that have been cut in the mine workings or otherwise disclosed by diamond drill in the areas of the three principal mines are largely included under the description of the individual mines near the end of this report. Only a brief and preliminary mention will be made at this point regarding these faults. The Metaline thrust, in the Metaline mine, has already been described under the important group of thrust faults (p. 36).

In the Metaline mine the four principal faults are the Metaline thrust and the Blue Bucket (Slate Creek), Bella May, and West Contact faults, as shown on plate 4 and the accompanying structure section. The Metaline thrust is chiefly preserved in the graben formed by the northeastward-trending Bella May and Blue Bucket faults. The apparent dip slip along the Bella May fault, as postulated in the structure section, is about 1,075 feet; the dip slip of the Blue Bucket fault is a minimum of about 700 feet. The West Contact fault, a normal fault with a stratigraphic throw of about 200 feet, strikes north and dips about 30° W.

In the Grandview mine the only major fault recognized is the Grandview fault. This normal fault strikes northeast and dips at moderate angles northwest, as shown on plate 2 and section *B–B′*, plate 3. The minimum stratigraphic throw is about 100 feet where section *B–B′* is drawn. This break is one of the few persistent faults found in the mines which can be definitely recognized as occurring before mineralization. It can be traced northeastward into the workings of the Pend Oreille mine.

The principal faults of the Pend Oreille mine are shown on plate 2 and plate 3, where it is evident that most strike northeast. The principal fault is probably the Chickahominy with a throw of about 500 feet along section *C–C′*. It is a normal fault, downthrown on the west, which probably extends about 2 miles northeast beyond the present mine workings as shown on plate 1. It is a postmineralization fault that has raised the ore bodies east of the Pend Oreille River. The Y.A. (Yellowhead adit) fault is another major northeastward-trending fault of this area. It is vertical where seen in the Yellowhead adit and on the basis of drill holes it has a minimum throw of about 450 feet as shown in section *A–A′*, plate 3. This fault separates the Yellowhead ore body on the west from Ledbetter Slate on the east, and the throw of this fault may be far greater than the minimum just given.

An area of highly complicated structure lies 500–1,000 feet southwest of the Cascade adit in the steep canyon of the South Fork of Flume Creek (pl. 1). There a reverse type of fault, possibly a low-dipping thrust, has brought Metaline Limestone on the west over Ledbetter Slate on the east. Additional faults of younger age and diverse trends have further complicated the structure and have locally offset this reverse fault and cut it off at the north. Records of several drill holes put down by the Pend Oreille Mines and Metals Co. in this area show a complex repetition of slate, carbonate rock, and wide zones of breccia and gouge. The main reverse fault is projected 2,000 feet south of the canyon, as shown on plate 1, largely on the basis of repetition of slate and carbonate rock cut in drill holes near the south end of this fault. The reverse fault may be part of the older thrusts, such as the Metaline and Washington Rock thrusts, or else a relatively local feature resulting from compressive stresses developed during the settling of the valley block.

FAULTS IN THE AREA SOUTH OF WOLF AND SWEET CREEKS

Several faults are shown in the southern part of the mapped area south of Sweet and Wolf Creeks (pl. 1). This area is one that contains broad expanses of glacial covering and relatively few outcrops, and bedding planes are difficult to recognize with certainty in many of the croppings. However, stratigraphic relations, brecciated zones, and data obtained from some diamond-drill holes, have established the presence of several faults.

One of the principal structures is the Sand Creek fault (pl. 1), which has a vertical displacement of at least 5,000 feet, and probably more. This fault brings Maitlen Phyllite in fault contact with Ledbetter Slate on the east, and dolomite and bedded limestone of the Metaline Limestone on the west. The fault extends northeast from Sand Creek to Pocahontas Creek, a distance of about 4 miles; it is offset about 700 feet left laterally by the Wolf Creek fault, an east-trending fault downthrown to the south. The Sand Creek and Flume Creek faults in this area form the boundaries of a graben about 2¼ miles in width between Lost Lake on the west and Sand Creek quarry on the east.

The Lunch Creek fault, west of the Pend Oreille River, is poorly exposed in the valley along the upper reaches of Lunch Creek, where Ledbetter Slate on the east is in fault contact with dolomite (Metaline) on the west. The Lunch Creek and Lost Lake faults form a structurally high block that contains three large areas of dolomite separated by glacial material (pl. 1).

STRUCTURAL HISTORY

The structural history of the Metaline region is complex as pointed out in the earlier work of Park and Cannon (1943, p. 28). These authors, on the basis of their more regional study of the Metaline quadrangle, recognized an early stage of folding and thrusting followed by at least two periods of faulting. Park and Cannon (1943, p. 34–35) were unable to date all periods of deformation, although from meager evidence they believe that the early stage of folding antedated the intrusion of the Kaniksu batholith. They believe that compressive stresses were dominant during the early period of folding and that some of the folds broke into thrust faults. The thrusts were obscured by a later stage of deformation and their extent is therefore unknown. Following the folding and thrusting another stage of deformation produced a series of vertical or steeply dipping faults which could be attributed to either compression or tension. The last stage of faulting that these authors recognized produced faults of northwest trend, such as the Pass Creek fault zone. Following this introductory statement of the general structural history of the pre-Tertiary sedimentary and metamorphic rocks, Park and Cannon (1943, p. 28–35) describe the structures found in each of the following five conveniently separated units; namely, (1) Flume Creek-Russian Creek block, (2) valley block, (3) Hall Mountain block, (4) eastern block, and (5) Kaniksu batholith. These authors likewise present their interpretation of these structures along with that of other geologists.

The work of the present investigation has been restricted largely to the valley block or graben, which is wedge-shaped and bounded, in general, on the west by the Flume Creek–Russian Creek faults and on the east by the Slate Creek, Blue Bucket, and Sand Creek faults (pl. 1). Since the work of Park and Cannon, additional structures have been recognized in the Metaline district and in adjoining or nearby areas to the north and west. The authors of the present report, using this additional data, present somewhat different ideas regarding the structural events. Four stages of deformation, listed below from oldest to youngest, are believed by the authors to have occurred in the Metaline region:

1. Folding and faulting that resulted from dominantly compressive stresses.
2. Faulting that produced the graben, or valley block. The principal faults are believed to be the result of tensional stresses, although both tension and compression developed during the settling of the graben.
3. Faulting and folding that resulted from localized compressive stresses.
4. Faulting that produced faults, chiefly of westerly to northwesterly trends, which offset some of the older structures.

The most intense deformation occurred during stage one which produced the conspicuous northeastward-trending folds and the thrust faults, and during stage two, which produced the graben. Some of the folds and faults now seen in the Metaline district are the result of several stages of deformation, and therefore it is not possible to assign every individual fold or fault to a specific stage. Little is known precisely regarding the age of the first recognized stage of deformation (post-Devonian), the interval between the various stages, and the time of the last recognized period of faulting. However, most of the stresses are believed to be related to the Laramide orogeny, which probably extended over a long period of time. In the Metaline district enough time must be alloted to account for early folds and thrusts, formation of a large and deep graben, intrusion of the Kaniksu batholith (and formation of related ores), and, finally, deformation that produced offsets of some of the older structures and the ore bodies.

The first stage of deformation was characterized by compressive stresses, probably acting in a northwest-southeast direction, that folded the rocks into the large anticlines and synclines which are regional features of the Metaline quadrangle, the Salmo mapped area to the north (Little, 1950, prelim. map), and the Leadpoint quadrangle (Yates and Robertson, 1958) to the west. In the Metaline district the Boundary, Styx Mountain, and Grandview anticlines and the Z Canyon and Beaver Mountain synclines were initially formed at this stage, as were the Hooknose anticline and associated folds to the west of the district. Some of the strata, such as those in the Russian Creek area, were thrown into tight and, in places, overturned folds which formed belts of strongly deformed rock that can be traced for many miles from the Leadpoint quadrangle northeast into Canada. Low-angle thrusting occurred at many places contemporaneously with, and following the development of, the folds; at some localities older strata were thrust over younger ones (Metaline thrust), whereas elsewhere, younger beds were thrust over older ones (Argillite and Washington Rock thrusts).

These folded and faulted belts and low-angle thrusts are believed by the authors to be far more widespread and of greater structural significance than heretofore realized. Many of the thrusts have been eroded, but remnants preserved in the downfaulted blocks indicate that the Metaline, Washington Rock, and Argillite thrusts are distributed over a known distance of about 11 miles in the Metaline district. Bedding-plane faulting so commonly noted in the Metaline district is believed to be one of the results of this stage of compression. As explained under regional metamorphism (p. 51–52), the more intense deformation of the Maitlen Phyllite as contrasted with that of stratigraphically higher formations may be in part the result of deep-seated thrusting and compression. Although conclusive evidence is not at hand, it is likely that the deformed belt of rocks now cut off on the west by the Slate Creek fault (pl. 1, section *C–C′*) may have been initially folded during this first stage of deformation. Moreover, many of the northeast-trending fractures and shears, which are some of the most notable structural features of the graben, were probably formed at this stage, although modified somewhat by later periods of deformation.

Tensional stresses developed after the folding and thrusting. Dominantly northeast- to north-northeast-trending normal faults were developed along, and at low angles to, the belts of deformed rock. Some of the folds, especially those in the tightly deformed belts, broke along their crests. Many of the thrust plates probably were cut locally by these faults and at places segments were dropped into positions where they escaped later erosion, as, for instance, the Argillite thrust, which was dropped on the Day fault in the Russian Creek area. (See section *B–B′*, pl. 1.) In the area centering around the mouth of Slate Creek, northeastward-trending faults, including the Lead Hill and Ledbetter Lake faults, developed in large part at this stage of deformation, offset the Lee thrust, and cut at low angles across the axis of the southwestward-trending Boundary anticlinal fold.

Probably some of the many northeastward-trending faults that are such conspicuous structural breaks in the area mapped (pl. 1) may have developed as minor structural features in this period of deformation, although they are greatly modified during the formation of the graben. Likewise, many of the fractures which trend dominantly N. 40°–65° E. over the entire district, probably developed at this time.

The second stage of deformation, probably resulting largely from tensional stresses, produced for the most part a series of steeply dipping normal faults, many with large vertical displacements. The large valley block, or graben, formed at this time. The faults, typified in the Metaline district by the Slate Creek, Sand Creek, Flume Creek, and Russian Creek faults among the major structures, have dominant northerly to northeasterly trends. The Flume Creek fault cuts across the older folds (pl. 1), whereas part of the Slate Creek fault is parallel to a belt of northeastward-trending folds that formed during the first stage of deformation. As pointed out clearly by Park and Cannon (1943, p. 30), the dropping of the wedge-shaped block between two downward-converging faults, the Flume Creek and Slate Creek, resulted in many of the complex structures seen in this area. The graben preserved remnants of the older thrusts and folds that formed during stage one, although it modified them greatly in places. Both normal and reverse faults developed in profusion. Slippage along bedding planes occurred at many places, especially along the contact of the Metaline Limestone and the Ledbetter Slate. Brecciation and fracturing of the rocks and forcing of slate into carbonate rock are features that are commonly observed in the mine workings where these rocks are best exposed. Some of the older folds were probably differentially dropped during the settling of the graben, as indicated by the southwesterly plunge of the folds north of Slate Creek (pl. 1) and the northerly plunge of folds farther south in the vicinity of the Grandview and Pend Oreille mines (pl. 2).

Some of the north- to northeastward-trending faults that are so evident in the mapped area may have formed during this stage of deformation, although many of this group are probably older faults along which additional movement, including rotation, has taken place as the valley block was lowered and the rocks compressed. Remnants of the older thrust plates, such as the Metaline and Washington Rock, were further broken, folded, and offset by faults. Probably at a still later time during the settling of the graben block, faults of dominantly northerly trends branched from or offset the major Lead Hill and Slate Creek faults. The Styx Creek fault is likely a somewhat younger fault than the northeast-trending faults found on the slopes to the east and west. Plate 1 shows many northward-trending faults which have offset the Divide, Lead Hill, and Slate Creek faults over a distance of many miles. These appear to represent relatively minor structural adjustments rather than a much later stage of deformation.

Special mention should be made of the somewhat peculiar sharp bend of the Russian Creek fault and of the relation between the Russian Creek and Flume Creek faults (pl. 1), because these structures form, in large part, the western boundary of the graben, the principal area of the present investigation. Furthermore, these faults, together with the Slate Creek fault, form the main boundaries in this area between moderately to highly mineralized ground and poorly mineralized ground. Moreover, considerable speculation has been advanced to explain these structures. The authors of the present report believe that the Russian Creek fault was developed principally during stage two, although, as explained in some detail in following paragraphs, it was later modified during stage three.

The curved junction of the Flume Creek and Russian Creek faults and the good exposures on the ridges nearby encouraged Park and Cannon (1943, p. 29) to make a somewhat more detailed structural study of this area than was possible elsewhere in the Metaline quadrangle. In the following paragraphs their observations and conclusions (1943, p. 28–30) are given, and those of the authors of the present report follow.

Park and Cannon report that the Russian Creek fault appears to dip more than 70° N., as computed from different altitudes along the strike. They note that the comparatively straight trace of the Flume Creek fault indicates that the dip is steep or vertical. They also point out that the linear structures on both sides of the Russian Creek fault are nearly parallel and do not change strike or pitch as the fault is approached; thus indicating, "that the Flume Creek fault and the Russian Creek fault cannot be one folded fault or, as the fault surface is not normal to the linear structures, that rotation has been minor." These authors further note that the attitudes of the linear structures east of the Flume Creek fault are, in general, obscure, and by a sketch (Park and Cannon, 1943, fig. 6), illustrate the squeezing out and thinning of beds in the part of the Hooknose anticline near the junction of the two faults.

Park and Cannon (1943, p. 29–30) have considered several explanations to account for the structure of the rocks of this area, and their ideas are quoted in the following paragraphs.

The steep dips of both the Russian Creek and Flume Creek faults and the constant direction of the linear structures across the Russian Creek fault may be explained as resulting from normal faults [favored by the writers] or by steep thrust and transverse faulting, such as has occurred at the Garrison Monster fault of Gold Hill, Utah [Nolan, 1935, p. 60]. If the explanation of thrusting and transverse faulting holds, the Flume Creek fault dips westward at an angle of probably 45° or more, and the Russian Creek fault is a transverse fault, formed during the forward motion of the thrust block. Although this explanation has not been demonstrated, it is, perhaps, favored by the following points:

(1) Confusion in both the upper and lower blocks at the junction of the Flume Creek and Russian Creek faults.

(2) Lack of radial faults in the lower block at the junction of Flume Creek and Russian Creek faults.

(3) Lack of drag effects along both the Flume Creek fault and the Russian Creek fault.

(4) Rough general accordance of the faults with the regional trend of folding.

(5) General position of the faults.

One alternative to this explanation is that the Flume Creek and Russian Creek faults are both normal and their hanging walls are depressed relative to the footwalls. This explanation is the one favored by the writers, although the thrust-fault and transverse-fault explanation is not discounted. If the faults are normal, the displacement would be essentially down the dip and nonrotational. The normal-fault explanation is possibly favored by the following points:

(1) Lack of drag folding in the upper or southwest block.

(2) Lack of overturn close to the faults in the lower or valley block.

(3) The trend of the faults is only in part accordant with the structure of the upper block.

(4) The trend of the faults is opposed to the direction of pressure as shown by the Ridge thrust and the asymmetry of the folds.

(5) The presence, in rocks in the valley, of normal faults nearly parallel to Flume Creek fault.

(6) Crumpling in the lower block north of and close to the Russian Creek fault. (See pl. 14*A*).

(7) Irregular thrust remnants in the valley east of the Flume Creek fault. The thrust represented by these remnants may have been formed by compression in the upper layers during settling of a down-pointed wedge.

The work of the present investigation and the major interpretations reached differ little from those of Park and Cannon. However, a few additional observations are recorded; some, as would be expected in this difficultly accessible area where critical exposures are sparse, are at variance with those just given. It is, however, necessary to consider these observations in evaluating any explanation advanced to interpret this structure. Exposures of bedrock or reliable float fragments are entirely too few and widely spaced along the course of the Russian Creek fault to postulate a northerly dip to this fault; the dip could be vertical, or it might be low and either to the north or to the south. For the same reasons, it is highly doubtful whether individual beds or zones in the Maitlen Phyllite can be followed around the sharp bend of the Russian Creek fault.

The structural interpretation of the Russian Creek fault by the present writers is a modification of the theory favored by Park and Cannon. It is believed, like Park and Cannon, that the Flume Creek and Russian Creek faults formed originally as a single steeply dipping normal fault that curved sharply around the nose of Russian Ridge. However, a somewhat later stage of deformation (stage three) is believed by the authors of the present report to have modified the fault, especially the part known as the Russian Creek fault. It is postulated that compressive stresses acting in a general north-south direction moved the block west of the Flume Creek fault northward and upward in the vicinity of Russian Ridge. The original steep northerly dip to the Russian Creek fault was overturned and the rock broken into a series of slice faults as postulated in section *B–B′*, plate 1. Folding and shearing of the beds north of the fault produced a marked effect upon the carbonate rock of the Metaline Limestone; the limestones and dolomitic limestones were folded, sheared, and recrystallized into a coarse-grained banded streaky marble locally containing segregated pods, lenses, and knots rich in dolomite. These features were the result of metamorphic differentiation induced by pressure and shearing during the northward movement of the fault block. The layers and lenses dip roughly parallel to the slice faults and shears. It is noteworthy that the carbonate rock north of the Russian Creek fault is metamorphosed for at least three-fourths of a mile, as shown on plate 1, whereas rock at the same general stratigraphic position near the Tom Cat prospect, only 3,000 feet to the east, shows no effect whatsoever of dynamic metamorphism. It seems unlikely that such selective metamorphism could be accounted for solely by the initial movement that formed the Flume Creek-Russian Creek fault, and that an additional pulse of deformation accounts for the features found.

The fourth stage of deformation recognized in the area mapped during the present investigation produced faults that offset the earlier formed and dominantly northeast-trending structures within and bordering the graben. Faults of this stage do not have a consistently well-defined trend, although most trend west to northwest. They are typified by the Wolf Creek fault in the southern part of the mapped area, which offsets the Sand Creek fault (pl. 1), and probably the Pocahontas Creek fault, about a mile to the north; however, no attempt was made to trace the Pocahontas Creek fault to the east of the area shown on plate 1, and its relation to the Sand Creek fault is not known. In the northeastern part of the Metaline district, a few thousand feet east of the Slate Creek Lookout, the northern extension of the Slate Creek fault, and also probably the Lead Hill fault, have been offset to the west along a northwestward-trending fault that probably formed at this stage of deformation. It is not known whether these faults formed as a result of tensional or compressive stresses, or whether they represent a major stage of deformation found in adjoining areas. The faults do, however, reflect the latest stage of deformation recognized in the district. It is probable that they formed during the same tectonic stage that produced the northwest-trending faults typified by the Pass Creek fault zone, which Park and Cannon (1943, p. 28) assign to the latest period of deformation.

PHYSIOGRAPHIC DEVELOPMENT

This section pertains chiefly to the topographic forms that were developed in the bedrock of the Metaline district during preglacial and postglacial times; topographic features of the glacial deposits, such as terraces and kettles, are described with Quaternary deposits on pages 30–31.

The landforms in the Metaline district are the combined results of differences in weathering of the various rock types, the structure of the underlying rocks, and the resistance of the rocks to erosion by glaciers and streams. Of these, the first is probably the most important. The carbonate rock of the Metaline Limestone and the small patches of trachybasalt are more resistant to weathering than either the Ledbetter Slate or the Maitlen Phyllite—the last two, as can be noted on the geologic map, trend, in general, to form smoother and more continuous slopes and ridges than the other two types of rock, and, except along the stream gorges, cliffs and bluffs are rarely present.

The Cordilleran icecap, which moved south, covered even the highest elevations in the districts and modified the pre-Pleistocene topography. It produced or accentuated the somewhat smooth and elongate hills and mountains that are common in the district. The ice tended to scour, deepen, and widen the older northward- and southward-sloping valleys, and in part to fill the valleys that sloped eastward or westward, perpendicular to the direction of flow of the ice sheet.

Topographic forms that have resulted largely from the structure of the rocks are strongly in evidence at places, notably the steep slopes on the west and upthrown side of the Flume Creek fault, and the ridges of Metaline Limestone east of Hoage Lake, which clearly reflect offset of the limestone along the Hoage and King faults. A conspicuous knob on the west side of the Pend Oreille River near the mouth of Slate Creek consists of slate overlain along the Lee thrust by a plate of carbonate rock. Some faults produced shattered zones that were more easily eroded than the bordering rock; thus, these faults lie in valleys or sharp ravines. In the southern part of the district a sharp valley marks the northern part of the Sand Creek fault throughout most of its extension. Sharp ravines occupied by faults are common near the Robert E. Lee and Lucky Strike mines and at Z Canyon. About 4,500 feet south of the international boundary along the west side of the Pend Oreille River the steep northeast-facing limestone cliff is the topographic expression of a nearly vertical fault. The series of northeast-trending ridges that lie north of Sullivan Creek and east of the paved highway are the result of differential erosion along steeply dipping strata that strike northeast parallel to the ridges. Many of the sharp gullies and ravines that are conspicuous northeastward-trending topographic features on the west slope of Confusion Ridge, in the extreme north-central part of the district (pl. 1), formed along some of the prominent fractures of similar trends that are characteristic of this area.

The main valley of the Pend Oreille River formed largely before glacial time and the drainage was then to the south, as indicated by the southward flow of the main or upper part of many tributary streams; only the lower courses of some of these streams flow northward in order to adjust to the later northerly flow in the inner gorge of the Pend Oreille River. A few hundred feet south of the area mapped, remnants of the Tiger Formation, of Tertiary age and continental origin, are exposed along the paved highway about 100 feet above the level of the Pend Oreille River; these remnants indicate that the main valley was largely in existence during Tertiary time, or less likely that the deposits are preserved in the valley block as a result of post-Tertiary downfaulting.

Postglacial erosion by the Pend Oreille River, and to a lesser extent by the other larger streams, such as Slate, Sullivan, Flume, and Wolf Creeks, has locally formed steep and narrow gorges that are conspicuous topographic features. The tributary streams throughout most of their courses are in V-shaped valleys and are bordered by terrace deposits or a narrow belt of bedrock that lies between the stream and the terrace deposits. These streams have attempted to adjust their drainage level to that of the Pend Oreille River, with the result that the lower courses of many streams have cut deep and narrow gorges. Some of the shorter and weaker streams, especially those that lie west of the Pend Oreille River, have been unable to cut their channels as rapidly as that of the Pend Oreille, and therefore their lower courses are unusually steep and characterized by falls. Examples of these are Pewee Falls on Pewee Creek, Corkscrew Falls on Flume Creek, and Sweet Creek Falls on Sweet Creek (last two falls not shown on map, pl. 1).

CAVES

Caves are widely distributed in the Metaline district, where they range in size from a few feet or less to a hundred feet or more in length and depth. All the cavities in the Metaline district that are large enough to be classed as caves occur in the Metaline Limestone, and most of these are in the upper part of the limestone, where they are commonly found along fractures, faults, or in brecciated zones; a few are along bedding planes. Many caves, some of considerable geologic interest, are exposed in the workings of the principal mines, where they are commonly associated with the ore bodies and altered rocks. These caves occur both above and below the level of the Pend Oreille River; those in the Pend Oreille mine range in altitude from about 2,500 feet in the old western workings, or more than 500 feet above the river, to 900 feet in the eastern workings, about 1,100 feet below the river.

The best known cave in the district is Gardner Cave, in the low hills between Russian Creek and the Pend Oreille River (pl. 1). This cave, which is a State park, is entered through an opening about 10 feet across. The cave extends to a depth of more than a hundred feet along steeply dipping fractures in marbleized gray limestone. Insofar as the writers are aware, no published record concerning the total depth and extent and sizes of the caverns in this cave is available, although local residents report having reached greater depths than the approximate 100 feet readily reached by the senior author in 1945.

The few caves that are present in the stratigraphically lower bedded dolomite unit of the Metaline Limestone are chiefly along the steep slopes of the valley of the Pend Oreille River and in the strata cut in the first part of the main adit of the Metaline mine. Those in the adit were filled with partly stratified clay, silt, and sand. They are located below the 2,575-foot lake terrace, and for this reason were probably formed before the last ice invasion, possibly during the Tertiary Epoch. Many years ago the Lehigh Portland Cement Co. mined brown clayey iron oxide from a similar cave on the southwest side of Washington Rock and used it in the manufacture of a certain type of cement. A few caves, probably not more than 10–20 feet deep, are scattered on the limestone hills east of Hoage and Beatty Lakes in the northwestern part of the district (pl. 1). The cave openings are generally elongated in northerly or northeasterly directions along bedding or fracture planes; the largest seen was about 1 foot in width and 10 feet in length. These caves are probably relatively recent features that developed by the dissolving action of surface waters along readily accessible channels.

Most of the caves in the mines are markedly different in appearance and in origin from those seen on the bare limestone hills and in the river gorge or in dolomite a short distance below the surface. The caves in the mines are almost everywhere in mineralized ground, commonly along fractures in compact dolomite breccia irregularly replaced by jasperoid; at many places the country rock is entirely silicified. The walls of most caves are in part smooth and in part corroded into jagged forms. In some caves sphalerite and galena occur in fragments of country rock lying on the floor or as corroded grains projecting into parts of the cavities; well-developed crystals of galena or sphalerite are rare. Coarse cleavable calcite is commonly present, in places largely filling cavities and elsewhere as partially corroded masses. Small crystals of light-brown barite are perched on cleavage surfaces of calcite (fig. 18) in one cave seen in the eastern workings of the Pend Oreille mine along the 2200-level stopes at an altitude of about 2,100 feet. Fragments and slabs of country rock, some as much as 10 feet or more in length, are on the floor of some caves. A cave off the 800 level in the western workings of the Pend Oreille mine contained many slabs and fragments which were firmly bound together by thin coatings of gray quartz. Pyrite crystals occurred between some of the fragments, and small crystals of calcite were scattered over some of the pyrite crystals and on much of the silicified surface of the fragments. This cave, now obliterated by subsequent mining—as so often happens—was a beautiful feature when seen by lamplight reflected from the thin coating of silica on the walls and huge pile of slabs.

Paligorskite (fig. 25), a hydrous magnesium-aluminum silicate, is commonly present in many of the caves where it fills fractures and hangs from the roofs and sides in dangling bodies resembling soiled and frayed rags or a wet and torn newspaper. Locally,

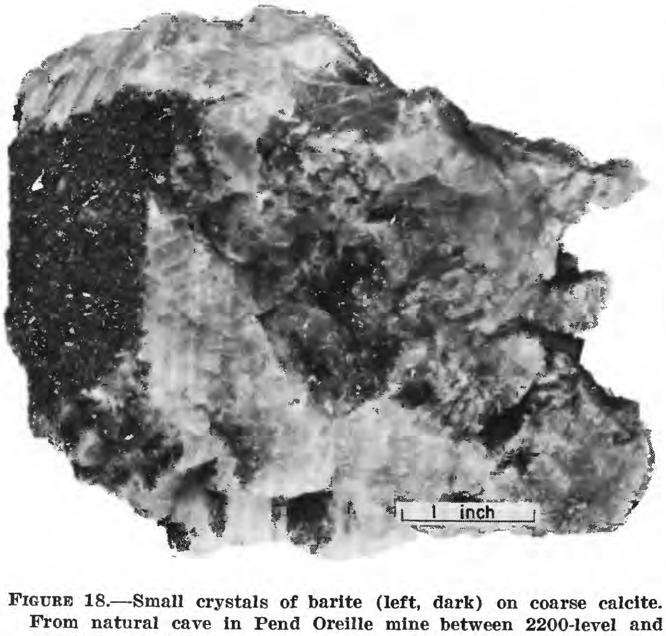

FIGURE 18.—Small crystals of barite (left, dark) on coarse calcite. From natural cave in Pend Oreille mine between 2200-level and 2000-level workings.

fragments of ore, quartz, calcite, and country rock hang haphazardly and loosely suspended on some sheets of paligorskite, indicating that they formed before the paligorskite. Some paligorskite, on the other hand, was deposited before sphalerite, quartz, and calcite, for these minerals are present locally as crystalline coatings.

By far the greatest number of caves are alined along fractures or faults. Many are bounded on one side by a smooth and, in places, slickensided surface. In one area in the eastern workings of the Pend Oreille mine, 7 caves have been recognized over a distance of about 650 feet along a northward-trending fault, or fault zone, that extends from the 1900 level to the 1700 level. Probably the largest cave found in any of the mine workings is off the 1900 level in the eastern workings of the Pend Oreille mine. This cave has been traced in length for at least 280 feet, and it averages 30 feet in width and 20 feet in height; at one place it rises to an estimated height of about 60 feet. In 1957 the lowest known caves in the district were found on the recently driven 900-level (alt. about 900 ft.) workings of the Pend Oreille mine (not shown on pl. 2), about 1,000 feet beneath the Pend Oreille River. Some caves with high roofs, or those with very narrow openings, have not been followed to their limits, and the extent and pattern of possible connections between openings is little known.

Most caves are dry, but it is reported that all three of the principal mines cut into some caves containing water, or mud and water. At places the discharge of water was reportedly large. Some caves cut in the eastern workings of the Grandview mine were partly filled with a mass of wet mud and silt, probably derived from the overlying lake silts which rest on the eroded surface of the Metaline Limestone.

Park and Cannon (1943, p. 39) suggested the following four possible modes of origin of the caves in the mineralized parts of the mine workings.

1. They are caves formed by downward-percolating waters above the water level,
2. They were formed by meteoric water circulating below ground-water level, as suggested by Davis (1930, p. 480),
3. They are related to a possible erosion surface at the top of the Metaline Limestone and below the Ledbetter Slate,
4. They resulted from solution by hydrothermal fluids that deposited jasperoid and ore.

For ease of reference, the authors of the present report quote the discussion of these theories by Park and Cannon.

The caves were not formed in recent time by downward-percolating vadose water, because: (1) no indication of surficial infiltration or deposition of weathered debris has been found except in the upper caves that are clearly connected with the surface; (2) paligorskite is unstable in the zone of downward percolation, and it is also unlikely that sphalerite and crystalline quartz would form under these conditions; (3) no evidence is available to show that the ground-water surface was ever appreciably lower than it is today, and considerable physiographic evidence indicates that it was probably higher near the end of Pleistocene time.

The second explanation, that the caves were formed by circulation below ground-water level, cannot be so summarily dismissed and has several points to commend it. The principal criticism is that the formation of paligorskite in pure calcite would necessitate the transportation of magnesium, silica, and aluminum in cold meteoric waters. The crystalline lining in the cavities, however, is not a convincing argument either for or against a meteoric origin, as crystalline sphalerite is very common between jasperoid and calcite, and if the calcite were leached crystalline sphalerite would project into the cavities. The small sphalerite and quartz crystals that are abundant on much of the paligorskite would under this theory be supergene. The principal points in favor of this explanation are the location of the caves where circulation of water is probably vigorous and the decrease in size and number of the caves in depth. The writers favor this explanation.

The third possibility—that the caves are related to an old erosion surface that separates the Cambrian and Ordovician strata—is unlikely, mainly because of the lack of other evidence for the existence of such an unconformity. Also caves formed before the Ordovician period would be earlier than the ore and would necessitate an explanation for the ore breccia found on their floors. Deeper exploration should furnish additional data concerning this hypothesis. The decrease in size of the caves down the dip makes it more reasonable to relate the openings to some other feature than an unconformity at the contact between the two strata. It is also a possibility that Ordovician caves would have been filled with redistributed carbonate during regional disturbance.

The fourth suggestion—that the caves result from dissolving action of the hydrothermal fluids that deposited the jasperoid and ore—answers many of the queries raised so far but does not explain why the caves decrease in size and number in depth, whereas jasperoid and ore, similar to those above, continue downward. The mineralizing solutions were capable of dissolving carbonates, as indicated by the fact that calcite and dolomite were removed from large masses now occupied by jasperoid and ore. As explained in the section on brecciation (p. 53) the conspicuous shattering near the ore bodies may in part have been accentuated by the corrosive activity of the mineralizing solutions. Under this theory the paligorskite and the sphalerite and quartz on the paligorskite would be hypogene rather than supergene minerals."

The authors of the present report reject the first and third mode of origin of the caves for almost the same reasons that Park and Cannon have given. However, the authors of the present report favor the last, or fourth, suggestion (dissolving action) over the second (circulation below ground-water level), which Park and Cannon favor, although these authors state that the fourth suggestion has much in its favor. The mine workings are now far more extensive and far deeper than when Park and Cannon studied the region, and these workings show that the caves neither decrease in size nor in abundance with depth, which removes their principal objection to this theory. The theory that the caves resulted primarily from the dissolving action of the hydrothermal fluids is favored by the fact that the caves are so widely distributed in, and closely associated with, mineralized ground. The mine workings are, of course, largely confined to mineralized and altered ground, but insofar as the authors of the present report know, caves are not present in the hundreds of feet of unaltered gray limestone cut in the mines, except where this rock is adjacent to altered ground, or is near the surface or the overlying lake silts. Also under this theory the sphalerite, galena, pyrite, barite, paligorskite, calcite, and jasperoid found in the caves are of hypogene rather than supergene origin, which is more in accord with the usual mode of formation of most of these minerals, especially when there is little suggestion of supergene deposition elsewhere in the mines. It is further known that the dissolving action of hydrothermal solutions has resulted in the removal of calcite and dolomite from large areas of rock now occupied by the jasperoid and ore, as noted previously and explained in more detail in the section on origin and interrelations of calcite, dolomite, and silica (p. 68–69). Considerable corrosive action is likewise indicated along the walls of some caves. The settling of the graben during ore deposition (p. 68) is also probably a factor favoring the formation of caves, because these repeated movements formed fractures and faults, or reopened older ones, which served as channels along which the hydrothermal solutions periodically migrated. At certain times the fluids actively dissolved the bordering rock, whereas a renewed stage of hydrothermal action filled or partly filled some of these caves that had previously formed. The pulses of movement, corrosion, and deposition that occurred would account for the cave breccias, the common, but not restricted, occurrence of caves along fractures and faults, and the variety and form of the minerals in the caves.

METAMORPHISM OF THE SEDIMENTARY ROCKS

Sedimentary rocks of the Metaline district are regionally metamorphosed to somewhat varying degrees. Argillaceous rocks were converted to argillites, slates, phyllites, and locally schists; some limestones and dolomites were recrystallized, and sandstones were converted to quartzites. A short distance beyond the limits of the area mapped, later igneous (thermal) metamorphism is conspicuous in the sedimentary rocks bordering the Kaniksu batholith (Park and Cannon, 1943, p. 40).

As previously noted by Park and Cannon (1943, p. 39–40), the regional metamorphism of the older formations, such as the Gypsy Quartzite and Maitlen Phyllite, is generally more complete and of somewhat higher grade than that of the Metaline Limestone, Ledbetter Slate, and the rocks of Silurian and Devonian ages. All ages of rocks, however, show considerable lateral and vertical variation in physical characteristics, and those of the relatively higher grade merge imperceptibly into those of lower grade. This irregularity in grade of metamorphism is especially characteristic of the Ledbetter Slate, which in a distance of a thousand feet or less along strike or at short vertical intervals passes from a bedded argillite to a slaty rock in which bedding has been obliterated and strong fracture cleavage has developed. Less commonly, shale grades into argillite and slate. Most of the quartzite beds of the Ledbetter are in slate, although a few are in argillite. Rocks of the Metaline and Ledbetter formations, the two main formations studied during this investigation, commonly show the effects of dynamic metamorphism adjacent to major faults or in strongly faulted areas. The Ledbetter in these areas is generally a slate, although locally a phyllite; limestone and dolomite of the Metaline are commonly crystalline, in places a fine- to coarse-grained marble, elsewhere a dense and streaky rock that resulted from plastic flow. Dark beds of limestone that have been deformed commonly lose their color and grade into light-gray rock. These features are especially well seen in the lower bedded limestone unit of the Metaline north of Slate Creek, where the normally dark-gray thin-bedded rock passes irregularly at many places into masses of light-gray crystalline limestone or dolomite that only slightly resemble the original rock.

Dynamic metamorphism is believed to have been responsible for most of the regional metamorphism. Load metamorphism, according to Park and Cannon (1943, p. 39–40), resulted in the very general upward change from higher to lower grade of metamorphism in the rocks of the stratigraphic column. This can be noted in the change in dominant rock type from quartzite (Gypsy) to phyllite (Maitlen) to argillite and slate (Ledbetter) to irregularly recrystallized limestone and dolomite (Metaline). However, as noted by these authors (p. 39, 40), the metamorphism is not uniform, and higher grade rocks merge into those of lower grade without a recognized hiatus. Work of the present investigation brought out this lack of uniformity in metamorphism. Argillite, for example, is far more abundant in the lower sections of the Ledbetter than is slate; moreover, almost all true shale in this formation lies at or near the base. Some of the rocks of Silurian and Devonian ages are metamorphosed to an equal or greater degree than those several thousand feet lower stratigraphically, as evidenced in the younger rocks by the presence of slate and of conglomerate beds having drawn out and elongated fragments.

The composition and physical characteristics of the strata before the regional metamorphism have been the dominant factors in producing certain types of metamorphic rocks. Before metamorphism the Maitlen Phyllite, for example, was chiefly a thick section of thinly bedded shales and sandstones that was readily converted to phyllite by stresses developed during the older periods of regional folding and faulting, especially since this section was overlain by at least 2 miles of rock. The thin-bedded nature of these incompetent beds made them especially susceptible to change by dynamic metamorphism by slippage, crumpling, and shearing along, or at low angles to, bedding planes. However, in spite of the two features mentioned above—depth of burial and lithologic character—the Maitlen rocks, when compared to the younger formations, appear to have been metamorphosed to a somewhat greater degree than can be attributed entirely to these factors. It is possible that the rather poorly exposed Maitlen Phyllite, which has not been structurally studied in detail in this area, is far more intensely deformed than realized, and it is not improbable that the rocks have been tightly folded and strongly faulted, perhaps deformed along some deep-seated thrusts.

HYDROTHERMAL ALTERATION

Hydrothermal alteration characterized by dolomitization, silicification and calcification probably occurred during Laramide time following the emplacement of the Kaniksu batholith. Hydrothermal alteration was, in general, associated in time with the introduction of the ores. The products of hydrothermal alteration—crystalline (nonbedded) dolomite, silicified dolomite, and coarse calcite—are distributed throughout the district (pl. 1); they are especially common in the Metaline Limestone.

DOLOMITIZATION

Dolomitization related in time to silicification, calcification, and mineralization was largely but certainly not entirely confined stratigraphically to the upper

1,000 feet of the Metaline Limestone, and was especially effective in altering the uppermost few hundred feet of this formation. This alteration produced a massive crystalline dolomite that varies greatly in color and widely in texture and structure (figs. 19–23, and 26–29). Bedding planes are very rarely recognizable. Park and Cannon (1943, p. 41–44) termed this rock "crystalline dolomite not bedded." In the present report the rock is referred to simply as crystalline dolomite—a term used interchangeably with recrystalline dolomite and recrystallized dolomite by some of the mine operators of the district. At many places crystalline dolomite cuts, replaces, or surrounds the older limestones and bedded dolomite of the Metaline (pl. 1), 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. At places the crystalline and bedded dolomites intergrade or are so intermixed on a small scale that they cannot be clearly separated and are included in the mixed dolomite group on the geologic map (pl. 1).

Crystalline dolomite ranges in color, locally within a few feet or less, from light gray to black, although most is a medium gray. The rock is composed principally of medium to coarse anhedral grains of dolomite, although locally large masses are fine grained. At many places this massive rock contains extremely variable quantities of coarse calcite, jasperoid, and locally sulfide minerals. Especially near the main ore bodies, crystalline dolomite passes very irregularly into faintly to strongly brecciated rock composed largely of fragments of fine- to medium-grained dolomite in a matrix of coarse dolomite (fig. 26). Bodies of crystalline dolomite range in length from a few feet or less to

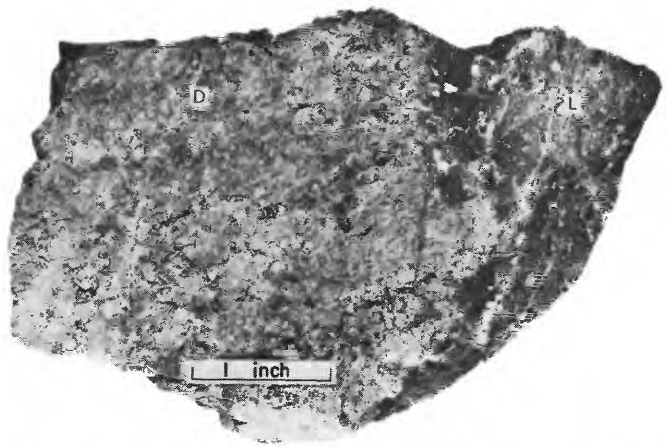

Figure 19.—Crystalline dolomite (light gray) replacing sublithographic limestone (dark gray). Metaline Limestone, Whoopie prospect.

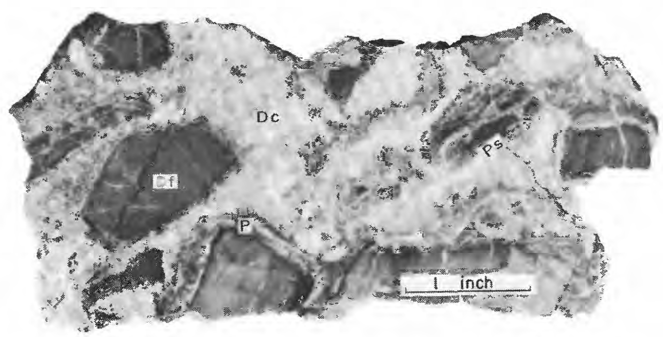

Figure 21.—Pyritic zinc ore in dolomite breccia, Yellowhead mine. Fine-grained dolomite fragments (Df) bordered by pyrite (P) or pyrite and sphalerite (Ps). Coarse-grained light-gray dolomite (Dc) forms the matrix.

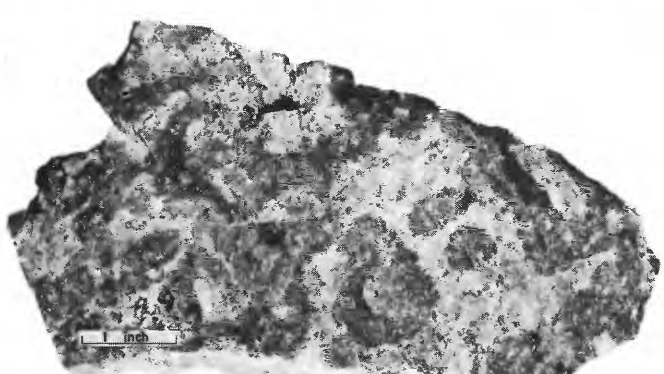

Figure 20.—Coarse-grained gray dolomite and quartz from near the Lead Hill mine. The "half-moon" structure consists of an outer layer of brownish-gray dolomite, a thin intermediate layer of dark-gray to black fine- to medium-grained dolomite, and a center of light-gray fine-grained quartz. Rare sphalerite occurs in the coarse-grained dolomite surrounding the structures.

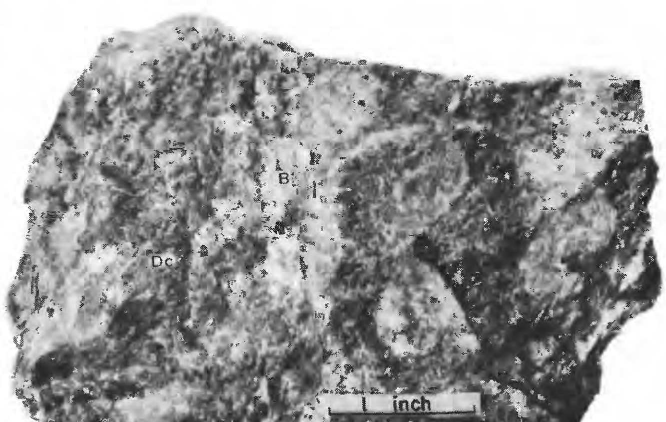

Figure 22.—Barite (B) and crystalline dolomite (Dc). Sparse sphalerite, not clearly visible, in parts of the dolomite, Lead Hill area. "Half-moon" structure in dolomite at right is only partially developed as compared to figure 20, but it consists of the three similar layers of dolomite.

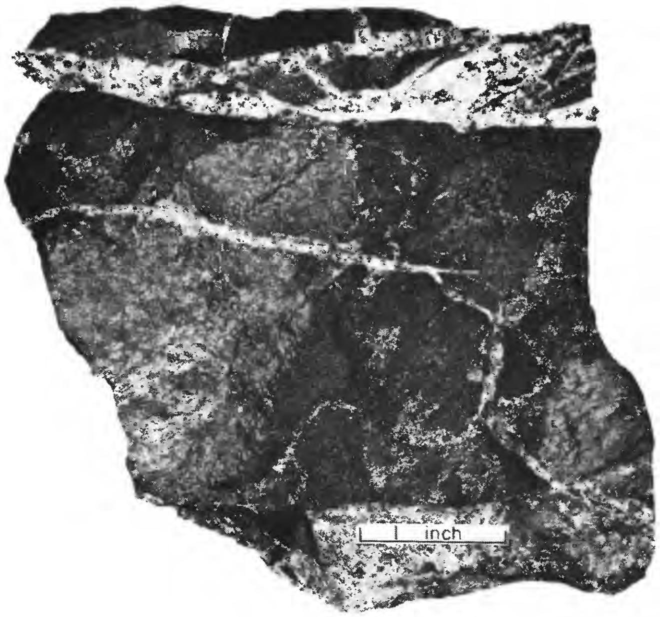

FIGURE 23.—Fine-grained black dolomite cut by stringers of coarse-grained light-gray dolomite containing sphalerite, Lead King mine.

several thousand feet. Scattered through the district are hundreds of the smaller bodies that are too small to show on the geologic map or in sections of drill core. Most of the large masses of crystalline dolomite occur directly beneath Ledbetter Slate in irregular tabular bodies ranging in thickness from 25 to 200 feet. (See sections on pls. 1, 3.)

SILICIFICATION

Silicified rock is widely distributed in the Metaline district. It is especially common in the upper 200 feet of the Metaline Limestone, although it occurs at many other stratigraphic positions in this and other formations. Only the larger areas containing roughly 15 percent or more silica by volume are included in the unit of silicified dolomite shown on plate 1.

The principal product of silicification is light-gray to black jasperoid (figs. 24, 26–28) that replaces limestone or dolomite. Jasperoid is especially abundant in bodies of brecciated dolomite and coarse calcite, where it occurs chiefly in irregularly shaped forms ranging in size from microscopic to masses several hundred feet or more across. At a few places jasperoid forms distinct veinlets, pods, or lenses. Jasperoid bodies generally pass very irregularly into nonsilicified or very slightly silicified dolomite, limestone, or a mixture of the two. Sphalerite and galena are commonly associated with jasperoid, although locally and also in some broad areas these minerals are absent.

At many places the typical gray to dark-gray jas-

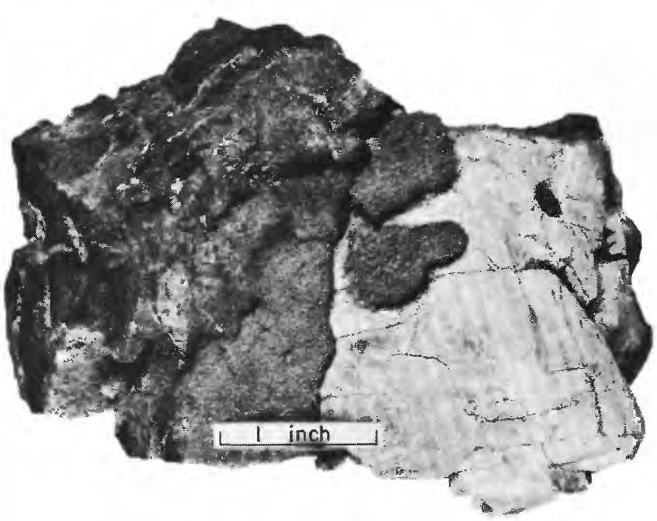

FIGURE 24.—Weathered surface of black jasperoid and coarsely cleavable calcite, Lead King Hills.

peroid is associated with, and locally grades into, smaller bodies of light-gray to white microcrystalline to crystalline quartz. The quartz also occurs as irregularly shaped stringers, pods, veins, and, less commonly, individual crystals, crystal aggregates or crystal-lined vugs. Locally, veinlets of milky quartz cut, surround, or partly surround jasperoid (fig. 7).

The Ledbetter Slate is locally silicified to a dense hard black rock along fault zones or in a few places for short distances above its contact with the Metaline Limestone. At several places along zones of deformation the Ledbetter is a silicified breccia, as, for instance, along the northward-trending fault southwest of Deer Mountain in the extreme southwestern part of the mapped area (pl. 1) and along the Hoage fault in the Lead King area. Some silicified slate in drill cores somewhat resembles, and has been mistaken for, fine-grained black quartzite, although the black quartzites when examined with a lens clearly show rounded grains in contrast to the dense flinty character of silicified slate.

CALCIFICATION

Coarse-grained calcite, locally with cleavage surfaces as much as 10 inches or more across, is very common in the mineralized areas; elsewhere, it is sparsely distributed in carbonate rock and rarely in slate. The calcite is generally white to pale yellow and translucent. It occurs as grains, pods, veins, crystals, and in bodies 50 feet or more long. Most commonly it is in grains and small irregular pods scattered through the medium- to coarse-grained hydrothermal (crystalline) dolomite in the upper few hundred feet of the Metaline

Limestone. Commonly the small grains, and some pods and veinlets, of calcite are very similar to crystalline dolomite and can be distinguished with certainty only by their effervescence with dilute acid. The variable proportions of calcite scattered through the crystalline dolomite in the upper part of the Metaline accounts for the wide variation in the calcium and magnesium content (table 4) of this section.

Masses of calcite, 10 feet or more in length, are exposed at many places in the mine workings. Some of these bodies are sharply defined, whereas others grade into the surrounding rock for 10 feet or more. Many drill holes in the mineralized areas cut long sections of pure calcite or strongly calcified rock. (See sections *B–B′* and *C–C′*, pl. 3.) Although hundreds of these larger bodies of calcite are in mineralized ground, many are also found irregularly distributed around the borders of altered and mineralized areas. An exceptionally large mass of coarse cleavable calcite, at least 75 feet in length, is present in the cliff west of Corkscrew Falls (not shown on map), where the old road to the western workings of the Pend Oreille mine crosses Flume Creek (pl. 1).

Throughout the district irregular bodies of calcite occur in and border many faults and fractures. Locally, calcite is along either the hanging wall or footwall side of faults; elsewhere, masses of calcite are in fault contact with limestone or dolomite. At scattered localities beyond the mineralized areas, pods and a network of stringers and veins of calcite are in limestone, bedded dolomite, silicified rock, and slate.

CHEMICAL ANALYSES OF ALTERED CARBONATE ROCK

Table 4, reproduced from Park and Cannon (1943, p. 43–44), furnishes analyses of 74 specimens of carbonate rock from the upper part of the Metaline Limestone found in holes drilled from surface locations in the mineralized areas of the Pend Oreille, Metaline (Bella May), and Lead King mines. The analyses show the irregularity of dolomitization, silicification, and calcification, especially in the upper few hundred feet of the holes, although in hole 234 there is considerable deeper alteration in the interval 500-710 feet. Parts of the carbonate rock can be classed as limestone, magnesian limestone, dolomitic limestone, limy (calcitic) dolomite, or dolomite, although it is noteworthy that most of the carbonate rocks are either limestone or dolomite, provided that the insoluble fraction, probably largely introduced quartz in the form of jasperoid, is disregarded.

The senior author examined the cores of some of these holes. At all depths where core was available and the analyses showed 10 percent or more insoluble material, the rock was a medium- to coarse-grained crystalline (nonbedded) dolomite containing variable amounts of quartz, generally jasperoid, thus showing the close association between jasperoid and crystalline dolomite.

TABLE 4.—*Analyses of carbonate rock from diamond-drill cores*

[From Park and Cannon, 1943, p. 43–44]

Depth (feet)	Acid insoluble (110° C)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
Pend Oreille mine. Hole 234, located 740 ft N. 13° E. of West shaft [Analyst, E. Theodore Erickson]						
25	50.52	0.64	25.20	23.53	0.02	99.91
50	1.62	.81	55.79	41.80	.05	100.07
75	1.24	.84	59.87	37.76	.03	99.74
101	.29	.84	56.16	42.26	.05	99.60
125	.08	.27	98.02	.69	None	99.06
150	.65	.16	95.31	2.11	Trace	98.23
175	4.46	.16	88.02	7.54	.02	100.20
198	.14	.13	98.56	1.46	Trace	100.29
225	.22	.16	98.96	.83	.02	100.19
250	16.69	.19	81.77	.77	.02	99.44
275	.12	.19	99.47	.43	Trace	100.21
300	.21	.08	99.27	.45	Trace	100.01
325	26.22	.27	69.12	1.99	Trace	97.60
338	.06	.11	99.51	.49	Trace	100.17
359	73.96	.51	11.78	9.22	.02	95.49
410	.27	.16	99.09	.22	Trace	99.74
440	12.02	.89	55.84	28.42	.02	97.19
480	.11	.16	98.94	.68	None	99.89
500	3.95	.21	92.82	3.18	Trace	100.16
525	1.20	.21	98.14	.39	Trace	99.94
550	12.44	.19	86.71	.35	Trace	99.69
588	.51	.16	98.56	.33	Trace	99.56
615	40.51	.58	42.76	11.84	.05	95.74
645	2.58	1.21	54.86	40.99	.02	99.66
685	2.67	.35	71.83	24.51	.02	99.38
710	.18	.47	56.08	41.95	Trace	98.68
Pend Oreille mine. Hole 235, located 215 ft N. 61° E. of West shaft [Analyst, R. E. Stevens]						
75	32.81	0.21	67.15	Trace	Trace	100.17
100	5.22	.56	53.02	41.44	.06	100.30
125	.99	.44	56.18	42.68	.05	100.34
146.5	58.65	.58	22.87	17.82	.03	99.95
175	3.82	1.05	53.50	41.81	.12	100.30
200	70.45	.68	11.09	8.11	Trace	90.33
225	80.95	.69	3.81	2.31	Trace	87.76
249	.70	.10	98.65	.32	Trace	99.77
275	.10	.08	99.42	.23	Trace	99.83
300	1.36	.08	95.65	2.80	.02	99.91
325	.17	.08	99.20	.40	.01	99.86
350	5.76	.07	93.50	.30	.01	99.64
375	1.80	.14	97.60	.48	.02	100.04
400	.02	.11	99.20	.39	.02	99.74
497	.35	.16	99.00	.64	.03	100.18
535	.14	.10	96.39	3.51	.06	100.20
550	1.59	.36	58.75	39.00	.07	99.77
589	.10	.06	99.70	.25	Trace	100.11

TABLE 4.—*Analyses of carbonate rock from diamond-drill cores*—Continued

[From Park and Cannon, 1943, p. 43–44]

Depth (feet)	Acid insoluble (110° C)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
Metaline (Bella May) mine. Hole 40, located 1,710 ft S. 75° W. of portal of No. 6 Bella May adit [Analyst, J. G. Fairchild]						
168	2.27	0.61	56.72	40.82	0.08	100.50
202	.69	1.08	56.58	42.20	.19	100.74
239	56.36	.28	42.05	1.39	.01	100.09
276	46.42	.71	30.06	23.52	None	100.71
299	76.21	.37	13.33	10.43	.01	100.35
325	47.35	.49	31.98	20.55	.02	100.39
336	33.83	1.43	36.97	28.31	.16	100.70
351	6.15	.38	53.35	40.62	.03	100.53
375	4.69	.38	54.90	40.12	.04	100.13
400	5.04	.39	54.90	39.85	.03	100.21
425	2.54	.27	95.62	1.70	.02	100.15
450	1.04	.10	98.18	.82	None	100.14
472	.72	None	99.22	.25	None	100.19
Metaline (Bella May) mine. Hole 42, located 1,690 ft S. 70° W. of portal of No. 6 Bella May adit [Analyst J. G. Fairchild]						
513	27.00	0.16	71.00	2.03	None	100.19
525	.10	None	99.90	.20	None	100.20
550	.10	None	99.80	.20	None	100.10
581	49.81	.58	28.40	21.36	None	100.15
600	62.38	.71	21.22	16.03	.02	100.36
631	10.46	.71	50.70	38.40	.05	100.32
646	.10	.53	56.35	42.65	.05	99.68
662	.97	.69	54.90	43.70	.08	100.34
Lead King mine. Hole 15, inclined 60° E., located 750 ft S. 17° W. of Lead King adit [Analyst, Jos. J. Fahey]						
200	82.94	0.23	15.15	0.21	None	98.53
300	.10	None	99.35	.86	None	100.31
400	.06	None	96.98	2.11	None	99.15
500	.17	None	57.82	41.40	.04	99.43
600	8.76	None	90.04	.65	None	99.45
692	5.83	None	89.54	4.28	None	99.65
800	.78	None	98.25	.04	None	99.07
900	.01	None	99.57	None	None	99.58
1,000	.36	.11	97.50	1.91	.02	99.90

ORE DEPOSITS

HISTORY OF MINING

The presence of lead deposits in the Metaline district was known as early as 1869, but no attempt at mining was made until about 1886 (Boutwell, 1907, p. 451). According to Bethune (1891, p. 82–83), the name Metaline was given to the district because of the large amount of "metal" in sight—presumably galena. The district was difficultly accessible until 1910 when the Idaho and Washington Northern Railroad, now the Chicago, Milwaukee, St. Paul and Pacific R.R., was completed to its present terminus at Metaline Falls. Before 1910 the Metaline district was reached by 50 miles of wagon road from Colville or by boat from Newport to Ione and thence from Ione by wagon road to Metaline, a total distance of about 60 miles. In 1906 the channel of the Pend Oreille River was deepened at Box Canyon, and boats were able to navigate as far north as Metaline. After the railroad reached Metaline Falls in 1910 the timber and mineral resources of the region were rapidly exploited. The Lehigh Portland Cement Co. soon built a plant at Metaline Falls to manufacture cement, utilizing the nearby sources of limestone and shale. Metal mining, however, was slow in getting started on a large scale, chiefly because of the irregular distribution and general low grade of the lead and zinc deposits and the general absence or rarity of gold and silver.

The late Lewis P. Larsen, for many years president and principal stockholder of the Pend Oreille Mines & Metals Co., is largely responsible for the successful development of the ore deposits of the district. He and his financial backers tried repeatedly from 1906 to 1928 to mine and mill the low grade zinc-lead ores on a profitable basis. It was not until 1928-29 that Larsen and his associates found, as a result of diamond drilling, a large body of minable zinc-lead ore on the property of the Pend Oreille Mines & Metals Co. in what is now the upper stopes in the abandoned western workings of the Pend Oreille mine. Since 1929 development has been rapid, and the Pend Oreille mine workings now extend northeastward beneath the Pend Oreille River and beyond to a point about 1,500 feet south of Threemile Creek (pls. 1, 2). In 1936–37, mining and development work started on a fairly large scale in the western, or Bella May, workings of the Metaline mine, and in later years the Grandview mine was worked as a fairly large-scale operation by the American Zinc, Lead & Smelting Co.

PRODUCTION

The earliest recorded production of ore from the district was in 1906 (table 5) when a small shipment of dominantly lead ore was made. From that time until 1929 production was relatively small and erratic, the only substantial output occurring in 1916, 1917, and 1927. Since 1929 the district has shipped ore yearly except in 1935. Substantial production, however, began only in 1938 when 249,184 tons of ore was shipped, and the district output has continued in a general upward trend with minor deviations to a peak production of 799,447 tons in 1956. Data are not at hand for the years following 1956.

Table 5 shows that during the period 1906-56 the mines of the Metaline district have yielded 8,284,053 tons of crude ore having a value of $75,228,452. Lead was the principal product of the early periods of mining, and much of it was probably from hand-sorted ore found near the surface. Since 1927, however, zinc has become the most valuable metal, although in 1948, 1949, and 1954 the value of lead approached or exceeded that of zinc. From 1906 to 1956 the district ratio of zinc to lead is about 2 to 1 in terms of recovered metals, and the metals recovered from the crude ore averages 2.77 percent zinc and 1.34 percent lead. Gold, silver, and copper are almost everywhere very minor byproducts of the zinc-lead ores, although some gold ore probably came from the Oriole mine. The relatively insignificant total value of gold obtained from a few small placers in the district is not included in table 5; the value is probably less than $5,000.

The yearly output and totals of ore and recovered metals from the three largest mines—Pend Oreille, Grandview, and Metaline—are shown in tables 6, 7, and 8 respectively. These 3 mines account for slightly more than 99 percent of all crude ore mined in the entire district from 1906 to 1956. Of the 8,284,053 tons of ore produced in the district (table 5), Pend Oreille has mined 5,451,328 tons (65.8 percent), Grandview 2,347,974 tons (28.3 percent), and Metaline 431,480 tons (5.2 percent). Substantial production from the Pend Oreille mine started in 1931, considerably before that of either the Grandview or Metaline mines. About half a million tons of crude ore was mined yearly from the Pend Oreille during the period 1953–56, the most active in its history. Substantial output from the Grandview mine did not start until 1941, shortly after the American Zinc, Lead & Smelting Co. became the operator for this property. Labor disputes have mark-

TABLE 5.—*Gold, silver, copper, lead, and zinc produced in the Metaline district, 1906–56, in terms of recovered metals*

[From Fulkerson and Kingston, 1958, p. 12]

Year	Ore (tons)	Fine ounces		Pounds			Value
		Gold	Silver	Copper	Lead	Zinc	
1906	26	----	45	----	34, 100	----	$1, 973
1911	51	9	1, 602	411	11, 982	20, 590	2, 799
1915	3, 111	----	----	----	----	244, 906	30, 368
1916	15, 145	----	85	----	37, 695	861, 322	118, 074
1917	15, 093	8	1, 504	490	129, 639	1, 176, 715	132, 717
1918	245	----	264	----	184, 734	38, 873	16, 917
1923	34	----	46	----	31, 233	----	2, 224
1924	966	----	1, 291	----	868, 920	----	70, 378
1925	914	2	1, 043	----	757, 652	----	66, 675
1926	813	4	1, 818	117	326, 931	65, 485	32, 313
1927	35, 348	11	2, 913	1, 075	290, 861	936, 576	80, 285
1929	50, 920	8	2, 250	4, 762	655, 958	2, 061, 574	179, 592
1930	7, 200	9	1, 023	315	534, 370	703, 782	61, 132
1931	80, 968	16	4, 595	2, 670	2, 514, 977	9, 947, 495	472, 959
1932	33, 443	28	2, 606	3, 396	1, 364, 066	4, 489, 334	177, 142
1933	48, 479	19	3, 263	5, 062	1, 443, 783	6, 738, 169	338, 365
1934	28, 322	----	1, 151	2, 575	473, 649	3, 852, 419	184, 567
1936	76, 060	----	3, 317	6, 011	1, 540, 847	8, 777, 220	512, 974
1937	106, 028	----	12, 525	----	5, 287, 797	8, 190, 600	854, 407
1938	249, 184	----	14, 584	----	8, 018, 500	22, 804, 000	1, 473, 116
1939	259, 320	----	11, 603	----	7, 018, 404	20, 260, 558	1, 391, 570
1940	273, 233	----	8, 609	----	4, 989, 500	23, 120, 000	1, 712, 157
1941	361, 041	----	10, 807	----	7, 637, 900	28, 402, 000	2, 573, 300
1942	397, 630	----	9, 630	----	9, 106, 000	27, 240, 000	3, 150, 270
1943	311, 245	----	7, 335	----	9, 161, 000	18, 584, 000	2, 699, 363
1944	305, 516	----	15, 580	----	10, 555, 000	18, 471, 000	2, 961, 173
1945	253, 884	----	11, 191	----	7, 011, 000	15, 588, 000	2, 403, 559
1946	247, 648	----	7, 375	13, 000	4, 448, 000	15, 370, 500	2, 368, 098
1947	295, 015	----	10, 674	4, 400	6, 900, 000	19, 508, 800	3, 364, 749
1948	223, 602	----	9, 521	----	8, 593, 000	11, 969, 000	3, 138, 641
1949	243, 962	----	11, 396	16, 500	8, 059, 200	12, 992, 200	2, 897, 951
1950	417, 228	----	20, 432	15, 500	14, 889, 000	22, 064, 000	5, 164, 819
1951	510, 207	30	22, 896	36, 900	10, 467, 800	25, 505, 400	6, 483, 614
1952	603, 022	22	29, 910	55, 000	18, 148, 000	28, 815, 010	7, 746, 270
1953	734, 967	50	34, 574	64, 000	17, 388, 000	34, 370, 000	6, 281, 787
1954	595, 629	20	22, 616	20, 000	17, 312, 000	17, 726, 000	4, 313, 221
1955	699, 107	9	26, 329	52, 000	16, 196, 000	23, 316, 000	5, 324, 612
1956	799, 447	2	29, 360	52, 000	18, 879, 000	25, 048, 000	6, 444, 321
Total	8, 284, 053	247	355, 763	356, 184	221, 266, 498	459, 259, 528	75, 228, 452

edly cut down production from the Grandview mine during the past decade. The principal output from the Metaline mine occurred during the period 1938–47.

Three mills are in the district. The largest, with a capacity of 2,400 tons per day, is owned by the Pend Oreille Mines & Metals Co. and is near the head of Pend Oreille's main incline on the east side of the Pend Oreille River (pl. 1). The old Pend Oreille mill on the west side of the river near the Cascade adit has a daily capacity of 800 tons. This mill, except during short periods, has been idle for several years. The Pend Oreille Mines & Metals Co. tentatively plans to use eventually this mill to handle the iron-rich zinc and lead ores of the nearby Yellowhead mine. The Grandview mill, owned by American Zinc, Lead & Smelting Co., is on Grandview Flats below and a short distance from the portal to the Grandview mine. In late 1957 the Grandview mill was in the process of being enlarged from 600 to 1,600 tons daily capacity. This mill, in addition to handling the ore from the Grandview mine, formerly milled ore which was trucked several miles from the Metaline mine.

TABLE 6.—*Production of the Pend Oreille (Josephine) mine, 1917–56*

[From Fulkerson and Kingston, 1958, p. 23]

Year	Ore (tons)	Ounces		Pounds		
		Gold	Silver	Copper	Lead	Zinc
1917	14,953		97		38,876	1,171,296
1918	55				1,202	38,873
1925	25		48		24,585	
1926	17		22		14,730	
1927	32,577	6	2,134	1,075	37,788	868,018
1929	320	8	1,172	436	6,510	47,324
1930	6,000		870	240	407,650	665,280
1931	80,968		4,595	2,670	2,514,977	9,947,495
1932	33,423		2,589	3,360	1,349,713	4,489,334
1933	48,479		3,260	5,062	1,443,783	6,738,169
1934	28,322		1,151	2,575	473,649	3,852,419
1936	76,060		3,317	6,011	1,540,847	8,777,220
1937	98,500		10,081		5,137,858	7,462,200
1938	214,120		14,584		7,413,000	18,598,000
1939	241,624		11,603		6,472,000	18,555,558
1940	232,587		8,587		4,152,700	18,792,000
1941	219,835		7,948		3,731,449	15,958,000
1942	234,215		9,622		5,091,141	14,508,700
1943	183,042		3,848		4,524,200	9,815,000
1944	157,638		7,172		4,070,593	7,959,000
1945	119,696		4,400		2,425,000	5,445,000
1946	122,106		3,050		1,496,200	6,252,700
1947	116,695		4,733	4,300	3,235,000	6,270,000
1948	133,755		7,377		5,825,500	5,462,188
1949	186,955		9,365	16,475	6,547,000	8,438,750
1950	186,197		9,001	15,347	6,126,500	8,774,470
1951	273,580	30	16,041	13,721	5,937,458	12,402,138
1952	336,205	22	20,882	24,220	9,721,198	15,604,647
1953	500,042	17	23,719	34,056	11,400,566	21,715,290
1954	482,055	3	19,000	8,200	14,946,000	12,890,600
1955	503,391	9	22,752	33,700	13,372,500	15,101,500
1956	587,891		24,206	30,200	15,884,400	14,689,200
Total	5,451,328	95	257,226	201,648	145,362,573	281,290,369

TABLE 7.—*Production of the Grandview mine, 1924–56*

[From Fulkerson and Kingston, 1958, p. 21–22]

Year	Ore (tons)	Silver (ounces)	Pounds		
			Copper	Lead	Zinc
1924	217	198		136,307	
1925	547	459		456,905	
1926	215	136		86,505	
1927	1,246	181		111,210	68,558
1929	50,600	1,078	4,326	649,448	2,014,250
1930	1,200	150	75	126,720	38,502
1940	15,757			383,200	1,476,000
1941	76,049	1,493		2,201,641	6,567,653
1942	95,131			3,097,500	6,569,000
1943	81,881	3,481		4,049,600	5,175,000
1944	97,543	5,744		4,436,000	6,809,500
1945	93,871	4,990		3,306,000	6,696,000
1946	88,617	3,560	13,000	2,410,300	6,818,000
1947	148,786	5,100		3,245,000	11,336,600
1948	89,831	2,150		2,750,000	6,505,000
1949	51,690	2,000		1,493,300	4,127,000
1950	231,031	11,431		8,762,514	13,289,552
1951	231,839	6,679	23,973	4,422,798	13,015,177
1952	239,366	9,027	30,790	8,179,305	13,002,364
1953	234,250	7,350	29,119	5,961,762	12,616,752
1954	113,502	3,062	11,600	2,357,200	4,828,900
1955	195,716	3,577	18,300	2,823,500	8,214,500
1956	209,089	4,415	21,800	2,947,300	10,176,400
Total	2,347,974	76,261	152,983	64,394,015	139,344,708

TABLE 8.—*Production of the Metaline (Bella May) mine, 1906–51*

[From Fulkerson and Kingston, 1958, p. 21]

Year	Ore (tons)	Silver (ounces)	Pounds		
			Copper	Lead	Zinc
1906	26	45		34,100	
1917	30	59		34,811	
1918	157	236		163,536	
1923	33	46		29,945	
1924	749	1,093		732,613	
1925	289	460		231,378	
1926	160	248	117	128,150	
1937	7,499			116,500	728,400
1938	35,064			605,500	4,206,000
1939	17,696			276,404	1,705,000
1940	24,883			446,300	2,852,000
1941	65,157	1,375		1,704,492	5,877,179
1942	68,280			912,449	6,162,400
1943	46,322			587,104	3,594,000
1944	49,486	2,664		2,047,800	3,664,200
1945	40,317	1,800		1,280,000	3,446,300
1946	36,925	765		542,000	2,300,000
1947	29,534	800		420,000	1,902,250
1949	5,317	28		18,800	426,370
1951	3,556	91	85	34,854	80,848
Total	431,480	9,710	202	10,346,736	36,944,947

MINERALS OF THE ORE DEPOSITS

In the following paragraphs the minerals in, or closely associated with, the ore deposits are listed alphabetically. Many of the minerals, as can be noted by the descriptions below, occur in small quantities, some only as a few scattered grains at one or two localities. Most ore bodies consist very largely, or entirely, of only six minerals—sphalerite, galena, pyrite, dolomite, calcite, and jasperoid. These minerals are described in more detail under principal ore and gangue minerals of the replacement deposits on pages 63–64. Dolomite, calcite, and jasperoid were partly described under hydrothermal alteration on pages 52–56.

Anglesite, $PbSO_4$.—The only anglesite noted during the present investigation was a small amount partly coating a crystal of galena in one of the high stopes in the western, or Bella May, workings of the Metaline mine. Park and Cannon (1943, p. 59) found anglesite at only one locality, in the Pend Oreille mine on the 300-foot level, where it occurred as tiny crystals on paligorskite.

Azurite, $2CuCO_3 \cdot Cu(OH)_2$.—Azurite is a very rare mineral in the district. A few thin films of azurite, closely associated with malachite and tetrahedrite, were seen in the white quartz veins in the upper prospect diggings at Uncas Gulch.

Barite, $BaSO_4$.—Barite is an uncommon mineral of the district, except at Lead Hill where it is locally abundant in the ore and altered zones. According to Delos Underwood, former superintendent of the Grandview mill (oral commun., 1955), several large shipments of ore in 1955 from the Lead Hill property contained 2 percent barite. The barite at Lead Hill, further mentioned on page 83 and illustrated on figure 22, is typically in light- to medium-gray irregular grains and patches. Small grains of barite are generally difficult to distinguish from the associated dolomite. A few narrow veinlets of barite occur locally at Lead Hill. Barite has been identified at a few places and in very small quantities in dolomite in the Metaline and Pend Oreille mines. Small crystals of light-brown barite on coarse calcite (fig. 18) were found in a fairly large cave between the 2200- and 2000-foot level workings of the Pend Oreille mine.

Calcite, $CaCO_3$.—Calcite is a very common constituent of the ores throughout the district, although on the average it is far less abundant than crystalline dolomite. The main physical properties and modes of occurrence of calcite are given chiefly on pages 54–55.

Carbonaceous globules.—Carbonaceous globules—the anthracite of Park and Cannon (1943, p. 59–60)—are included with the minerals of the ore deposits, even though they are not strictly mineral species, largely for simplicity of arrangement and because they are extremely minor, although somewhat unusual constituents. The carbonaceous material occurs as shiny black globules or buttons generally one-eighth inch or less in diameter. They occur in quartz, dolomite, and calcite associated with the ores or with strongly altered bodies. Black globules are fairly common in the dump material at the Wolf Creek mine and were seen very sparingly and widely distributed in the ore bodies of the Pend Oreille, Metaline, Grandview, and Lead Hill mines and at a few other prospects and surface croppings.

Globules collected by Park and Cannon (1943, p. 59–60) show about 90 percent fixed carbon and burn clean with no fusing and little residue. No radioactivity was noted in a few globules collected during the present investigation. The carbonaceous buttons probably formed from finely divided carbonaceous material in the gray limestone of the Metaline which was expelled during alteration processes and concentrated in tiny globules.

Cerussite, $PbCO_3$.—In the oxidized parts of the ore bodies cerussite is widely distributed throughout the region, but in bulk it is a very minor constituent of the ores. Some cerussite is gray or dark gray and tabular in form, although most of it occurs in vugs as fine white slender crystals an inch or less in length, commonly closely associated with galena and at places smithsonite. Cerussite is relatively abundant in some of the upper openings in the western, or Bella May, workings of the Metaline mine, and it occurs scattered in the higher workings of the Pend Oreille and Grandview mines.

Chalcedony, SiO_2.—Chalcedony is rare. It locally forms narrow stringers in fractures in the mine workings and rocks near the surface. It is probably of supergene origin.

Chalcocite, Cu_2S.—The only occurrence of chalcocite reported in the district is by Park and Cannon (1943, p. 54) who noted a small amount in a prospect cut in the Uncas Gulch area.

Chalcopyrite, $CuFeS_2$.—Chalcopyrite is a very rare mineral in the mapped area; it was recognized only at one place, in drill hole U.S. 43, in association with molybdenite and pyrite in the Gypsy Quartzite, as mentioned below under molybdenite.

Cuprite, Cu_2O.—Cuprite is very rare in the district. It was not identified during the present investigation, but Park and Cannon (1943, p. 56) noted a few grains in a specimen of partly oxidized calcite and white quartz rock in the Uncas Gulch area, where cuprite was associated with black copper oxide, malachite, and azurite.

Dolomite, $CaMg(CO_3)_2$.—Dolomite is by far the most abundant and widespread gangue mineral of most of the replacement deposits, although locally in some ore shoots it is exceeded by quartz (chiefly jasperoid) and in a few by calcite. The principal physical properties and modes of occurrence of dolomite are given chiefly on pages 52–54.

Galena, PbS.—Almost the entire output of lead from the district is obtained from galena which is found in varying quantities in almost all the large replacement ore bodies as described chiefly on page 63. The galena contains only a trace of silver.

Gold, Au.—A small quantity of gold in well-worn particles has been recovered from the stream gravels, chiefly along the banks of the Pend Oreille River at the Schierding and Harvey placers.

Graphite, C.—A few small and irregular flakes of graphite are very widely scattered along some faults,

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especially in or near the black argillaceous beds of the Ledbetter Slate. Probably considerable fine-grained graphite occurs locally in some of the soft gougy borders of a few faults. Some small black particles and minute stringers of black material in parts of the ores may be largely graphite.

Greenockite, CdS.—A very small amount of greenockite was seen on one specimen of oxidized ore at the Z Canyon mine, and Park and Cannon (1943, p. 55) found it on several pieces of dump material near the shaft in the western workings of the Pend Oreille mine.

Limonite.—Limonite, here used as a field name for fine-grained aggregates of ferric oxide that contain varying amounts of water, is found at many places in the district, particularly at or near the surface of pyrite-bearing rocks from which it has largely been derived. Yellowish, reddish, and brownish limonite is especially common and is vividly seen in large and small masses at many places along the steep walls of the gorge of the Pend Oreille River near Metaline Falls, at the Riverside mine, and at the Flusey prospect. Limonite in fine botryoidal form was seen on the east bank of the Pend Oreille River at the Canadian border. Limonitic iron-stained rock occurs locally in the workings of the mines, especially along fractures and faults. It is common in the strongly pyritized rock of the Yellowhead mine.

Malachite, $CuCO_3 \cdot Cu(OH)_2$.—The only two known occurrences of malachite in the area mapped for this report are at the Oriole mine and in the Uncas Gulch area. It is present in minor quantities at both localities, commonly as thin coatings. At Uncas Gulch malachite is closely associated with tetrahedrite and azurite in white quartz veins situated high on the slopes northeast of the stream valley.

Marcasite, FeS_2.—Marcasite is a rare mineral in the mapped area. It was identified with certainty only in a small vug in the higher workings of the Grandview mine off the main incline, although it probably occurs sparingly elsewhere. The marcasite is probably of supergene origin.

Molybdenite, MoS_2.—A few small flakes of molybdenite were found in the diamond-drill core of hole U.S. 43, 1,700 feet west of the Sullivan glory hole in the valley of Flume Creek. This drill hole, on the west or upthrown side of the Flume Creek fault, showed scattered flecks of molybdenite, chalcopyrite, and pyrite in the Gypsy Quartzite at depths between 240 and 250 feet.

Paligorskite.—Scattered through all the large and many of the small ore bodies is the somewhat unusual mineral, paligorskite, a complex hydrous magnesium-aluminum silicate of the sepiolite group. Paligorskite occurs in white to dirty-gray thin (one-eighth in. or less) tough raglike forms (fig. 25) commonly an inch to several inches in longest dimension, although at places individual "rags" a foot long were noted. Paligorskite occurs typically along fractures and as dangling masses in some caves. In the mine workings, where it is best observed, paligorskite at many places is wet and slimy, similar to a very damp newspaper or rag. When much paligorskite is mixed with ore, it is a considerable nuisance during milling. Paligorskite, in general, shows no marked change in abundance throughout the total vertical or horizontal range in the mine workings, although it seems to be less abundant near the surface. This may be due to leaching by surface waters, as pointed out by Park and Cannon (1943, p. 59), or to the fact that this mineral is difficult to detect near the surface because it dries out, becomes brittle, and is thus easily removed by weathering processes.

The authors of the present report believe that paligorskite is of hypogene origin, and that it formed at a late stage after most of the sulfides and coarse carbonates were developed. At many places paligorskite cuts ore, jasperoid, and the carbonates; elsewhere, fragments of these minerals are included in paligorskite. A hypogene, rather than supergene, origin for this mineral is indicated by its close association with altered and mineralized bodies, and its presence in the deepest of the Pend Oreille mine workings, about 2,000 feet below bedrock surface and well below the water table.

Pyrite, FeS_2.—Pyrite, described chiefly on page 64, is widely and erratically distributed through some of the ore bodies. At places, such as the Yellowhead and

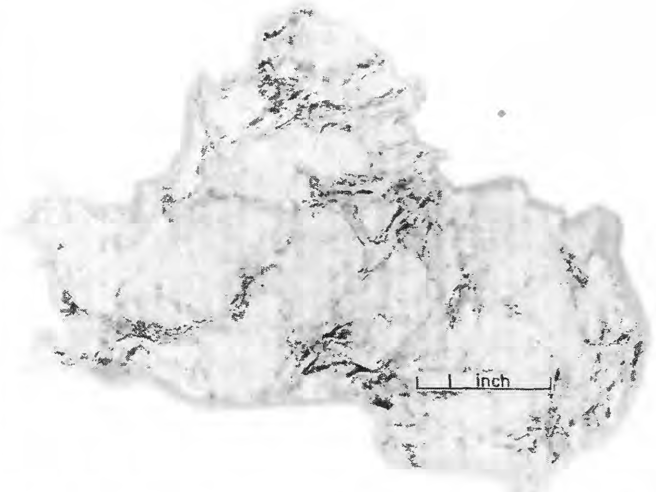

FIGURE 25.—Paligorskite showing typical raglike form. Specimen found hanging from fracture in stope of Pend Oreille mine.

Lucky Strike ore bodies, it is very abundant, but elsewhere over large areas in the three principal mines it is absent or else sparsely distributed in the replacement bodies. Minor amounts occur locally in some vein deposits of the district.

Quartz, SiO_2.—Quartz is one of the most widespread and generally abundant minerals of the ore deposits. It is especially common as fine-grained light- to dark-gray jasperoid in the ores of the Grandview, Metaline, and Pend Oreille mines. The mode of occurrence and physical properties and varieties of quartz are described chiefly on page 54.

Smithsonite, $ZnCO_3$.—Scattered throughout some of the oxidized parts of the ore bodies are small amounts of smithsonite, although some smithsonite was reported to have been mined many years ago in the old upper and western workings of the Pend Oreille mine. Smithsonite occurs chiefly in white to light-gray cellular or "dry bone" form, although locally it is gray and botryoidal.

Sphalerite, ZnS.—Sphalerite so far has been the most abundant, widely distributed, and economically important ore mineral of the district. It is described chiefly under principal ore and gangue minerals of the replacement deposits on page 63.

Tetrahedrite, $Cu_8Sb_2S_7$.—A few small grains of tetrahedrite were seen in quartz veinlets in carbonate rock at one shallow prospect high on the slopes in the Uncas Gulch mineralized area. Park and Cannon (1943, p. 55) report a few spots of tetrahedrite (or tennantite) in the Pend Oreille ore.

Wulfenite, $PbMoO_4$.—Wulfenite is a rare mineral in the district. The only known occurrences are those reported by Park and Cannon (1943, p. 59) in oxidized ore at the Metaline (Bella May) mine and at the old Diamond R diggings, about 1,000 feet northwest of the head of the West Contact raise (pl. 1). The mineral is in colorless or pale-yellow plates; on one specimen they noted small wulfenite crystals on the surface of a larger crystal of cerussite.

TYPES OF ORE DEPOSITS

Three types of ore deposits—replacement, vein, and placer—are found in the mapped area. By far the most widespread, and the only large and productive ore bodies yet known, are replacement deposits, accompanied by minor cavity filling, in limestone and dolomite. At a few places quartz veins and veinlets contain scattered grains of sulfides, chiefly sphalerite and galena, and locally tetrahedrite. Small amounts of gold have been recovered from placer deposits in the stream gravels, chiefly along the banks of the Pend Oreille River.

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Except for the Oriole mine, which is in the Monk Formation, all the zinc-lead ore produced in the district has come from deposits in the Metaline Limestone. However, a few miles north of the mapped area, in British Columbia, important zinc-lead replacement deposits occur in dolomitized limestone of the Maitlen (Laib) Phyllite at the Reeves-MacDonald mine (Fyles and Hewlett, 1959, p. 139–145).

REPLACEMENT DEPOSITS

The typical replacement deposits are irregularly shaped bodies that vary greatly in size. Most occur in the Metaline Limestone, 35–200 feet stratigraphically below the overlying Ledbetter Slate. Commonly, mineralized zones conform in a very general way to the dip of the enclosing strata, although, in detail, individual ore shoots crosscut bedding at varying angles, some high. The principal, and generally the only, ore minerals are sphalerite and galena; sphalerite is generally predominant. Very small quantities of silver and copper are recovered in some ore. Locally, pyrite is abundant; elsewhere, it is rare or absent. The gangue is largely composed of varying amounts of jasperoid, crystalline dolomite, and coarse calcite. A few other minerals, as well as unaltered limestone, occur locally in some mineralized bodies. The rock consisting of the gangue and ore minerals is typically medium to moderately dark gray, massive, and faintly to strongly brecciated. Small cavities and, in places, large caves are locally associated with the ore deposits.

AREAL DISTRIBUTION

Mineralized replacement bodies are scattered throughout almost the length of the graben shown on plate 1, from the Bailey and the Tom Cat prospects in the north to scattered sulfides found in dolomite about three-fourths of a mile southeast of Lost Lake. By far the most productive bodies yet discovered lie in the southern half of the mapped area centering around Metaline Falls. In the northern part of the district, north of the mouth of Slate Creek, zinc and lead minerals are present in carbonate rock at many small prospects, in a few mines, and in the core of some exploratory drill holes. In this northern region the largest replacement bodies so far disclosed are in the Lead Hill and Lead King areas (pl. 1).

SIZE AND SHAPE

The mineralized replacement bodies range in size from a few feet to several hundred feet or more in length and breadth. One of the longest mineralized bodies yet discovered is in the western workings of the Pend Oreille mine where connected stopes extend betwen irregularly and closely mineralized ground for about 800 feet (section *C–C′*, pl. 3). Most individual ore bodies are from 15 to 25 feet high; one ore body (stope 7–19) in the Pend Oreille mine is 115 feet high, and several ore bodies off the 2200-foot level in the same mine have been stoped vertically for distances of 60–90 feet.

The shape of most of the mineralized replacement bodies is highly irregular. Some ore bodies have poorly defined tabular forms whose principal axes are alined roughly parallel to the bedding of the enclosing rock. (See sections on pls. 3, 4.) A very few ore bodies can be classed as bedding replacements, but most are irregular replacement deposits in a zone that only roughly parallels bedding. Some ore bodies along faults are markedly elongate in form; these, in places, pass irregularly and imperceptibly into forms that coincide roughly with bedding.

The sulfide minerals are so irregularly distributed within the ore bodies that core drilling in advance of mining has at places given very erroneous ideas on the grade of ore. Some drilled areas were much lower grade than anticipated; others were much higher. One outstanding example of the latter type is found in stope 7–19 of the Pend Oreille mine, which yielded a large body of ore over a vertical distance of 115 feet although the core from a hole drilled through the center of this body showed only a 5-foot section of ore in spite of the fact that core recovery was about 90 percent.

CHARACTER OF THE ORE

Most of the ore occurs in a medium to dark-gray irregularly silicified dolomite breccia (figs. 26–28). The degree of brecciation ranges from intense to vague, not uncommonly within a distance of a few feet (fig. 29); some massive and nonbrecciated bodies of mineralized rock grade irregularly into the breccias. The breccias consist typically of fragments of fine- to medium-grained dolomite in a matrix of medium- to coarse-grained crystalline dolomite, locally some coarse calcite, and variable amounts of jasperoid and sulfide minerals. The silica and sulfide minerals irregularly replace both the fragments and matrix of dolomite, although they are more commonly found in the matrix. Some breccia or massive rock is completely silicified. Sphalerite and galena, although generally in silicified rock, occur locally in coarse calcite or fine- to coarse-grained dolomite, or in gray limestone. Some rich ore bodies of both lead and zinc have been found in coarse calcite surrounded by gray limestone, especially in the southeastern workings of the Pend Oreille mine off the 1900-foot level. At many places in the mines there is a concentration of ore, especially sphalerite, at or near the contact between jasperoid and coarse calcite. In the eastern workings of the Pend Oreille mine rich lead ore is commonly, but not everywhere, found near the base of the mineralized bodies and in association with strongly silicified rock.

Some ore bodies partially or completely obliterate faults and fractures, whereas others are cut or bounded

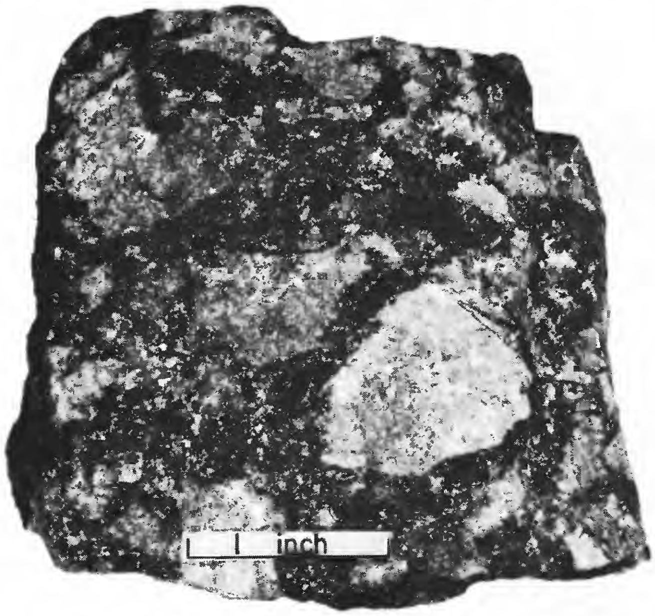

FIGURE 26.—Silicified and mineralized breccia, Sullivan glory hole. Fragments are chiefly light-gray fine-grained dolomite. Dark areas are interstitial material consisting chiefly of sphalerite, jasperoid, and coarse-grained dolomite.

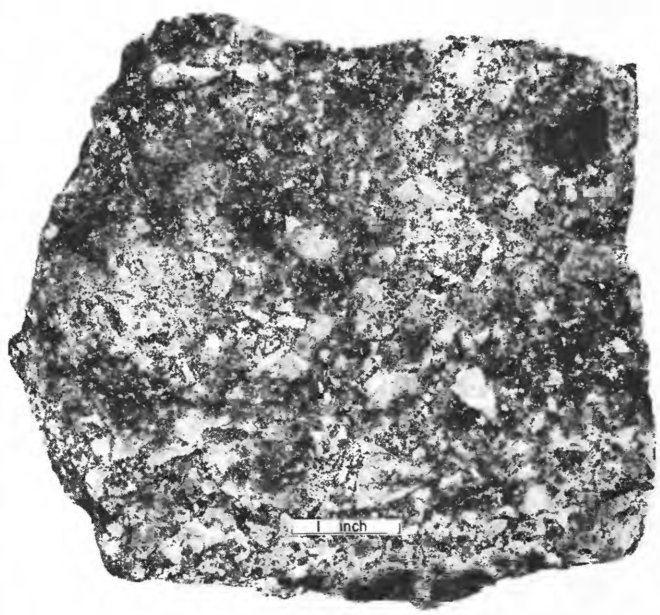

FIGURE 27.—Silicified and mineralized breccia, western workings of the Pend Oreille mine. In general, mineral content similar to that in figure 26, but contains some calcite and white quartz. Degree of brecciation strong, but less pronounced than that in figure 26.

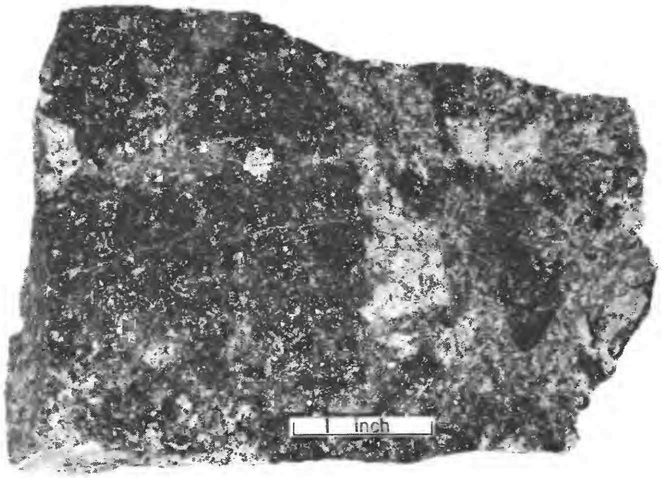

FIGURE 28.—Silicified and mineralized dolomite, faintly brecciated. Collected 2 feet from breccia shown in figure 27. Black areas consist chiefly of relatively high-grade sphalerite ore in jasperoid. Light areas are largely fine-grained to coarse-grained dolomite.

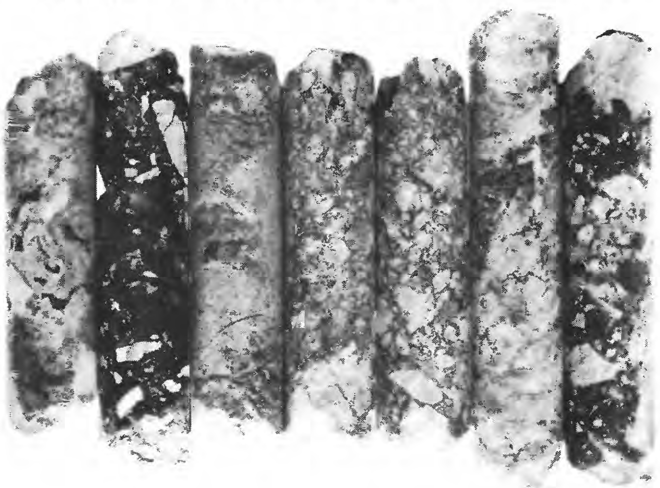

FIGURE 29.—Diamond-drill core from the main ore zone (upper part of the Metaline Limestone) of the district, Grandview mine area. Core shows how degree of brecciation of the dolomite may vary within a distance of a few feet or less. Core taken over a vertical interval of 10 feet.

by postmineral faults along which the ore minerals are locally polished or brecciated. Fault displacements that occurred after mineralization range from a few inches to several hundreds of feet.

Openings ranging in size from small cavities to large caves are scattered throughout the ore zone, especially along faults and fractures. Some earlier formed openings are partially to completely filled with calcite or calcite and dolomite, and locally with ore.

PRINCIPAL ORE AND GANGUE MINERALS

Only a few minerals are commonly found in the replacement ore bodies, but they range widely in relative abundance, color, texture, and mode of occurrence. The principal minerals are sphalerite and galena contained in a gangue of quartz—mostly jasperoid—dolomite, calcite, and locally pyrite.

Sphalerite and galena typically occur in scattered grains, small clusters, and in very irregularly shaped pods and lenses; galena is more commonly found in pods and lenslike forms. Sphalerite ranges in color from white (rare) to very pale yellow, yellow, and dark reddish brown, although most of the sphalerite is brownish red or, less commonly, pale yellow. Grains are mostly irregular in shape and generally range in size from minute specks to one-fourth inch across. Much of the ore shows, within distances of a few feet or even a few inches, considerable range in grain size and in the color variations of the sphalerite. Most of the galena is coarse grained, although locally fine-grained or "steel" galena is present. Cleavage surfaces are readily seen on most specimens of galena, but well-developed crystal faces are rare. Most of the sphalerite and galena is intimately associated with gray jasperoid (figs. 26–28); but some is in coarse dolomite or calcite, or in white quartz, and at a few places they directly replace unaltered or slightly altered limestone (fig. 16) or fine-grained dolomite rock. These minerals show no consistency in regard to distribution in the ore bodies, except that, locally, more galena than sphalerite is found near the borders of the ore bodies.

Light- to dark-gray jasperoid, chiefly described under "Silicification" on page 54, is almost everywhere irregularly associated with the ore deposits. It generally replaces crystalline dolomite, although some large masses of limestone and bedded dolomite are largely or entirely replaced by jasperoid.

Crystalline dolomite, described chiefly under "Dolomitization" on pages 52–54, is found in the replacement deposits at almost all places where sphalerite and galena are present. It typically is in light- to medium-dark-gray anhedral grains. In the ore breccias it commonly forms the matrix between fragments of fine-grained light-gray dolomite, as clearly shown in figure 21 and less distinctly, but far more typically, in figures 26–28. Elsewhere, crystalline dolomite occurs in large and small irregular bodies, locally as veinlets (fig. 23) or in distinct or fairly distinct concentrically banded forms (fig. 22), and in zebra-banded forms (fig. 30). At a few places in the mines, particularly in the Metaline mine, sharply defined veins of dolomite several inches thick are exposed for 25 feet or more.

Coarse crystalline calcite, as described under calcification on pages 54–55, is irregularly distributed through the ores in much the same manner as crystalline dolomite. Although calcite occurs locally in huge masses 50 feet or more in largest dimension, it is, on

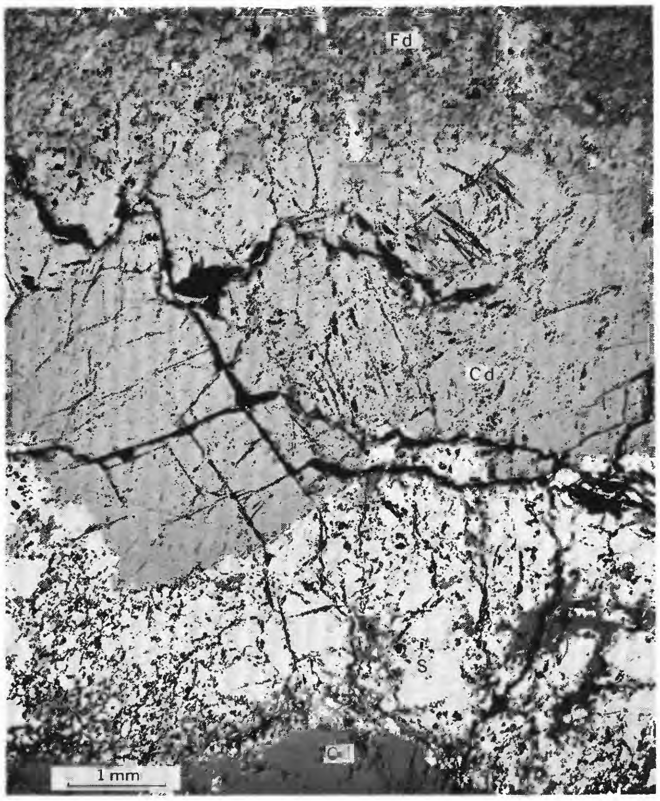

FIGURE 30.—Photomicrograph of sphalerite in zebra dolomite, Lakeview prospect. Sphalerite (S) replacing part of layer of coarse-grained dolomite (Cd). Coarse-grained dolomite alternates with layers of fine-grained dolomite (Fd) to form zebra structure. Reflected light. ×12.

the average, a far less abundant gangue mineral than crystalline dolomite. Most of the calcite is white to pale yellow, but locally it is gray or nearly black. Small grains, pods, stringers, veins, and small and large masses are commonly found both in and bordering the ores. Calcite crystals line, or partly line, some fractures, vugs and caves, and in places rest on fragments of cave breccia. Elsewhere, coarse calcite fills or partly fills caves. Locally, large bodies occur just beneath ore, especially in the eastern workings of the Pend Oreille mine. Some bodies composed almost entirely of calcite contain little or no ore, whereas others are very rich in ore. Some of the rich calcite ore bodies are largely surrounded by unaltered gray limestone. However, like the crystalline dolomite, some large bodies of coarse cleavable calcite are far removed from the sulfides.

Pyrite, in a variety of forms, is irregularly distributed through parts of the zinc-lead ore bodies. It is especially abundant in the ores of the Yellowhead mine where it is disseminated through the rock in isolated grains, pods, small stringers, and in narrow layers bordering brecciated fragments of the fine-grained dolomite country rock (fig. 21). In the other mines pyrite generally occurs in irregular forms scattered through the crystalline dolomite. At many places concentrations of pyrite occur at or near the contact of the Metaline Limestone and Ledbetter Slate. A few vugs contain well-developed crystals of pyrite, and in one cave a pyrite crystal was seen resting on fragments of cave breccia. Rare vugs contain filaments and spindles of pyrite.

AGE RELATIONS

Clearly defined crosscutting relations between sphalerite and galena are rarely found, although at some places, especially in the western workings of the Pend Oreille mine, galena was seen cutting sphalerite and at a few other places in this mine the reverse relation was seen. In many places sphalerite (fig. 31) or galena replace or crosscut jasperoid and to a lesser extent white quartz, but, locally, white quartz or jasperoid clearly penetrate or cut across either sphalerite or galena. At a few places galena was deposited on crystal faces of white quartz, as shown in figure 32, of a specimen from a vug in the Grandview mine. Sphalerite and galena commonly cut across coarse calcite or dolomite (fig. 30), or they penetrate the cleavages of these two carbonate minerals; but else-

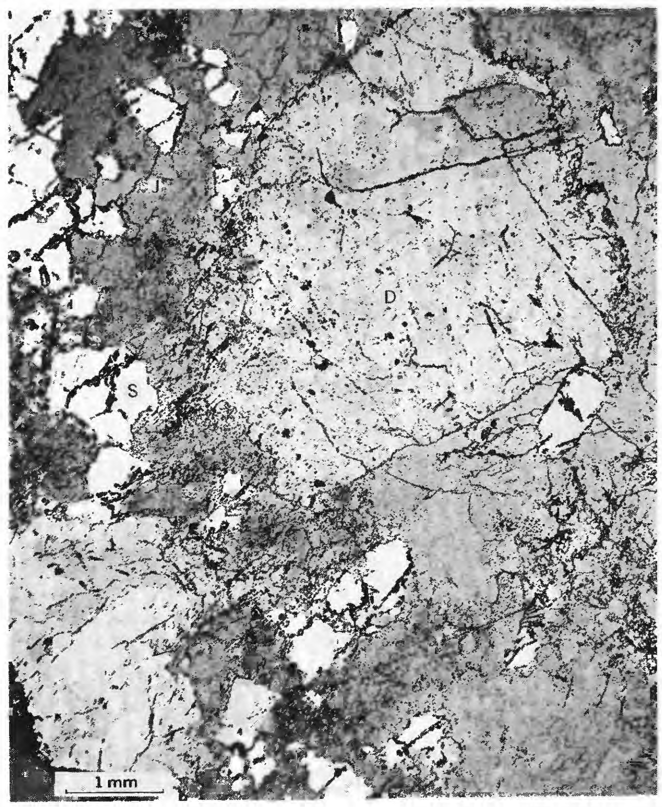

FIGURE 31.—Photomicrograph of typical zinc ore, Pend Oreille mine. Shows irregularly shaped grains of sphalerite (S) in jasperoid (J) that has replaced part of the dolomite (D). Reflected light. × 12.

where, calcite or dolomite veinlets or seams cut either one of the principal sulfides.

The conflicting age relations cited above indicate that deposition of the ore and gangue minerals overlapped, or that it occurred in pulsations, or both.

STRATIGRAPHIC POSITIONS WITHIN THE METALINE LIMESTONE

By far the most productive ore bodies occur in an irregular zone lying 35–200 feet below the Ledbetter Slate, as can be seen in the sections on plates 3 and 4 showing some of the stopes in the Pend Oreille, Grandview, and Metaline mines. The replacement ore bodies along the southeastern slopes of Lead and La Sota Hills and along the western slopes of Lead King Hills are probably in this upper stratigraphic zone.

Beyond the main ore zone, small irregular replacement bodies or scattered grains of sphalerite and galena occur at widely distributed intervals in the Metaline Limestone over almost its entire stratigraphic thickness from just below the Ledbetter Slate to bedded limestone within a few hundred feet or less of the base (Lower quarry). A few mineralized replacement bodies occur in the bedded dolomite unit at much lower stratigraphic positions than the main ore zone. Among these are the deposits at the Yellowhead and Lucky Strike mines and the Scandinavian and Lakeview prospects. Although it is not possible to assign definite stratigraphic positions to these mineralized bodies, the authors believe that they all lie somewhere in a zone 500–1,200 feet below the top of the Metaline, but not at any one restricted zone within this interval. Abundant pyrite is commonly, but not everywhere, associated with these stratigraphically lower deposits, especially in the Yellowhead and Lucky Strike deposits. Sphalerite and pyrite are present in the core from a deep drill hole (U.S. 24) that was put down in the western workings of the Pend Oreille mine. This iron-rich mineralized zone, shown in section *C-C′*, plate 3, lies 1,100–1,170 feet stratigraphically below the slate. The iron-rich Yellowhead ore body, 1,600 feet to the north (section *A-A′*, pl. 3), may possibly, as suggested by other workers in the district, be at the same stratigraphic position as that cut in this hole. However, the Ledbetter Slate over the Yellowhead ore body has been removed by erosion, and any definite stratigraphic correlation between the two iron-rich bodies on the basis of abundant introduced pyrite is highly speculative.

FIGURE 32.—Crystal faces of quartz partly surrounded by fine-grained galena, Grandview mine. Natural size.

The replacement deposits found in the bedded limestone unit are all small and widely scattered bodies; commonly, only a few grains of sulfides are present in dolomite or dolomitic limestone. Mineralized ground at the Lower quarry, on the ridge west of Lime Lake, and in the old upper Dumont prospects north of Uncas Gulch (pl. 1) are all in this lower stratigraphic position. The mineralogy and mode of occurrence of these deposits differ little from other weakly mineralized parts of the Metaline Limestone, except that brecciated host rock associated with the sulfides is uncommon or absent in the bedded limestones.

STRUCTURAL AND STRATIGRAPHIC CONTROL OF REPLACEMENT DEPOSITS

One of the outstanding economic features of the district is that practically all zinc and lead ore so far produced has come from the upper 200 feet stratigraphically of the Metaline Limestone. This stratigraphic control is far more evident than the individual structures that have localized ore shoots, although, as explained in following paragraphs, major structures were probably the main guiding channelways for the introduction of the ore-bearing solutions, and in a few places structures such as folds and faults locally concentrated the ore.

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. Park and Cannon (1943, p. 52), very logically suggest that ore deposition was aided by the damming action of the relatively impervious Ledbetter Slate. However, under such a theory it is difficult to explain why the main ore bodies lie 35 feet or more below the slate rather than directly beneath it, unless it is further assumed that a gaseous or fluid blanketlike barrier formed in the uppermost strata. Another explanation is that the original limestone beds in this zone were more easily replaced than others through which the ore solutions passed, owing either to the chemical or physical character of the rock, or to both. Although it would explain much, there is little evidence to suggest that a widespread network of cavities and caves existed in this upper zone of the Metaline Limestone before the introduction of the dolomitizing and ore-bearing fluids and acted as a guide for the fluids. Both of these explanations are difficult to prove because the limestone beds in and near the ore bodies are generally so thoroughly altered to crystalline dolomite, jasperoid, and calcite that both the original chemical properties, as well as physical properties, such as porosity and permeability, are obliterated.

In the Yellowhead mine, ore locally follows bedding planes, but elsewhere in the district the relation of ore to bedding is vague or absent, except that the major ore zones follow the strata in a general way. This vague relation of ore to bedding is due in large part to the fact that at most places in the district bedding planes are poorly developed in the upper part of the gray limestone. At a few places ore bodies appear to roughly follow shaly seams in the upper part of the Metaline; but at many more places abundant ore is found where little or no shale is present, or else where the individual ore shoots cut across shale seams. At a few places ore deposits are clearly alined along premineralization faults and elsewhere they are associated with minor folds; the vast bulk of the ore, however, 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.

The upper part of the Metaline Limestone—the main ore horizon—is a poorly bedded rock, and thus a close relation between ore and bedding is generally absent. Furthermore, the sparse bedding planes near, and generally for considerable distances from, the ore bodies are commonly obliterated by the alteration products, especially crystalline dolomite. The overall relation of ore to the dip of the beds is usually determinable only by the position of these bodies in respect to the overlying and generally conformable contact of the Metaline Limestone and the Ledbetter Slate, a relation which is clearly shown in the sections on plate 3, and which is generally brought out only by a study of diamond-drill holes that extend downward from the surface through the slate or upward from the mines into the slate. The limestone-slate contact is very sparsely exposed in most of the mine workings, because ground at this horizon is generally poorly mineralized and unstable.

A reference to the accompanying structure contour map of part of the mineralized area (pl. 2) shows that the individual ore shoots, as outlined in general by the mine stopes of the Pend Oreille and Grandview mines, are parts of one major mineralized body. The principal ore bodies west of the Pend Oreille River lie southeast of the Yellowhead fault and trend northeastward roughly parallel to this fault; those east of the Pend Oreille River are irregularly disposed along the axes and flanks of a broad and gently plunging anticiline and syncline, both cut by many faults. The ore bodies so far mined east of the river show no definite relationship to major structures. Several large ore shoots and many smaller ones definitely trend northeast; these may likely have resulted from replacement along incipient fracture zones of similar trends, for northeastward-trending fractures are very common in the Metaline district. At a few places in the mines, northeastward-trending fractures and faults in the country rock fade out in the mineralized ground, suggesting that the alteration and mineralizing solutions followed along and obliterated these structures.

Probably the outstanding example of local structural control of ore bodies along a premineral fault is found in the southeastern, or upthrown, side of the Grandview fault (pl. 2) which extends at least 2,500 feet from the Grandview mine into part of the workings of the Pend Oreille mine. The ore bodies in the footwall of this normal fault were higher grade than most others in the mines, especially in lead. The concentration of ores along the fault zone is a result of premineralization movement that produced a fractured zone which, in turn, formed a channelway for the ore solutions. The higher concentration of the ores in the footwall rather than the hanging wall of this fault is explained in part by migration of the ore solutions into and along bedding slip surfaces that dip, as a result of drag, into the fault on the footwall side. Another example of local structural control is the localization of ore near the premineralization Metaline thrust in the eastern, or Blue Bucket, workings of the Metaline mine (pl. 4) where at many places the ore solutions migrated along and replaced sheared layers in carbonate rock (fig. 16).

Ore is concentrated locally in minor folds in the South crosscut area of the Metaline mine, and possibly at a few places in the Pend Oreille and Grandview mines, although in the last two mines minor folds are difficult to recognize because of the usual absence of bedding in the carbonate rock, the common presence of nearby faults, and the general lack of sufficient drill holes into the overlying slate to determine the structure definitely.

It is noteworthy that, broadly considered, the known major ore deposits, which are those in the Metaline, Pend Oreille, and Grandview mines, are all in strongly faulted areas within the valley graben. The ore bodies of the Metaline mine are in or adjacent to the Metaline thrust and the Blue Bucket and Bella May faults; the ore bodies of the Pend Oreille and Grandview mines are also in highly fractured and faulted ground, probably in a thrust plate or above a zone of local thrusts related to the nearby Washington Rock thrust (pl. 1). The early thrusting and subsequent movements during the settling of the graben produced low- and high-angle faults, bedding slips, and highly fractured ground which provided the channelways that guided the ore solutions into these favorable areas. Thus, strongly deformed areas containing the upper beds of the Metaline Limestone are favorable ones in which to seek ore in this district.

VEIN DEPOSITS

All vein deposits so far discovered in the district are relatively small and widely distributed bodies of quartz and sparse sulfides. They occur chiefly in the Metaline Limestone, although Park and Cannon (1943, p. 51–52) describe somewhat similar deposits a few miles from the borders of the mapped area that are in formations both stratigraphically below and above the Metaline Limestone.

Vein deposits in the area mapped for this report are found at the Sanborn prospect on Lead Hill and the upper prospects at Uncas Gulch, at several shallow diggings on the western slopes of La Sota Hill, and at several places in the large mass of dolomite one-fourth mile northwest of the mouth of Styx Creek (pl. 1).

The sulfide minerals are chiefly galena and sphalerite locally accompanied by silver-bearing tetrahedrite and pyrite. The gangue is a vitreous milky-white quartz, locally containing fragments of country rock or calcite. The deposits locally occur in sharply defined veins, generally less than a foot thick, but more commonly in irregular bodies consisting of pods and stringers or as a network of stringers and small veins that extend outward from and between massive bodies of quartz 10 feet or more thick. The sulfides, insofar as it could be determined from scanty exposures, are generally irregularly distributed throughout the quartz gangue in small and generally lean shoots. No ore, other than perhaps a few tons of hand-sorted material, is known to have been produced from these deposits.

The genetic relationship between these deposits and the economically far more important replacement deposits is not known. Although most of the ore in the replacement bodies is largely in gray to black jasperoid, some is in a milky-white quartz gangue that is similar to the quartz of the vein deposits. For this reason the authors believe, but none too firmly, that both types of deposits were formed during the same general period of metallization; perhaps the vein deposits formed during a late pulse of the regional mineralization.

PLACER DEPOSITS

A few placer deposits that have yielded a small amount of gold have been worked intermittently for many years. They are of very minor economic importance when compared to the replacement deposits. The gold is irregularly distributed in the alluvial sands, gravels, and boulders that occur chiefly along the banks of the Pend Oreille River; a few placer deposits are along streams tributary to the Pend Oreille. The deposits consist of well-rounded fragments, chiefly of rocks found in the surrounding area, although many other types of rock that are foreign to the district are present. Gold obtained by Park and Cannon (1943, p. 78) from several pans of black sand at the Schierding placer showed flat forms with rounded edges, indicating that it had traveled long distances. These authors also state that one gold nugget of about 2 pennyweight was reported to have been recovered from this placer deposit.

OXIDATION OF ORE DEPOSITS

Oxidation of the ore deposits in the district has been very slight, although the products of oxidation, principally iron oxide derived from pyrite, are widely distributed. The generally shallow zone of oxidation, commonly a few feet or less thick, in the result of the removal of most of the weathered material by the scouring action of the Pleistocene glaciers.

At the surface, galena is almost everywhere unaltered, but, locally, sphalerite is partially leached, and at places vugs and small cavities, either with or without iron stain, suggest former sphalerite. Some croppings show smithsonite, and in places cerussite, in a gangue of jasperoid, white quartz, and soft carbonate rock. Other products of oxidation, such as malachite, azurite, and rarely cuprite, anglesite, and greenockite, occur at a few places in isolated or scattered grains and small patches. However, at many places iron-stained rock and limonite can be seen at the surface in bodies measuring a few feet to 500 feet or more in length, especially in the pyrite-rich rocks that are well exposed in the steep slopes of the Pend Oreille Rievr gorge near Metaline Falls and farther north in the area extending from the Riverside mine to and beyond the Flusey prospect (pl. 1). Most exposures of ore in the mines show fresh grains of sphalerite and galena, and, where present, of pyrite. However, locally, such as in the higher workings of the Metaline and Pend Oreille mines and elsewhere, small oxidized patches of ore contain smithsonite and cerussite. A few vugs contain blades of cerussite an inch or more in length. Limonite, commonly in fracture zones, occurs scattered through the larger mines at varying depths, locally as much as several hundred feet below the surface.

SOURCE OF THE ORES

The ore bodies of the Metaline district are believed by the authors to have been deposited chiefly by hydrothermal solutions genetically related to the magma that in part formed the Kaniksu batholith and smaller outlying bodies of rock. The ores were probably introduced into the carbonate rock late in the igneous history, after partial or complete solidification of the batholith, as postulated by Park and Cannon (1943, p. 53). They noted the similarities between the replacement deposits in the Metaline Limestone and the replacement bodies in the igneous-metamorphic zone (situated beyond the area mapped for the present investigation), and they tentatively assumed that both types were deposited during one period of mineralization.

Although no igneous bodies of the Kaniksu batholith are in the mapped area, except a few dark mafic dikes that are probably closely related genetically to this intrusive body, several large masses are a few miles or less distant, as shown on the geologic map of Park and Cannon (1943, pl. 1). It is probable that outlying bodies or apophyses of the batholith extend beneath parts of the area mapped, because large bodies of similar granitic rock crop out several miles north of the mapped area in British Columbia; these pass northward into the Nelson batholith, which, like the Idaho batholith to the east of the Metaline district, is correlated with the Kaniksu. Thus, the mineralizing solutions in the Metaline district probably originated in or beneath the batholith and migrated upward and probably laterally along the major faults and fractured zones, or at places along the borders of the batholith. However, the final place of deposition of ore from the fluids was controlled in part by relatively minor structural features and, above all, by the readily replaceable beds in the upper part of the Metaline Limestone.

MODE OF FORMATION OF THE ORE AND ALTERED BODIES

The detailed features of the individual ore bodies, such as irregular brecciation, abundance of closely associated alteration products, and inconsistent and confusing paragenesis of the principal minerals, indicate that the mode of formation was moderately complex and probably extended over a considerable period of time. One of the principal factors causing these features is a repeated settling of the graben block during mineralization, resulting in the development of crushed zones, fractures, and faults which periodically afforded channelways for the migrating hydrothermal fluids. Especially susceptible to fracturing were the brittle fine-grained dolomites that, before the main period of ore deposition, formed irregular bodies in the upper gray limestone unit of the Metaline Limestone; evidence for this is the abundance of angular fragments of this type of dolomite in compact breccias healed by coarse dolomite, calcite, jasperoid, and ore.

Park and Cannon (1943, p. 45–46) recognized the complex relations of jasperoid, ore, coarse calcite, and coarse dolomite and aptly stated that the origin of one must consider the origin of the others. Knopf (in Westgate and Knopf, 1932, p. 49–50, 52) mentions the occurrence of coarse crystalline calcite at Pioche, Nev., similar to that found at many places in the Metaline district, around the peripheries of many replacement deposits in limestone. He suggests two possible modes of origin. The first is that calcite formed from the recrystallization of fine-grained limestone and that the "spent or depleted ore-forming solutions, though no longer able to replace the limestone that surrounds the ore body by ore, were able to recrystallize it." The other suggestion is that calcite was "the most advanced member of the vanguard in front of the growing ore body." Although calcite probably formed in both ways in the Metaline district, there is evidence of a sort to suggest that much of it formed in front of the growing ore body, because many of these calcite bodies, both adjacent to and far removed from the borders of the main ore zone, are cut by ore minerals. Considerable coarse calcite was also deposited contemporaneously with the ore.

Most, but not all, coarse-grained crystalline dolomite associated with the ores resulted largely from hydrothermal solutions that preceded and, to a lesser extent, accompanied the introduction of jasperoid and the sulfides. Parts of the crystalline dolomite, however, formed by recrystallization of the older bedded dolomite during deformation. A few large areas of crystalline dolomite are far removed from known bodies of ore, although most are in or adjoining silicified areas. Hewett (1928, p. 859), in a discussion of the origin of dolomite associated with ore, mentions that magnesium is freed during the silicification of dolomite, and that this magnesium could accomplish alteration to dolomite of any limestone through which the solution later passed. As described previously, most of the ore minerals are in jasperoid, and, in turn, jasperoid commonly replaces crystalline dolomite. Some large bodies of jasperoid contain no ore, and at many places jasperoid is associated with either coarse calcite or coarse dolomite. Moreover, all gradations can be seen locally between small fractures in carbonate rock filled with jasperoid and quartz and completely silicified rock. 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.

Repeated movements during the adjustment of the graben developed new channels and reopened many of the older ones, resulting in migration of the hot solutions into unaltered or slightly altered parts of the host rock as well as into areas that had been strongly altered previously. Therefore, both the physical and chemical environments were changed locally, in places probably several times. These factors in conjunction with the others just described are believed to account for the complicated age relations among the ore and gangue minerals, the irregular shapes and varying sizes of the altered bodies, and the irregular distribution of the breccias.

MINES AND PROSPECTS

The mines and prospects, arranged in alphabetical order, are described on the following pages. The only mines in which any substantial amount of work was being done during the present investigation are the Pend Oreille, Grandview, and Metaline mines, and, to a far lesser extent, the Lead Hill mine. In addition to the principal mining operations, several companies have put down a total of many thousands of feet of exploratory drill holes in outlying areas, principally by diamond drill. These drill holes have furnished much valuable information concerning the extent of mineralization in parts of the district as well as supplying geologic information relating to structure and stratigraphy.

BAILEY

The Bailey group of 17 unpatented claims and 2 fractions borders the international boundary and lies across the long ridge that trends northeast from the Slate Creek Lookout (pl. 1). The property, which was formerly known as the Bailey and Hanson group, is held (1955) by Ray A. Bailey and associates of Metaline Falls. It can be reached by a good dirt road that branches from the road to the Slate Creek Lookout near the Lead Hill mine about 1½ miles to the south. Bulldozed roads and trails lead to most of the prospects. The work on the property, other than for assessment, has been carried on intermittently for at least the past 30 years. The property has yielded a small tonnage of hand-cobbed ore, chiefly lead.

The developments have been done chiefly in two areas, one about 1,000 feet northwest and the other about 600 feet southwest of the cabins by the road (pl. 1). In the northern area, exploration work consists of many shallow pits and cuts, one short adit, bulldozed roads, small bulldozed areas, and several diamond-drill holes. In the southern area the developments consist of several pits, an adit driven 60 feet into the hill on a bearing of S. 78° E., and, about 300 feet to the east, another adit (caved at portal) that bears S. 25° W. Most of the bedrock between these two adits is exposed in bulldozed cuts. The 60-foot adit follows a fault, believed to be of minor structural significance, that dips 80° N.

The country rock in the main prospected area is mixed dolomite of the Metaline Limestone, although the claims extend east into the overlying Ledbetter Slate which covers the slopes west of Lead Creek (pl. 1). The area is extensively mantled by both a thick deposit and thin veneer of glaciofluvial material. Much of the glacial material contains fragments of Ledbetter Slate, which, combined with poor exposures and heavy growth, made difficult and somewhat uncertain the task of delineating the boundaries between the Metaline and Ledbetter Formations, for this boundary has been largely determined by float material. The dolomite to the west of the slate is gray, fine grained and crystalline; locally, it grades irregularly into a medium- to coarse-grained rock. Small irregular patches and stringers of white quartz are sparsely scattered through the dolomite. About 1,000 feet west of the main diggings some of the rock contains the black-and-white-spotted variety of bedded dolomite. The strata near the southern prospected area probably lie 400–600 feet stratigraphically below the Ledbetter Slate, whereas the beds in the northern prospected area are probably near the top of the Metaline Limestone, because a small patch of slate crops out in this area (pl. 1).

The Ledbetter on the east side of the property is chiefly black slate and some argillite that contain a few thin beds and lenses of gray to black quartzite. Some beds of black platy limestone and black limy argillite crop out locally. Bedding planes are obscure, but the well-developed slaty cleavage strikes north to northeast and dips 20°–50° W.

The dolomite is strongly fractured over a fairly large area around the main diggings, and bedding planes cannot be recognized with certainty. However, the general attitude of the strata is, with little doubt, similar to that in the rocks to the south and west where the beds strike N. 25°–40° E. and dip 40°–60° SE.

Some galena and a little sphalerite occur in the northern prospects, commonly in small irregular spots, pods, and veinlets in fine- to coarse-grained dolomite. A mineralized knob a short distance west of the isolated patch of Ledbetter Slate consists of light- and dark-gray, brecciated and silicified dolomite that contains some pieces of black squeezed shale (Ledbetter?) and much coarsely cleavable gray to black calcite. One specimen of dark calcite contained a black carbonaceous button. Sparse galena, a few relics of sphalerite in small iron-stained patches, and a little smithsonite occur locally. In the southern prospected area galena, commonly associated with white crystalline quartz, occurs chiefly along poorly defined northeastward- to eastward-trending fractures. The galena occurs as small irregular spots, patches, and veinlets as much as 2 inches wide; locally, galena fills the spaces between angular fragments of dolomite. Both fine- and coarse-grained dolomite are associated with the mineralized ground. Very minor amounts of anglesite and cerussite were seen in close association with galena in one specimen observed. Limonite occurs at many places along fissures, and it is abundant on the dump of the caved adit.

BLUEBIRD

The Bluebird group of claims on lower Slate Creek adjoins the lower Dumont property and extends far up on the mountain slope southeast of Slate Creek. In an easterly direction the claims extend almost to the mouth of Uncas Gulch. In 1952 these claims, as well as several others that adjoin on the west, were held by the American Zinc, Lead & Smelting Co., who started a program of diamond drilling to explore for possible ore bodies that might lie concealed beneath the wide belt of glacial deposits that border Slate Creek. The company has kindly permitted the publication of general information derived from this drilling. Figure 33 shows the location of the holes drilled at the end of 1955, and the geologic map, plate 1, shows the main geologic features of the bordering areas. Twenty holes

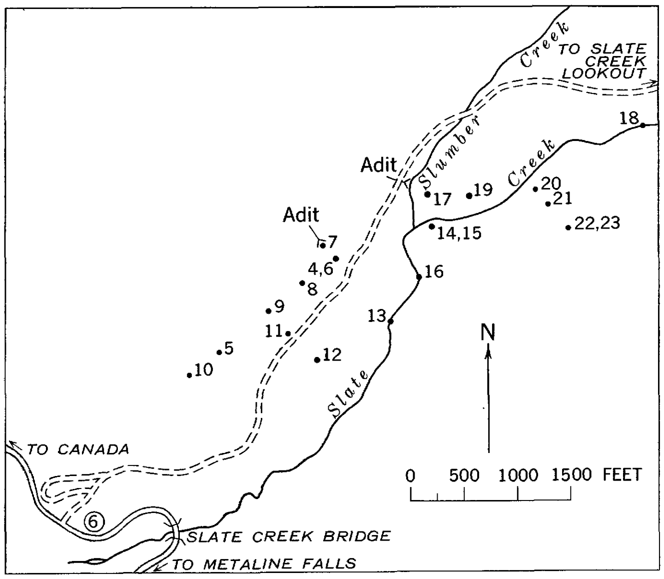

FIGURE 33.—Map showing location of diamond-drill holes drilled on the Bluebird claims by American Zinc, Lead & Smelting Co. Numbers beside collar of hole refer to American Zinc's system of nomenclature.

with a total footage of about 8,700 feet had been drilled by late 1955. All holes except 6, 7, 14, and 23 were drilled vertically—at least they were started vertically, but, it is likely that the deeper holes deviated considerably. Only holes 12, 22, and 23 were surveyed at depth for deviation.

Most of the holes went through Ledbetter Slate and into limestone and dolomite of the upper part of the Metaline. The Metaline in most of the cores examined is similar to the altered upper part of the formation seen elsewhere in the district. It consists of variably textured and varicolored dolomites associated with any or all of the following: limestone, calcite, chert, jasperoid, pyrite, sphalerite, and galena. Brecciated and broken zones occur irregularly; some holes cut repeated sections of Ledbetter Slate and Metaline Limestone, thus indicating the presence of faults concealed under the glacial deposits.

Because so many of the holes, especially the deeper ones, have not been surveyed at depth for deviation, it is not possible, except locally, to interpret the geologic structures. As determined largely from drill-hole data, in the vicinity of holes 20 to 23 the slate beds concealed beneath the glacial material strike northeast and dip about 30° SE. Scanty information could be obtained concerning the lithology of the Ledbetter Slate because only a relatively small part of it was cored, most of the formation having been drilled with a plug bit. The part seen in cores is black slate, argillite, and some shale, all of varying lime content. A few limestone beds and thin quartzite lenses are present;

some quartzite occurs 125–150 feet above the base of the Ledbetter. Some of the slate is strongly silicified, and at other intervals part of the core shows layering which likely represents bedding. Layering parallel to the core may within a few feet become normal to the core; this rapid change in attitude, plus contorted bands and common fractured intervals, indicate that at many places sharp folds or faults, or both, are present. Nearly all core recovered at the contact of the Metaline Limestone and Ledbetter Slate showed some effects of movement along the contact.

In a line extending from hole 20 southwest to Slate Creek Bridge, the depth of the slate-limestone contact becomes progressively greater, and a hole drilled during World War II by the U.S. Bureau of Mines near this bridge bottomed in slate at a depth of 2,050 feet.

CLIFF

The Cliff mine is three-fourths of a mile north of Hoage Lake and about 1,500 feet east of the road to Russian Creek. When last visited in 1955 a poor road led to the property. The mine is on the patented Cliff claim which is owned by Jerome Drumheller, Spokane, Wash. Most of the early history of the property is vague. Pend Oreille Mines & Metals Co. held it from 1926 to 1930 but did little or no development work. Columbia Lead & Zinc Co. held the property from 1942 to 1945 and did considerable development work and some mining. In 1955, Robert Wallis, Metaline Falls, Wash., held an option on the claim. A small shipment of ore was made sometime before 1910 (Bancroft, 1914, p. 49), and Gerry (1927, p. 293; 1928, p. 559) mentions some production in 1924 and 1925. Most of this early production was probably hand-sorted high-grade lead ore obtained from the old upper workings. From May through August 1944, Columbia Lead & Zinc Co. trucked 848 tons of crude ore to the Pend Oreille mill at Metaline Falls. This ore averaged 0.16 percent lead and 2.96 percent zinc. From September 1944 to January 1945 Columbia did underground diamond drilling in the main adit. Reportedly, some mineralized ground, chiefly sphalerite in silicified dolomite and dolomite breccia, was cut in the drill holes. Little work has been done since January 1945.

The principal development work on the claim was done by Columbia Lead & Zinc Co. when they held the property. They drove an adit S. 85° E. for 200 feet to undercut a mineralized knob about 75 feet higher on which the older diggings had been made (pl. 1). At a point in the adit 165 feet from the portal, a 15-foot raise connects with the western end of a stope 45 feet long, 15 feet wide, and averaging 15 feet high. In longest dimension the stope roughly parallels the adit and plunges about 30° W. Among the older workings on the knob is a trench 15 feet deep that trends N. 30° E. for 50 feet. In the trench two shafts have been sunk; both have been inaccessible for many years and their depths are not known, although both are probably less than 50 feet deep. A prospect adit (10 ft long) and several shallow diggings have been made elsewhere along the knob. Nearly all of Columbia's ore came from the stope in the lower adit; the old surface diggings yielded mostly lead ore.

The country rock is chiefly soft very fine grained light-gray limestone and dark-gray crystalline dolomite, both believed to be stratigraphically within the upper 200 feet of the Metaline Limestone in the immediate vicinity of the mine workings. The only extensive cropping of crystalline dolomite is on the knob east of the mine portal. The knob is surrounded by glacial debris, but a few hundred feet east a relatively bare hill exposes a thick section of limestone.

The structure of the rocks in the immediate vicinity of the Cliff mine is vague, for no attitudes are determinable in the isolated knob of dolomite or in the adit. A northeast-trending fault is believed to be concealed beneath the glacial debris east of the mine (pl. 1). East of this fault the limestone beds strike N. 10°–25° E., and dips range from 25° to 35° W; the principal fractures in the limestone are steeply dipping and strike on the average N. 45° E. The dolomite on the knob is highly fractured with two dominant sets of fractures; one set strikes about N. 32° E. and dips 65° SE.; the other strikes about N. 30°E. and dips 55° NW. At the southern end of the trench, possible bedding slips trend N. 30° E. and dip 30°–40° NW., and another set of fractures, many filled with white quartz veinlets, strikes N. 55° W. and dips 70°–90° NE.

Weathered Ledbetter Slate can be seen on the dump at the old upper workings, and it is reported (Park and Cannon, 1943, p. 67–68) that slate was found at the bottom of one of the old shafts. Park and Cannon also reported finding poorly exposed croppings of slate on the hillside east of the knob. Several pits were dug in these questionable outcrops during the present investigation, and the mixture of glacial debris and slate is such that it is unlikely that they represent bedrock. The slate reported from the old shaft has probably resulted from squeezing and dragging in a fault zone, and it is on this evidence, plus the sharp valley, that a fault is placed east of the knob.

Sphalerite and galena are irregularly disseminated or in small shoots and streaks in dolomite and dolomite breccia; generally they are associated with the silicified parts of the rock, although not all the silicified parts contain ore minerals. The mineralized ground is well exposed in the main adit and stope. The first 80 feet of the adit cuts glacial sands, gravels, and boulders; the remaining 120 feet is dolomite. The dolomite is medium to coarse grained, gray to black, and irregularly brecciated. Dark-gray to black jasperoid is irregularly distributed, but it is especially common as a filling between broken fragments of dolomite. Calcite occurs in sizes ranging from small specks to masses several feet long. Columbia Lead & Zinc Co. drilled 17 holes in a wide range of directions and inclinations in the eastern part of the adit. Many of these diamond-drill holes passed through altered rock into limestone; others cut several alternations of dolomite, breccia, and limestone. No slate was penetrated. Examination and plotting of the rock types found in the cores discloses much irregularity in the hydrothermal alteration and outline of the dolomite breccia; however, in general, the main altered zone seems to plunge moderately northwest.

Future exploration work should be directed west or northwest of the adit in order to explore ore bodies that may be concealed beneath the glacial debris. A drill hole 1,000 feet west of the mine portal would likely cut Ledbetter Slate and pass into the uppermost section of the Metaline Limestone, which is the most favorable host rock for ore.

DUMONT

A group of small diggings including prospect pits, cuts, and short adits extends along the north side of the Lead Hill fault from near Slumber Creek southwest for about 2,000 feet (pl. 1). The present ownership of all the ground in this area is not known; but most of the prospects are believed to be on claims held by William and George Dumont of Vancouver, Wash., and this part of the area is generally referred to as the Dumont property. It was formerly known as the lower Dumont group to distinguish it from the upper Dumont claims that are now known as the Uncas Gulch prospects. Most of the diggings were put down more than 20 years ago. Insofar as could be learned, no ore has been shipped from this area.

The country rock north of the Lead Hill fault is chiefly crystalline dolomite that is fine to medium grained and ranges from light to dark gray. It is sparsely and irregularly silicified and brecciated and grades into limestone, dolomitic limestone, and, especially to the north, into a very fine grained light-gray dolomite. Some of the dolomite contains small patches and irregular nodules and stringers of chert. The rocks are in the upper part of the Metaline Limestone, but their precise stratigraphic position below the Ledbetter Slate is not known; however, they are probably within 1,000 feet of the slate because a few patches of unaltered upper gray limestone are present. Although bedding planes cannot be recognized in the prospected area, it is believed from a regional study that the strata strike northeast and dip 20–35° SE. Near the Lead Hill fault they probably dip much more steeply because of drag along the fault.

The dominant structure is the Lead Hill fault that brings slate on the south against dolomite on the north. The fault strikes N. 60°–70° E., and, as exposed in three prospect pits, dips 70°–85° SE. The throw of the fault is not known, chiefly because of the uncertain stratigraphic position of the strata north of the fault. Drill holes just south of the fault cut what is assumed to be for the most part the normal slate-limestone contact within 150 feet or less below the surface. A few northward-trending faults offset the Lead Hill fault (pl. 1).

FLUSEY GROUP

Two patented claims, referred to locally as the Flusey group, are high up on the steep cliffs on the west side of the Pend Oreille River about a mile north of the mouth of Slate Creek and a mile east-southeast of the Lead King mine. The property can be reached by a steep poor road, shown as a trail on plate 1, that leaves the road to Russian Creek a few hundred feet south of the Lead King mine. Most of the prospecting was done many years ago; it consisted of several shallow diggings and two adits, both inaccessible when visited. Reportedly, no ore has been shipped.

The mineralization, as determined chiefly from dump material, consists of galena, reddish-brown to nearly black sphalerite, and abundant pyrite in a gangue of predominantly coarse-grained dolomite. Limonite, derived from the oxidation of pyrite, is very conspicuous in the rocks in the immediate prospected area and far to the south and east along the cliffs that border the Pend Oreille River. The country rock is creamy to light-gray dolomite of the bedded dolomite unit of the Metaline Limestone. East of the prospects along the west riverbank some black-and-white spotted dolomite occurs in this unit. There the strata strike N. 38° W. and dip 38° SW. but near the prospected area the strata strike N. 10°–20° W. and dip 30°–35° W. In the vicinity of the prospects the dolomite beds are stratigraphically about 1,500 to 1,800 feet below the Ledbetter Slate and are in the thick and irregular pyritic zone seen at other places in the district.

GALENA

The Galena prospect is a mile west of Crescent Lake and a few hundred feet south of the road to the Schierding placer (pl. 1). The prospect is on the Silverado group of claims held by William Schierding, Yellowpine, Idaho. The property was idle when visited in 1955, and from the appearance of the workings little development has been done for some years. The principal development work is in an adit that bears N. 60° E. The portal was caved when visited, and the length of the tunnel is not known; but judging from the size of the dump, it is several hundred feet in length.

The dump material consists of medium- to coarse-grained gray dolomite—some of which is the zebra type—common chert, and some coarse cleavable calcite. Some iron-stained material may represent oxidized sphalerite. A few small pieces of black shale on the dump may be from the Ledbetter Slate.

GALENA HILL

The Galena Hill prospects are a series of shallow diggings and short adits ½ to ¾ mile southwest of the Whoopie property on a steep hill south of Slate Creek (pl. 1). The claims adjoin, and are a southwest extension of, the Whoopie prospected area. The property consists of 6 unpatented claims (Galena Hill 1–6) held by the estate of the late Ira S. Troyer, Metaline, Wash. Most of the diggings were made many years ago, and no ore has been shipped from the property.

The developments are along the southwest extension of the Lead Hill fault, and the diggings are in dolomite, limestone, and Ledbetter Slate, all within a few hundred feet of the fault (pl. 1). The lower part of the gray limestone unit of the Metaline Limestone lies north of the Lead Hill fault in a belt about 1,800 feet long and a maximum of 350 feet wide. Parts of the limestone are altered to coarse-grained dolomite. Some of the dolomite is irregularly silicified. North of the belt of limestone the fine-grained bedded dolomite rocks strike northeast and dip moderately to gently southeast. No ore was seen in any of the rocks of the area.

GIANT

The Giant mine is 100 feet east of the road to Russian Creek and about 700 feet north of Hoage Lake (pl. 1). James Ehle held the property for many years and did most of the exploratory work. In November 1943 the Columbia Lead & Zinc Co. obtained control of the property from the Ehle estate. Little work, other than for assessment, has been done during the past decade. A small tonnage of hand-sorted ore may have been shipped a long time ago, but no published record of ore shipment could be found.

Three adits a short distance east of the road were driven into the hill to explore mineralized outcrops. The principal adit (fig. 34) bears N. 55° E. for 373 feet; another adit 135 feet northeast bears N. 60° E. for 50 feet; and the third adit, 150 feet southeast of the main mine adit, was driven northeast for 30 feet. Numerous cuts, pits, and very short adits, some too small to show on the geologic map, are found in an area extending to the top of the hill east of the lower workings.

The country rock, Metaline Limestone, is light- to medium-gray limestone, locally containing several large areas of irregularly silicified dolomite (pl. 1). Most of the area shown as limestone, however, contains small irregular patches, nests, and stringers of dolomite, calcite, and jasperoid, either singly or in various combinations. The dolomite ranges in color from light gray to a predominate dark gray; the texture ranges from fine to coarse grained, although medium grain is most abundant. Calcite ranges in size from specks to coarsely cleavable masses as much as 15 feet long. The jasperoid is chiefly dark gray or black, and it is commonly associated with and grades into irregular patches of white quartz. Locally, white quartz veinlets cut jasperoid and dolomite. A few poorly defined bedding planes in the limestone indicate northerly strikes and westerly dips of about 25°–30°. The beds on the hillside east of the adits form, in large part, a dip slope. Stratigraphically the beds are at, or very near, the top of the Metaline Limestone. A small remnant of graptolitic slate was found resting in a small irregular pocket of the limestone near the top of the hill. This small exposure of the contact, if projected west with a dip of 25° connects with the slate-limestone contact as determined from numerous diamond-drill holes put down by the Sullivan Mining Co. over a fairly large area west of the Giant mine.

Sphalerite and a little galena are irregularly distributed in most of the large dolomite patches. Most of the dolomite contains small iron-stained cavities, a few of which show relics of partially leached sphalerite. A few pits near the top of the hill expose small irregular shoots of ore that appear to be of higher grade than elsewhere in the area. Chip samples taken from the north pit over a 3-foot zone assayed 7.10 percent zinc and no lead. Another assay made from samples taken along a 12-foot mineralized zone in a trench 50 feet S. 20° E. showed 0.50 percent lead and 3.45 percent zinc. Both assays were made by J. C. Crampton, of the Pend Oreille Mines & Metals Co. The two assays and observations of the outcrops indicate that the ratio of zinc to lead is somewhat greater here than at the Lead King property to the south.

The main adit of the Giant mine was driven to undercut the mineralized body found to the northeast and also to explore at depth a possible downward continuation of the mineralized ground exposed at the top

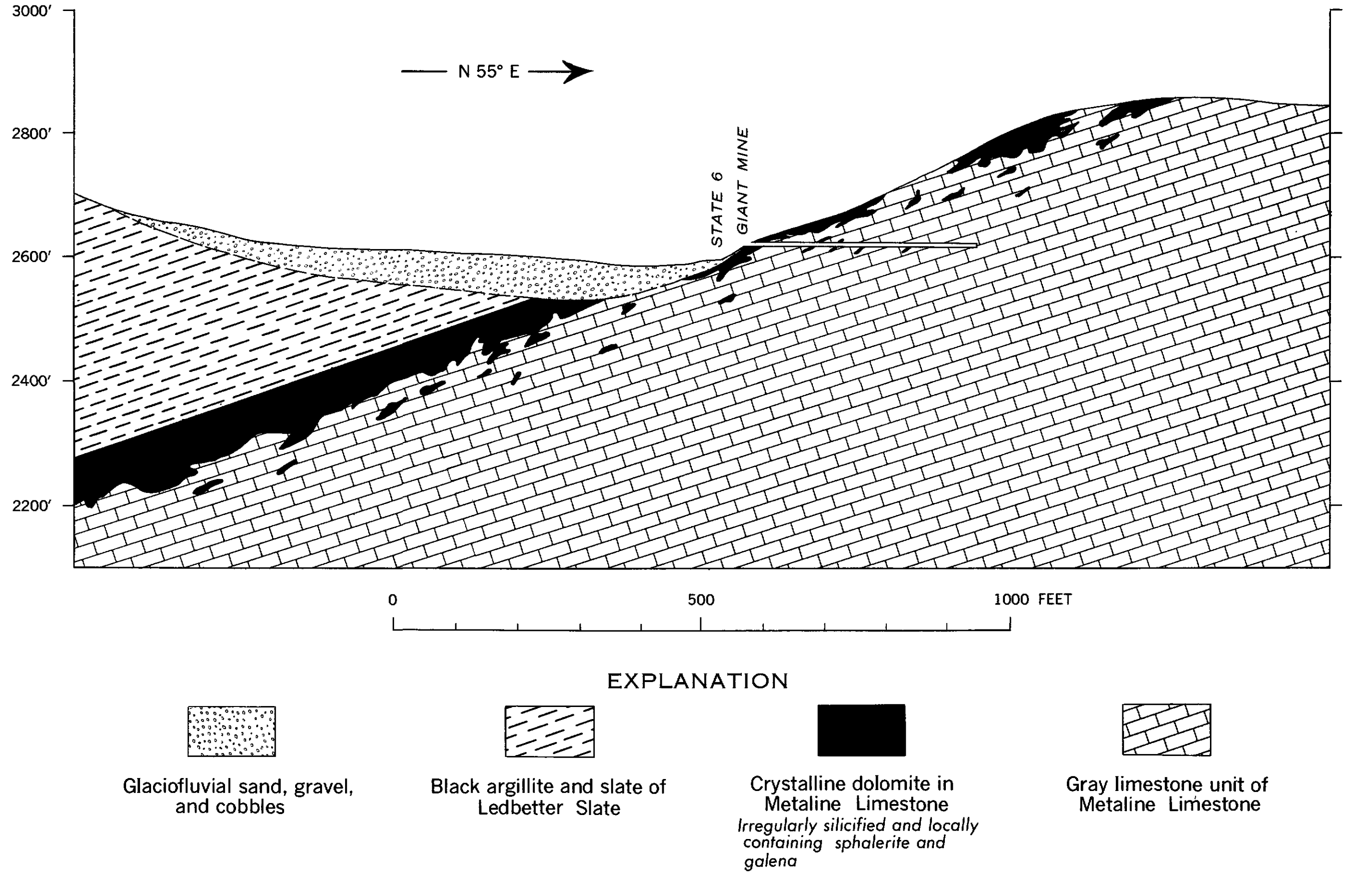

FIGURE 34.—Section in the vicinity of the Giant mine, showing relation of slate, ore-bearing dolomite, and limestone.

of the hill. A section parallel to the main adit (fig. 34) shows the general type of rock cut in the adit as well as the westerly dip of the altered zones beneath the glacial debris and beyond to the slate-covered hills. Some very low grade mineralized dolomite was cut in the first 30 feet of the adit. Except for a few narrow zones of unmineralized coarse dolomite, the remaining part of the adit penetrated limestone. In the limestone a few minor slips and a vague westward dip to the beds of about 30° were observed.

GRANDVIEW

The Grandview mine is on the east side of the Pend Oreille River about a mile northeast of Metaline Falls (pl. 1). On the north the property adjoins the eastern workings of the Pend Oreille mine. Little work was done on the Grandview property until 1937 when control was acquired by the Metaline Mining & Leasing Co. and an intensive diamond-drilling program was started. The old mill on the property was remodeled, and late in the year it began to handle ore that was trucked from the Metaline mine. In 1938 the property passed into the hands of Grandview Mines, Inc., and soon afterward it was leased on a long-term basis to the American Zinc, Lead & Smelting Co., which has operated the mine since 1940.

The greatest period of mining activity at the Grandview was during World War II, when the output reached as much as 800 tons a day, and for some months the mine ranked first in production for the district. During the decade 1945–55 the yearly average production declined rapidly from that of the war years, owing very largely to several long labor strikes. However, during this decade daily production was increased by improvements in drilling, mucking, and haulage of ore. The crude ore is concentrated at American Zinc's Grandview mill. The lead concentrates are shipped to Kellogg, Idaho, and the zinc concentrates to Butte, Mon.

Table 7, page 58, shows the yearly production from the Grandview mine for the period 1924–56. The mine ranks second in the district in total production. The grade of ore for this period, based on metals recovered, averaged 1.37 percent lead and 2.97 percent zinc.

The principal mine workings, as of 1955, are in an area about 2,200 feet long and 2,000 feet wide; it extends from the stopes near the hoist house, pls. 2, 3) east to the stopes off the 300 level and in a northerly direction from the old stopes near the glory hole almost to the northern boundary of the claims where they adjoin the Pend Oreille Mines & Metals Co. property. In altitude the stopes range from about 2,500 feet at the glory hole to about 2,150 feet in stopes off the 300 level. The principal levels are the main-haulage, 100-foot, 200-foot, and 300-foot, each spaced vertically about 100 feet apart (pls. 2, 3). The main haulage adit bears north-northwest from the portal for a little more than 2,000 feet where it connects a short distance below the surface with an incline. The incline, to which the lower levels are connected, bears about N. 40° E. on an inclination of —22°. During the summer of 1955 when the mine was last visited, a station on the lowermost level (500-ft) was being developed off the incline at an altitude of about 1,930 feet. The company plans to drive the 500-level drift eastward to undercut the eastward-dipping ore bodies mined off the 300-level workings (pls. 2, 3) and also to develop and explore mineralized ground much farther east that is indicated in the cores of diamond-drill holes.

Ore from the lower levels is hoisted by car up the incline to an ore pocket above the main-haulage level where it is loaded into a train and carried to the Grandview mill, located a short distance from the portal. The hoist house is on the surface at the edge of the gorge of the Pend Oreille River about 600 feet above the water at a place that is locally known as Grandview Point, which can be reached by a road that passes the Grandview glory hole. From Grandview Point an excellent view can be had of the river gorge, the town of Metaline Falls, and the buildings and shaft around the old western workings of the Pend Oreille mine.

Around Grandview Point are some of the old Grandview surface diggings along the cliffs, many of which connect eastward with the mine workings. These workings and those on the surface near the glory hole were some of the earliest explorations on the Grandview property. Most of these were diggings on somewhat spotty occurrences of ore near the limestone footwall, and it was not until the incline was sunk and mining was carried on at lower depths that the main body of ore was encountered and the mine yielded important tonnages of ore. Many diamond-drill holes, put down from the surface over what is now largely stoped-out ground, indicated the presence of ore bodies at depth before the deeper mining developments. These holes as well as many others that were drilled from underground locations during the progress of mining (fig. 35) guided the deeper exploration. Only a few of the many older holes drilled from surface locations are shown on the structure contour map (pl. 2) because most of them are located where the Ledbetter Slate has been removed by erosion, and they are therefore of little aid in structural interpretations.

The country rock in the vicinity of the Grandview mine is Metaline Limestone and Ledbetter Slate; however, no Ledbetter Slate is exposed at the surface. A wide belt of glacial lake deposits covers most of the workings north and east of the glory hole (pl. 1). West of the glory hole a low knob of limestone and dolomite protrudes above the glacial material, and bedrock is intermittently exposed from here westward to the steep slopes and cliffs along the east side of the Pend Oreille River. In this area and northward to and beyond the hoist house, irregularly silicified and brecciated crystalline dolomite can be seen grading into small and large bodies of gray limestone. On part of the knob west of the glory hole glacial grooves have been cut in the bedrock. The cliffs and steep slopes from the hoist house westward down to the Pend Oreille River were not accessible to close observation; therefore the various types of altered rock of the Metaline Limestone were not mapped. However, a narrow strip along the east bank of the river was accessible, and here the rock is chiefly light-gray fine-grained bedded dolomite. Detailed geologic work along the slopes east of the river would, with little doubt, show an extremely irregular pattern of altered rock similar in a general way to that mapped on the west side of the river opposite this area (pl. 1).

The glacial lake deposits consist of silt and sand and some cobbles and boulders which, except in roadcuts and recent excavations, are largely covered by a mat of forest growth and decayed vegetation. The lake deposits range in thickness from a thin veneer over parts of the area west of the glory hole to about 450 feet in one place near the paved highway 1,600 feet east-southeast of the glory hole. Here Grandview drill hole 308 was bottomed and abandoned at a depth of 435 feet in glacial material; 650 feet farther north, drill hole 968 cut 419 feet of glacial debris before being abandoned (pl. 2). It is possible that this area represents an old river channel modified by later glaciation, for elsewhere in this area bedrock is commonly reached by the drill at considerably higher altitudes.

The principal structure of the Grandview area is a broad anticline that is (pls. 2, 3) cut by many faults. The anticline plunges gently northeast and continues for a long distance into the Pend Oreille property where the contact of Metaline Limestone and Ledbetter Slate is reached at much lower altitudes. Most of the Grandview mine workings are in an area near the crest of the anticline where the slate has been eroded, and details of the structure cannot be determined because

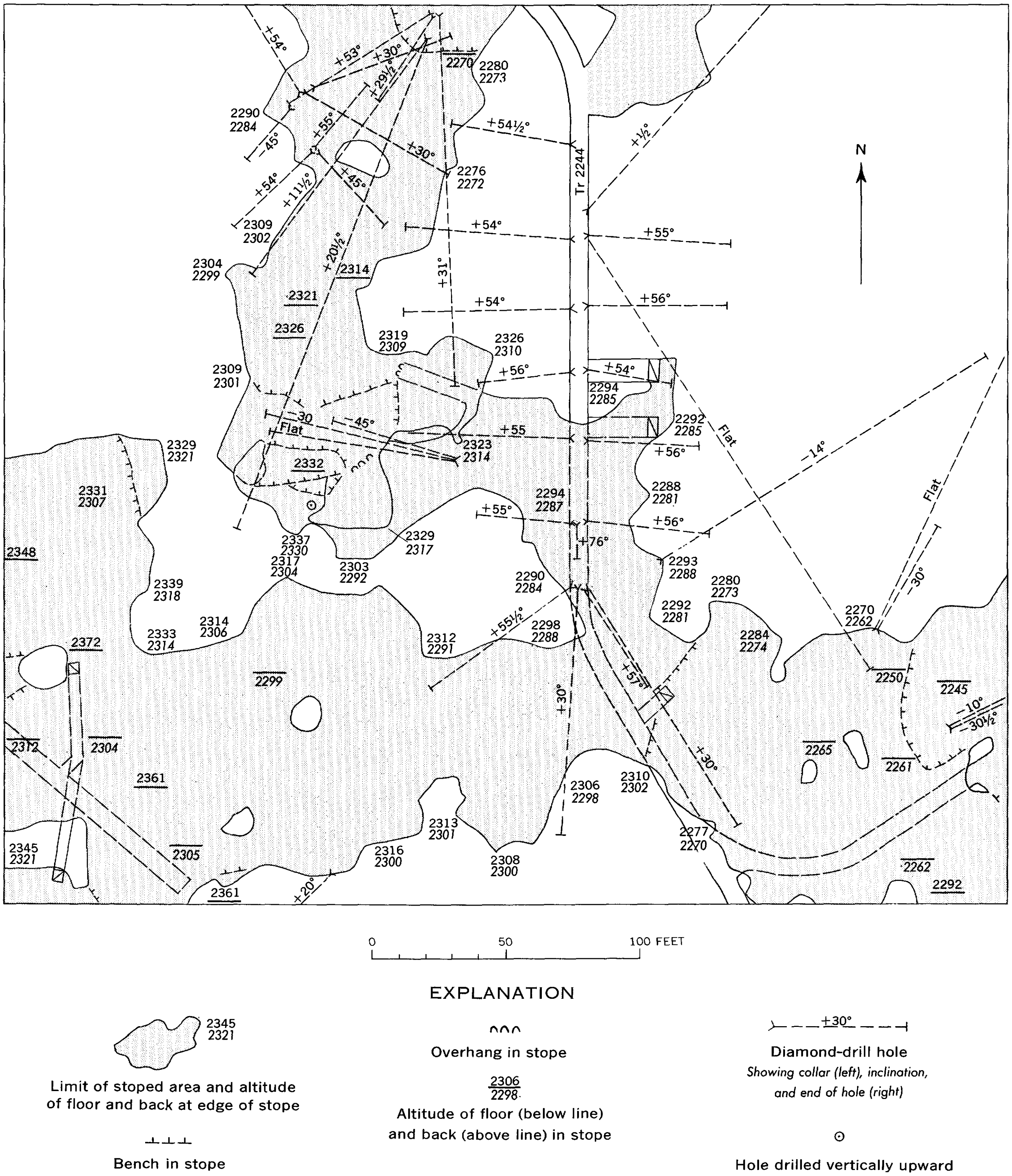

Figure 35.—Map of part of the eastern workings of the Grandview mine, showing the typical irregularity of the ore bodies and the location of diamond-drill holes used in underground exploration. Map by American Zinc, Lead & Smelting Co., with minor simplification, 1955.

of the almost entire absence of bedding planes in the Metaline. The Slate Creek fault to the east, although largely concealed under glacial material, is known by many drill holes and a few surface outcrops to bring Ledbetter Slate on the west against the lower bedded limestones of the Metaline Limestone on the east. The throw of this fault is at least several thousand feet. One diamond-drill hole (AZ 21), which drifted far to the southeast from its surface location, cut the Slate Creek fault at an altitude of 1,255 feet (pl. 2). The drill passed from Ledbetter Slate through a fault zone into thin-bedded limestone with phyllitic partings (Metaline). Much of the limestone in the core is strongly fractured and folded on a small scale. Along the western side of the Grandview mine workings and roughly parallel to the incline is the Grandview fault, which strikes northeast and dips at moderate angles to the northwest. Ledbetter Slate to the northwest has been faulted down about 75 to 100 feet. This fault, preore in age and discussed in more detail under the description of the ore bodies, continues northeast at least 1,000 feet into the Pend Oreille workings (pl. 2). The Washington Rock thrust, a complex structure cut in holes CS 12 and W 15 and described on pages 37–39, underlies part and possibly all of the Grandview workings.

In addition to the major faults just described, the mine workings cut hundreds of faults that are usually of short extent and probably have displacements of only a few inches or rarely as much as 10 or 15 feet. For example, 110 faults were mapped in the main-haulage level between the portal and the station at the incline, a distance of a little more than 2,000 feet. Many of these faults have gouge and breccia zones a fraction of an inch to several inches thick, and nearly all faults have smooth slickensided surfaces which at many places are striated and grooved. These faults, as well as many others observed in the lower workings, have diverse strikes and dips, but most strike northeast or northwest and the dips are generally moderate to steep and show no dominant direction. Most of the grooves along the fault surfaces plunge steeply. A few faults in the northern part of the mine workings in drifts and stopes off the 200- and 300-foot levels can be followed or reliably projected for 75 to 300 feet. These faults strike N. 60°–80° W. and, except for a few, dip moderately to steeply north. Some of these faults appear to drop the ore zone down a few feet to the north. Some faults that appear to fade out in the stopes were probably formed before the deposition of the ore, although most of the faults cut the crystalline dolomite and in places the ore, and are therefore of postore age.

Ore in the Grandview mine occurs as irregular replacement bodies of sphalerite and galena which are largely within a zone 35–150 feet below the top of the Metaline Limestone. In general, the ore zone conforms roughly to the dip of the strata. The ore bodies are part of a much larger mineralized area that includes the Pend Oreille mine workings to the north and west, and the mineralogy and mode of occurrence of the ore and gangue are very similar in both mines. Sphalerite is generally dominant, although, in places, some stopes have yielded rich lead ore. The ore minerals are irregularly distributed and are most commonly in a gangue of faintly to strongly brecciated and silicified dolomite. Calcite in variable quantity is commonly associated with the ore.

Sphalerite is mostly reddish brown or brownish red; although some is a very pale yellow, and other grains are resinous yellow, brown, or red. Several colors may be present in a single ore shoot. Some red grains have irregular yellow centers; others grade into, or are partly bordered by, yellow sphalerite. Sphalerite grains range widely in size, commonly from 0.1 to 5 mm. Nearly all sphalerite is in anhedral grains. Galena occurs as isolated grains, or in pods, lenses, and irregular stringers. Some grains are as much as half an inch long, although very fine grained galena occurs locally. Some of the fine-grained galena is streaky. Well-developed crystal faces are rarely seen. Pyrite is rare and of local occurrence.

The gangue consists largely of medium- to dark-gray medium- to coarse-grained crystalline dolomite, although locally it contains some gray limestone and very fine grained light-gray dolomite. The rock ranges from a strong breccia of recemented fragments to dolomite that shows little or no brecciation. White to dark-gray calcite is irregularly distributed in small and large grains, patches, and stringers, and, in places, as large masses 25 feet or more across. In places, coarsely cleavable calcite forms an irregular footwall between the ore and the underlying gray limestone. Light- to dark-gray jasperoid is irregularly distributed in the gangue, in places forming a large part of the rock. The ore minerals are commonly, but not everywhere, contained in the silicified parts of the host rock. Some strongly silicified rock, however, contains little or no ore. Milky quartz occurs as stringers and irregular bodies in the dolomite and at many places grades into jasperoid. Quartz, jasperoid, and calcite also occur at many places in the mine beyond the limits of individual ore shoots and well into the slightly altered limestone.

Galena, sphalerite, and the gangue minerals show variable age relations among themselves, which is the

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usual pattern for the ores of the district. Figure 32 shows a somewhat rare occurrence of galena deposited upon a large quartz crystal. At many places in the mine calcite cuts the ore minerals, but elsewhere either galena or sphalerite has been deposited in cleavage fractures in coarse calcite. Quartz likewise cuts ore and, in turn, is replaced or cut by either sphalerite or galena. Much of the recemented dolomite crush breccia contains fragments of fine- to medium-grained dolomite surrounded and replaced by coarsely crystalline dolomite, jasperoid, calcite, and the ore minerals.

Small caves and vugs are scattered through the mine workings, and, in places, some are lined with small crystals of quartz and sphalerite. Caves are especially common in the southeastern part of the main stoped area off the 300-foot level. One cave in this area is 120 feet long, a maximum of 60 feet wide, and reaches a height of about 50 feet. Several other caves in this area, and also a few hundred feet west off the 200-foot level, average 50 feet or more in length. Some of these caves when broken into were found to contain large amounts of wet mud and silt. Some of this material possibly may be insoluble material from the country rock, although the authors believe that it is mostly from glacial lake material that has worked its way down into the caves through fractures, because the thick glacial deposits overlie the bedrock within a vertical distance ranging from 100 to 200 feet above the caves.

The ore bodies range greatly in length, breadth, and thickness. Some are too small to mine, whereas others extend several hundred feet in irregularly mineralized ground, and in places reach a height of about 100 feet. At most places the structures that controlled the deposition of the ore are not evident. However, the ore bodies that lie irregularly along the southeast, or upthrown, side of the Grandview fault were with little doubt localized by this fault. The Grandview fault, as noted in a preceding paragraph, extends into the Pend Oreille mine workings where rich ore bodies, especially lead ore, also occur on the hanging-wall side of the fault. At one place in the Pend Oreille workings the ore clearly cuts across the fault zone, showing that this fault formed before the ore was introduced. In the Grandview mine, high-grade lead stopes are especially common in the northern part of the workings in an irregular zone that extends from the fault eastward about 300 feet. Zinc ore of higher grade than average for the mine has been taken from stopes along a large part of the footwall side of the Grandview fault. In some of these stopes, low-angle slips dip into the Grandview fault. These slips are probably along bedding planes and antedate the period of deformation that produced the Grandview fault. It seems reasonable to explain the concentration of the ores along the fault zone as a result of premineralization movement that produced a fractured zone which, in turn, formed an accessible channel for the ore solutions. The marked concentration of the ores in the footwall side of the fault rather than in the hanging-wall side is explained in large part by postulating that the ore-forming fluids spread upward and laterally along earlier bedding slip surfaces dipping into the fault on the footwall side.

HANLEY

The Hanley prospect is high on the west bank of the Pend Oreille River a mile south of the Canadian border and about 2,200 feet southeast of the Tom Cat prospect. It can be reached from the road to Russian Creek by a steep and, at places, faint trail. The prospect is on the Hanley patented claim which is reportedly held by Jerome L. Drumheller, Spokane, Wash. Some high-grade and hand-cobbed lead-silver ore is reported to have been shipped from the property in the eighties. Little work has been done on the claim for many years. Most of the development work was in an opencut about 30 feet long, 6 feet wide, and 15 feet deep at one end.

The geologic structure, country rock, and mineralization (sparse sphalerite and galena) are similar in a general way to those of the Tom Cat property, described on page 98. The dolomite in the opencut, however, is not so strongly silicified as at the Tom Cat. It is likely that the contact of the Metaline Limestone and Ledbetter Slate lies concealed beneath the glacial material 300 to 400 feet south of the cut, and any future exploration should be done in this area by diamond drilling.

HOAGE

The Hoage mine, on the Red Fir 1 claim, is east of the road to Russian Creek and a few hundred feet north of Hoage Lake. The property is held by Columbia Lead & Zinc Co. For many years the mine was worked intermittently as a one-man operation by the late E. J. Hoage, who drove an adit north into the hill to a small pocket of ore. For several years about 50 tons of the hand-sorted ore obtained from this pocket was piled near the portal of the mine. In 1945 Columbia Lead & Zinc Co. acquired the property and reportedly trucked most of this ore to the Pend Oreille mill at Metaline Falls. No other shipments of ore are known.

The geologic setting of the property is similar to that of the Lead King and Giant mines in that it is in an area of westward-dipping beds of the upper part of the Metaline Limestone that contain patches of silicified dolomite. Most of the property, however, lies a few hundred feet stratigraphically lower than the other two mines. The northeast-trending Hoage fault lies in the glacial-filled valley south of the mine (pl. 1). This fault, information on which is based chiefly on data obtained from many drill holes west of Hoage Lake, is downthrown on the southeast, and has a stratigraphic throw of about 300 feet.

The property is explored and developed by two adits and a few shallow surface diggings. The underground workings of the main mine adit (pl. 1) were examined in July 1944, at which time the adit had been driven north-northwest about 150 feet. Entrance to this adit was closed when revisited in 1955. The adit was directed under a hill of gray limestone with the hope that it might intersect an ore body lying beneath the mineralized ground east of the Giant property. The first 75 feet of the adit is in gray limestone that strikes N. 5° W. and dips 30° W. The next 30 feet is coarse-grained dolomite followed by 30 feet of gray limestone before reaching ore-bearing dolomite, jasperoid, and calcite. A small stope about 13 feet long, 7 feet wide, and 7 feet high has been made in this mineralized zone. North of the stope the adit passes out of dolomite into limestone and continues a short distance to the face.

Sphalerite, galena, and sparse pyrite were seen in the stoped area. Sphalerite ranges from yellow to reddish brown, the latter being the most common. It occurs as crude elliptical patches averaging 0.2 inch in length, as vaguely defined stringers as much as 0.4 inch wide, and as irregularly disseminated grains. Some yellow sphalerite rests on dolomite crystals that line small vugs. Most of the sphalerite is coarse grained, but some is very fine grained. Galena, which is subordinate in quantity to sphalerite, occurs as small disseminated grains, generally less than 0.5 inch long, or, less commonly, in small irregular patches and stringers. Samples of the hand-cobbed ore from this stope collected in 1944 from the stockpile at the entrance to the mine and assayed by J. C. Crampton, of the Pend Oreille Mines & Metals Co., showed 11.1 percent zinc and 4.15 percent lead. This small ore body is a good example of an isolated occurrence of ore surrounded by gray limestone and at a considerable distance stratigraphically below the main ore zone, which in this area lies on the hillside of the Giant mine.

About 300 feet southeast of the Hoage mine an adit 50 feet in length was driven S. 82° E. to explore at depth the altered rocks on the hill to the east (pl. 1). Overburden was penetrated for 29 feet before reaching fine- to coarse-grained gray to black silicified dolomite and calcite that was barren of sulfide minerals.

LAKEVIEW

The Lakeview prospect is about 700 feet northwest of Crescent Lake on the south slope of Forest Mountain. The main workings can be reached by a faint trail that starts near the cabin on the west side of Crescent Lake. In 1955 the Lakeview group of 7 claims and 1 fraction was held under option by Robert Wallis, Metaline Falls, Wash. The property, which was idle when visited in 1955, is developed by two adits and many shallow cuts, trenches, and pits; most of this work was done some time before 1938. Reportedly, no ore has been shipped, although a little zinc ore is piled near the entrance to the main adit.

The country rock is fine-grained, creamy and gray bedded dolomite locally recrystallized to a coarse-grained rock near the mineralized bodies. Black-and-white spotted and streaky dolomite occurs irregularly throughout the area. Most of the dolomite, which is sparingly exposed in this heavily forest covered area, is strongly and irregularly fractured and bedding planes are rarely recognizable; however, in the main adit (fig. 36) about 125 feet from the portal the beds strike north and dip west on an average of 37°. In stratigraphic position the beds very likely are at least 1,000 feet, and possibly even as much as 2,000 feet, below the top of the Metaline Limestone.

The main adit enters the hill at the base of a small cliff of dolomite and bears N. 28° W. for 272 feet. About 40 feet from the heading an irregular drift with short branches extends northeast for about 35 feet (fig. 36) in the fractured footwall of a fault having ½ to 2

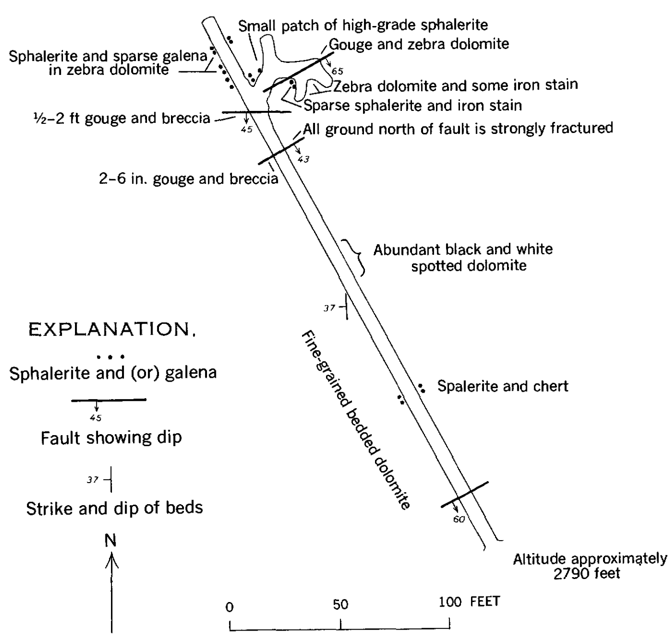

FIGURE 36.—Map of main adit, Lakeview prospect.

feet of gouge and breccia. The principal mineralized ground is in the footwall of this fault, although a little sphalerite and some iron stain occur elsewhere along the adit. Sphalerite and sparse galena occur in small irregular shoots in a gangue consisting of banded, streaky, and wavy dolomite that is coarse grained and ranges from white to dark gray. Zebra dolomite is especially common, and in places, individual bands are as much as 1 inch wide. Some of the dolomite is iron stained. Most sphalerite is reddish brown, but a small amount is resinous and yellow. Sphalerite commonly occurs in the coarse-grained and white parts of the streaks and bands of the recrystallized dolomite, and, in places, is concentrically arranged around centers of dolomite, or, rarely, around a center of galena. Pyrite and calcite are rare. Some chert occurs with dolomite and sphalerite in a small patch of mineralized ground 75 feet from the portal.

Most of the surface prospecting has been done on the hill northwest of the main adit and about 75 feet higher. Here a series of trenches and pits extend northeast for about 250 feet. All are on the hanging-wall side of the main eastward-trending fault cut in the adit below. Both fresh and oxidized sphalerite occur in small patches in irregularly fractured and brecciated dolomite. About 250 feet southwest of the main adit, another adit has been driven northwest a short distance into a slightly mineralized and strongly fractured cliff consisting chiefly of fine-grained creamy dolomite and some black-and-white-spotted dolomite. Brown sphalerite and a little galena are well exposed in a small cut near the junction of the roads to the Lakeview cabin and to the Schierding placer. There the ore is clearly associated with, and parallel to, bands and streaks of coarsely crystalline zebra dolomite in a dense and fine-grained dolomite.

LA SOTA HILL AREA

About 1½ miles southwest of the Slate Creek Lookout are many claims under various ownerships that cover the slopes of La Sota Hill (pl. 1). These claims adjoin the Whoopie workings on the southwest and the Lead Hill group of claims of the American Zinc, Lead & Smelting Co. on the northeast. This area has been prospected in a small way for many years, and a little hand-cobbed ore has probably been taken from the area. Most of the older work was done in shallow diggings; but more recently diamond-drill holes have been put down, and roads and small areas have been bulldozed within much of the area. The area can be reached by a road that leaves the Slate Creek Lookout road at an altitude of about 4,200 feet, or about a mile northeast of the sharp switchbacks on the Slate Creek Lookout road east of the Whoopie prospects.

The main prospected area lies northwest of the Lead Hill fault where the Metaline Limestone strikes on the average N. 60° E. and dips 25°–35° SE. The country rock consists of light- to dark-gray mixed dolomite and some fairly large areas of gray limestone (pl. 1). Much of the dolomite is a fine-grained crystalline rock that intergrades on both a large and small scale with medium- to coarse-grained dolomite and some very fine grained dolomite. On the northwest slopes of La Sota Hill the rock passes almost imperceptibly into typical bedded dolomite as stratigraphically lower beds are reached, although even here there are patches of coarse-grained dolomite and remnants of only slightly altered gray limestone. On the southeast side of the hill the patchy outline of the dolomite and limestone is caused by the irregularity of dolomitization as noted above and by the dipping of the strata southeast at about the same angle as the slope of the hill. The beds that lie between the top of La Sota Hill and the Lead Hill fault are believed to be stratigraphically in the upper few hundred feet of the Metaline Limestone.

The Lead Hill fault is not exposed in this area, but its position from the end of the road at the La Sota prospect northeastward for three-fourths of a mile to the Bunker Hill tunnel can be fairly closely located by several limiting exposures of slate and dolomite. About 700 feet southwest from the end of the road the fault is offset a few hundred feet to the south by a northwest-trending fault. Several diamond-drill holes put down near the end of the road indicate that the Lead Hill fault dips 80°–90° SE. The throw of the fault is probably about 1,000 feet. This is based upon the assumption that the large quartzite bodies in the slate to the south are at the same stratigraphic position as the quartzite bodies cut in the north Pend Oreille area.

Mineralized rock is scattered throughout the area, but it is largely confined to a belt a few hundred feet wide north of the Lead Hill fault and to a lesser extent on the northwest slopes of La Sota Hill a few hundred feet below the crest of the ridge. In the mineralized area near the Lead Hill fault, galena and sphalerite are in irregularly silicified and brecciated dolomite. The silicified rock includes light- to dark-gray jasperoid, chert, and white quartz which locally grade from one type into the other. Calcite occurs with some of the ore as small patches and stringers, and on the hillside northwest of the fault some masses of coarsely cleavable calcite are several hundred feet in length. Many shallow diggings have been made on the northwest slopes of La Sota Hill to explore for galena, which is exposed at a few places. The country rock here is the fine-grained bedded dolomite that lies a few hundred feet stratigraphically below the mineralized beds near the Lead Hill fault. In the mineralized parts of the rock, galena is in small patches and stringers as much as 2 inches wide in association with calcite, limonite, some quartz and pyrite, and coarse-grained dolomite. Part of the ore is strongly oxidized and consists of vuggy dolomite, gray cerussite, much limonite, and a few grains of galena. Steeply dipping fractures that strike northwest cut most of the country rock. Some of the galena stringers appear to follow these fractures, although exposures in this area are scanty and of small extent.

LEAD HILL

The Lead Hill mine, in the northeastern part of the mapped area, is 2 miles south of the Canadian border on the east slope of Lead Hill at an altitude of about 4,900 feet (pl. 1). The mine can be reached from the paved highway to Canada, over about 8 miles of dirt road. The mine is near the center of the Lead Hill group of 18 unpatented claims held (1955) by the American Zinc, Lead & Smelting Co. The claims lie along the steep eastern slope of Lead Hill and in the valley of Slate Creek.

The property has been variously controlled for many years, and considerable exploration work has been done on the claims. The claims were staked in 1930 by C. A. Bostrom and Iver Luhr, of Metaline Falls, Wash. During 1931 and 1932 Bunker Hill and Sullivan Mining & Concentrating Co., of Kellogg, Idaho, drove a 1,400-foot adit (Bunker Hill adit, fig. 37), put down about 40 diamond-drill holes totaling 8,400 feet, and did surface trenching. In 1937 some surface diggings were made by C. A. Bostrom and associates. The Butte-Highlands Mining Co. of Butte, Mont., surveyed the property in 1942 and put down 2 diamond-drill holes totaling 930 feet in the Ledbetter Slate east of the Lead Hill fault. The locations of these older surface diggings, adits, and diamond-drill holes are shown on the detailed geologic map (scale: 1 in equals 100 ft) that accompanies the report on the Lead Hill area by James and Albers (1944). Shortly after World War II, American Zinc, Lead & Smelting Co. acquired control of the property and started a program of exploration by diamond drilling, surface bulldozing, and driving short adits into the hill. Much of this work was done in an area 900–1,250 feet northeast of the old Bunker Hill adit. The Lead Hill mine, in the northern part of this area (pl. 1), has been worked through three northwest-bearing adits, all within 150 feet of each other, that extend 100 feet or less into the hill. Two small stopes extend upward to, or a short distance below, the surface. These workings have yielded most of the ore from the Lead Hill area. In the summer of 1955 American Zinc, Lead & Smelting Co. trucked 717 tons of ore from the Lead Hill mine to their Grandview mill. Before this time only a very small tonnage of hand-sorted ore came from the Lead Hill claims.

The country rock is largely Metaline Limestone (dolomite), although some Ledbetter Slate is exposed on the lower slopes of Lead Hill on the southeast side of the Lead Hill fault. The dolomite, shown as mixed dolomite on plate 1, is characterized by great variation in texture, color, and alteration. These variations are on both a large and small scale. Color ranges from light gray to black, although medium-gray tones are most common. In the vicinity of the workings and along the east slope of Lead Hill for a long distance to the south the dolomite shows a complex variation in texture, and gradations from fine to coarse are commonly seen within single small outcrops. Small, usually discontinuous patches exhibiting vague to well-defined zebra banding are common within the coarse-grained dolomite. Vague to conspicuously brecciated dolomite is widely distributed, but it is especially abundant in the vicinity of the diggings. Locally, angular fragments of a fine-grained dolomite are in a coarse-grained matrix, but at many other places the outline of individual fragments is vague. This vague to prominent brecciation is also evident in the cores of many drill holes. Several varieties of quartz occur irregularly distributed throughout the dolomite, commonly as small patches and veinlets that cut irregularly through the rock. Some quartz is in bodies several feet thick that have a planar alinement along the regional attitude of the beds. Color of the quartz ranges from white to black, and texture ranges from very fine (jasperoid) to coarsely crystalline patches and nodules. Many of the nodules, which are especially prominent on weathered surfaces, grade into dark fine-grained quartz and are connected by veinlets of light and dark quartz. Some of the nodules have an inner cavity lined with quartz crystals. Coarsely crystalline calcite is abundant and widely distributed in spots, patches, stringers, and, locally, as masses as much as 20 feet long. Westward across the south-trending ridge of Lead Hill the dolomite grades irregularly into the fine-grained bedded type of dolomite, and the irregular patches of quartz, calcite, and breccia became less abundant. Stratigraphically the beds on the east slope of Lead Hill probably lie within the upper few hundred feet or less of the Metaline Limestone. The eastward slope of the hillside is about the same as the dip of the beds, and thus the irregularities of alteration and variations in grain size are accentuated by irregularities of erosion. In the Lead Hill area the uppermost limestone unit of the Metaline has been even more completely altered to dolomite than the rocks farther south on La Sota Hill, where a few remnants of limestone remain in the dolomite.

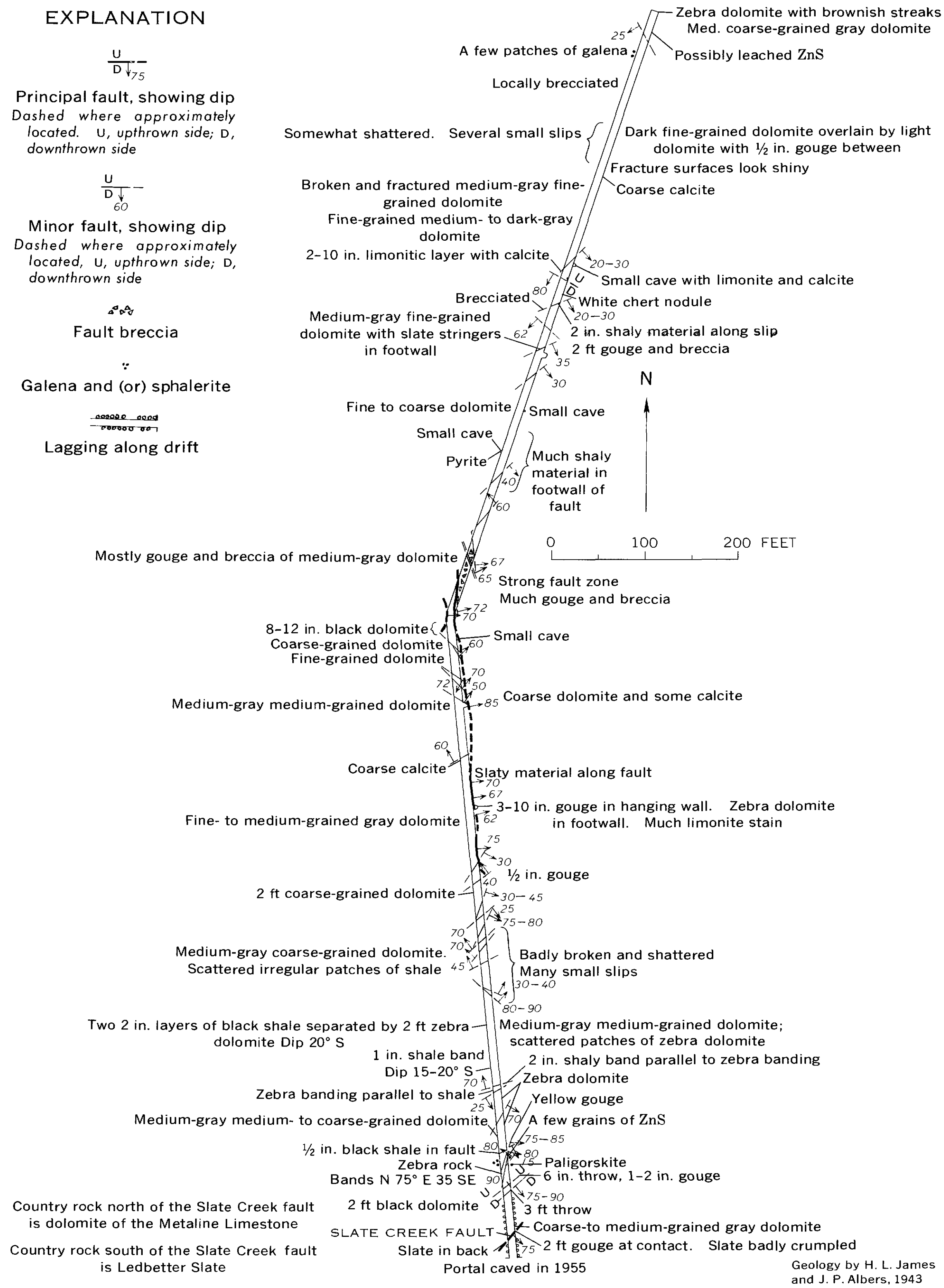

FIGURE 37.—Geologic map of the Bunker Hill adit, Lead Hill area.

The Ledbetter Slate is dark-gray to black rock that locally contains lenses of light-gray to black quartzite. The quartzite masses are commonly cut by many white quartz veinlets. A short distance south of the Bunker Hill adit a mass of quartzite is faulted against the dolomite. Both slate and quartzite are well exposed in roadcuts across the valley east of the Lead Hill mine.

The dolomite beds strike N. 45°–65° E. and dip on the average 35° SE. No bedding planes could be recognized in the Ledbetter Slate. The dominant structure is the Lead Hill fault that brings slate on the southeast against dolomite on the northwest. This fault, which dips about 75°–85° SE., is exposed near the portal to the Bunker Hill adit (fig. 37) and in a bulldozed cut 150 feet east of the junction of the roads to the Bailey property, the Lead Hill mine, and the Slate Creek Lookout. The fault probably has a stratigraphic throw of between 1,000 to 1,500 feet; this estimate is based in large part upon the assumption that the large masses of black quartzite in the Ledbetter Slate near the fault are stratigraphically about 1,000 to 1,200 feet above the base of the formation. On the basis of past diamond drilling, it can be stated with reasonable certainty that the Lead Hill fault in this area has a minimum throw of 550 feet, unless the unwarranted assumption is made that the slate beds dip very steeply, instead of moderately, to the southeast. This minimum throw becomes evident by drawing a section through Butte Highlands hole 1 and westward through the fault to the Metaline. The drill hole is located on the surface 775 feet N. 73° E. of the Bunker Hill adit and was drilled on a bearing of N. 65° W. at an inclination of —68°, bottoming in Ledbetter Slate at a depth of 589 feet. The first 67 feet of the hole was through glacial sand, cobbles, and boulders; the next 67 feet cut black quartzite with some slate; and the remaining 455 feet was chiefly black slate with common pyrite, a few quartz stringers, and one 7-foot section of pyritized dolomite.

The Slate Creek fault, with a vertical displacement of at least 5,000 feet, lies about 1,000 feet southeast of the Lead Hill fault but is largely concealed by glacial material (pl. 1). Northeast- to northwest-trending faults, having very minor displacements, occur widely distributed through the dolomite, especially near the Lead Hill fault. Most of these faults cannot be traced with certainty for more than a few feet on the surface. The Bunker Hill adit follows the fractured footwall of one of the more continuous faults for about 700 feet (fig. 37). This fault strikes north and dips on the average about 70° E. The vertical displacement of the fault is probably less than 50 feet, and some, if not all, movement along the fault is postore.

The ore minerals, sphalerite and galena, occur typically as irregularly distributed grains, patches, and poorly defined stringers in a gangue of coarse-grained dolomite, jasperoid, barite, and calcite. The sphalerite is in reddish-brown and resinous yellow grains that range from fine to coarse. Some grains are part yellow and part reddish brown. Galena, which is far less abundant than sphalerite, occurs in scattered grains, blebs, and stringers. Both sphalerite and galena are most commonly contained in the silicified parts of the gangue, although some ore, especially galena, is in dolomite that contains little or no quartz. Barite is in irregular grains, patches, stringers, and, locally, sharply defined veinlets. At one locality, barite was found closely associated with galena in a narrow vein. Much of the fine-grained barite is difficult to distinguish from calcite in hand specimens. According to Delos Underwood, Mill Superintendent of the Grandview mine (oral commun., 1955), the ore shipped from Lead Hill during the summer of 1955 averaged about 2 percent barite. The ore and gangue are in irregularly brecciated rock that is typical of the ore-bearing zones in the Metaline district.

Except for the presence of considerable barite and perhaps a little lower average silica content, most of the ore of Lead Hill is similar to that found at many places in the mines near Metaline Falls. The authors believe that the ore solutions forming the Lead Hill deposits are genetically related to those that formed the main deposits near Metaline Falls, even though the Lead Hill ores are derived from solutions that locally contained or deposited an above average amount of barium.

The known ore bodies appear to be confined to shallow erosional remnants that lie on the southeast slopes of Lead Hill. The extension of the ore body, if it exists, is to the southeast beyond the Lead Hill fault and under the Ledbetter Slate. The probable great depth to the favorable ore zone in the upper part of the Metaline is a discouraging factor for exploration of this narrow belt between the Slate Creek and Lead Hill faults.

LEAD KING

The Lead King mine is 1½ miles north of Ledbetter Lake and just east of the highway to Russian Creek (pl. 1). The property is at the southern end of a large irregularly mineralized area that extends 1½ miles north to the Cliff mine. The prospected area around the Lead King mine lies chiefly within the Lead King and Lead King Extension claims, which are held by the Pend Oreille Mines & Metals Co. Although production has not been large, this mine is among the older group of diggings in the district. Jenkins (1924, p. 60) states that two or three carloads of ore, principally lead and zinc, were reportedly shipped in 1918. Small shipments of ore were reported in 1925 and 1926 (Gerry, 1928, p. 559; 1929, p. 468). No ore has been shipped since 1926.

The mine workings consist of a shallow surface pit connected by a chute to a lower adit. The pit, about 60 feet in longest dimension, was dug in a mineralized outcrop 150 feet east and 50 feet above the main road to Russian Creek. The adit, driven from the level of the road, bears S. 70° E. for 195 feet. Many shallow diggings extend both north and south from the mine along the westward-sloping hill for a total distance of about 1,500 feet. Many years ago five relatively short diamond-drill holes were put down in the valley southwest of the mine, and within the past decade some deeper holes have explored the ground farther west and south of the mine.

The country rock is very fine grained gray limestone and large irregular bodies of gray to black crystalline dolomite, all stratigraphically within the uppermost few hundred feet of the Metaline Limestone. Most of the limestone contains irregular spots, streaks, and nests of gray dolomite and some patches of coarsely crystalline calcite. The large patches of dolomite shown on the geologic map (pl. 1) are chiefly fine- to coarse-grained gray to black dolomite in which jasperoid and calcite are irregularly distributed. Both limestone and dolomite locally contain white quartz in spots, veinlets, and small stringy nodules. Bedding is vague, but the few reliable readings obtained indicate a northerly strike and dips of 30°–35° W. The glacial-filled valley to the west is bordered by slopes of poorly exposed Ledbetter Slate. The diamond-drill holes in this valley strongly indicate that the Metaline Limestone and Ledbetter Slate are in normal rather than fault contact; if it is a fault contact, the throw of the fault is small. One of the old drill holes located 150 feet southwest of the Lead King mine reportedly cut 200 feet of alternating limestone and dark igneous rock.

The west slope of the hill east of the Lead King mine is a little more gentle than the dip of the beds; thus, the irregular silicified dolomite patches near the mine are erosional remnants of what was probably a much larger altered zone at the top of the Metaline Limestone. This hill and those to the north as far as the Cliff mine afford the best exposures of the upper part of the Metaline in the district (pl. 1). It is noteworthy that relatively unaltered gray limestone is 850–1,300 feet thick along this belt, whereas gray limestone averages less than 500 feet thick in the vicinity of the Pend Oreille and Grandview mines.

The ore consists of irregularly distributed galena and sphalerite, in most places associated with jasperoid, dolomite, calcite, and vague to well-defined breccia zones. Fresh sulfides are found at the surface. The mineralized alteration zone conforms in a very general way to bedding and dips to the west, as indicated by surface studies and the relation between alteration in the Lead King adit and pit. The adit cut 35 feet of very poorly mineralized dolomite before penetrating 160 feet of gray "footwall" limestone. A section along the adit and pit shows a westward dip of about 35° for the base of the altered zone.

Samples of ore were cut across the southern part of the mineralized zone in the pit. The area sampled is 10 feet wide and appears to be typical of much of the mineralized ground near the Lead King mine. The ore, which was assayed by J. C. Crampton, of the Pend Oreille Mines & Metals Co., yielded 0.13 percent lead and 1.35 percent zinc.

ROBERT E. LEE

The Robert E. Lee mine is high on the west bank of the Pend Oreille River about a mile northeast of Ledbetter Lake (pl. 1). It is reached by a dirt road that leaves the main road to Russian Creek near Ledbetter Lake. The mine area is heavily timbered and the topography is rugged, although the relief is not great. The property, consisting of five unpatented claims held by Jerome Drumheller, Spokane, Wash., was staked and prospected many years ago. Before World War II exploratory diggings consisted of a few shallow pits and a short inclined shaft. A few diamond-drill holes were sunk by the Pend Oreille Mines & Metals Co., which held the property under option for a short time. About 1942 Columbia Lead & Zinc Co. started exploration work that extended over a period of several years. This company bulldozed a road into the property, drove two adits westward near a mineralized outcrop, and did both underground and surface diamond drilling. Little work, other than for assessment, has been done since June 1945. Tonnage of ore shipped from the property, if any, is probably small.

The main mine working is an adit that was driven westward under a mineralized outcrop (pl. 6). The adit was inaccessible when visited. According to reports, it was driven for about 75 feet and the surrounding ground explored from the tunnel by diamond drill. Another adit 100 feet to the northwest bears southwest somewhat irregularly in black slate for about 125 feet. In the roof of the adit about 40 feet from the heading a small irregular block of dolomite has been faulted into the slate. The dominant cleavage of the slate ranges in strike from N. 35°–60° E. and dips 45°–65°

NW. The short inclined shaft described and illustrated by Park and Cannon (1943, p. 71 and fig. 11) was filled with dirt during construction of the road to the property.

The country rock in the main prospected area, which lies between the mine road and Everett Creek, is Metaline dolomite and Ledbetter Slate. Outcrops of dolomite are sparse. The largest and best exposure is west of the mine adit where a knob consists of dark-gray to black medium-grained dolomite irregularly silicified by jasperoid and cut by narrow northwest-trending veinlets of white quartz. Patches and short stringers of galena are exposed at numerous places and some of the rock contains fine- to medium-grained sphalerite. The outcrop is strongly fractured, the attitudes of the two most prominent fracture sets averaging N. 10° W., 40° E. and N. 40° E., 70° NW. Near an embayment at the southwest side of the outcrop is a fault of probable slight displacement that strikes N. 25° W. and dips 70° E. Black slate of the Ledbetter which locally contains a few graptolites, is well exposed at several places, especially in cuts along the road to the mine. Slate is also exposed in the lower part of the valley of Everett Creek and in the adit 100 feet north of the mine. A lamprophyre dike, rich in biotite, is exposed in the roadcut and south of a shallow prospect pit about 300 feet northwest of the mine. The dike is 3 feet wide, strikes N. 75° W., and is vertical.

The property lies within an area of strongly faulted and fractured rocks where Metaline Limestone has been thrust over Ledbetter Slate, and later was offset along northeast-trending faults. Plate 6 shows the major relations among slate, gray limestone, and silicified and crystalline dolomite. It is likely that many faults other than those shown on the map are present west of Everett Creek. A more accurate structural interpretation could likely have been made had detailed records or core of the underground and surface diamond-drill holes been available. Reported information of a very general sort indicates that some holes penetrated a complexly repeated sequence of slate, carbonate rock, and, in places, ore. The confused structural relations are reported to have led the operator to discontinue further exploration because it was decided that minable ore bodies would not extend far in such badly broken rocks. The highly faulted and fractured ground would also have added greatly to the cost of mining.

Galena, and to a lesser extent sphalerite, occur in scattered spots and streaks in dark-gray irregularly silicified and brecciated crystalline dolomite. The stratigraphic position of the mineralized ground is probably within the upper 200 feet of the Metaline Limestone.

LUCKY STRIKE

The Lucky Strike property consists of five unpatented claims (Lucky Strike 1–5) located east of the Pend Oreille River and about half a mile north of the mouth of Slate Creek. Access to the buildings on the property is over a narrow dirt road that leaves the paved highway to Canada at a point about half a mile north of Slate Creek Bridge. Faint to well-defined trails lead from the mine buildings to most of the scattered diggings. In 1955 the property was held by E. M. Skaug, Jr., Spokane, Wash. The property was originally located about 1920 by R. L. Lakin, of Spokane. An unspecified tonnage and grade of ore was shipped in 1926 (Gerry, 1929 p. 468). It is reported that the Hecla Mining Co. in 1927 sank a 90-foot inclined shaft and drove a 200-foot adit. No ore was shipped by Hecla. In 1952 a lessee, W. E. Curtis, mined from the surface and shipped 5,642 pounds of ore to the Consolidated Mining & Smelting Co. at Trail, British Columbia. This was probably mostly lead ore, for the Lucky Strike property is chiefly a lead producer.

The principal mine workings consist of an inclined shaft bearing southeast at a slope of —57° and, to the north about 125 feet, an adit bearing N. 80° E. When visited in 1954, the adit was caved at the portal and the shaft was filled nearly to the surface with water. The inclined shaft is reported to have been sunk 90 feet and the adit driven 200 feet. Many shallow prospect pits and cuts have been dug in a belt about 1,500 feet long that trends northeast (pl. 6). Most of these are located in an area of sharp northeast-trending ridges and valleys with a maximum relief of 175 feet.

The country rock is chiefly very fine-grained to fine-grained creamy to gray bedded dolomite. Locally, this rock grades into irregular patches of coarse crystalline dolomite. In the vicinity of the prospected area and for a long distance to the south, bedding is absent or so faint that it cannot be distinguished from the numerous strong fractures; however, northwest and west of the mineralized area the beds clearly strike north and dip 30°–40° W. (pl. 1). The mineralized area is in a strongly fractured zone striking N. 55°–70° E. that is related to the faults that extend southwest to and beyond the Robert E. Lee mine. Irregular alteration plus faulting and a wide belt of covering to the east make it impossible to determine the precise stratigraphic position of the ore zone, although it is probably about 1,000–1,500 feet stratigraphically below the top of the Metaline Limestone.

Galena and sphalerite are found in some of the prospects and on the main mine dump, commonly associated with streaks, veins, and patches of coarse white calcite and crystalline dolomite. Some of the crystalline dolomite cleavage surfaces are as much as 1½ inches long, although most dolomite grains average far smaller and grade into the fine-grained dolomite country rock. Limonite is widespread. One stringer of fine-grained galena 2 inches wide was seen on the dump at the inclined shaft. Most of the mineralized material on this dump consists of patches and stringers of fine-grained pyrite, locally in radial form, and limonite. Some fine-grained light-brown sphalerite occurs in association with the pyrite. According to information obtained by Park and Cannon (1943, p. 71) from R. L. Lakin, then owner of the property, the workings off the inclined shaft stopped in heavy iron sulfide. Some galena is exposed in the small cliff of fractured dolomite just east of the inclined shaft. The galena is granular and fine to medium grained; it occurs in irregular pods and in stringers generally less than 1 foot long and ¾ inch wide. There is a faint, but uncertain, suggestion that the lead ore in the cliff follows a structural or bedding trend having a strike of about N. 40° W. and a dip of about 60° SW.

The deposit, although containing little sphalerite, resembles somewhat the ore body found in the Yellowhead mine (p. 100–102) because of the common occurrence of pyrite and rarity of jasperoid. Both deposits are also in a relatively low stratigraphic position in the Metaline Limestone.

METALINE

The main entrance to the Metaline mine is between the paved highway and the west bank of the Pend Oreille River a little less than half a mile south of Metaline (pl. 1). In the past the mine has also been known as the Bella May. Although work on some of the high surface diggings and short adits far to the northwest of the main entrance to the mine was done many years ago, it was not until 1937 that the mine yielded any significant tonnage of ore. During the period of greatest activity, 1937–47, the property was held by the Metaline Mining & Leasing Co. and operated by the American Zinc, Lead & Smelting Co. The ore was trucked to the mill at the Grandview mine and the concentrates were shipped to American Zinc Co.'s smelter at East St. Louis. The Sullivan Mining Co., Kellogg, Idaho, acquired a lease on the property in 1950, and most of their work has been development in the western part of the mine. The mine has been idle since 1953. When the authors attempted to revisit the mine in 1955, it was found that the main adit was badly caved not far from the portal and water had apparently backed up for a considerable distance in the adit.

The Metaline mine ranks third in total production of ore from the district. Table 8 (p. 58) shows production from 1906 to 1951. Most of the ore shipped before 1937 was probably hand-sorted galena obtained from the old surface, or near-surface, diggings over the Bella May and Blue Bucket workings.

The Metaline mine is divided into three groups of workings—the Blue Bucket, Bella May, and West Contact (pl. 4). These workings, which extend through a vertical distance of about 1,300 feet, are connected to a long haulage adit, most of which was driven during the years 1936–38. An extension at the western end was made in 1952 in order to connect to a raise that later was driven into the West Contact area. The total length of the haulage level from the portal to the foot of the West Contact raise is about 6,600 feet. Most of the mine workings are above the main haulage level; those below are in the southern Bella May area where an incline extends from the haulage adit to the lower levels. A raise off the 800 level of the West Contact workings connects with the surface at an altitude of about 3,050 feet. The northern and older part of the Blue Bucket workings were first opened from the surface by a shallow shaft which has been inaccessible for many years. The Bella May ore bodies were also first developed through surface openings, the longest of which is adit 6 (pls. 1, 4), extending west and southwest into the hill almost 1,000 feet to the stopes. In the main mine workings, crosscuts have been driven both above and below the haulage adit, and one, the South crosscut, which is at the same altitude as the haulage adit, has been driven southwest to undercut and explore the southern part of the Blue Bucket ore bodies. Most of the raises in the mine are inclined at 55°.

Many diamond-drill holes were put down from surface locations before the main haulage adit was driven, and as the work progressed throughout the years diamond drilling continued both on the surface and underground. Precise figures have not been compiled, but it is likely that the total length of holes drilled is about 200,000 feet. During the second World War the U.S. Bureau of Mines, on the recommendation of the mine operator and the U.S. Geological Survey, drilled many deep holes from surface locations in the West Contact area. Considerable diamond drilling has been done by the mining companies about 2,000 feet south of the haulage adit in order to explore for a possible southward extension of the Blue Bucket ore bodies (section *B–B′*, pl. 4).

The country rock cut in the mine workings and sparingly exposed at the surface is the Metaline Limestone and Ledbetter Slate. Glacial lake deposits, consisting chiefly of silt and sand, cover most of the workings east of the Bella May area where they range in thickness from a thin veneer to 200 feet or more. A mass of

Metaline Limestone about 850 feet long and a maximum of 200 feet wide protrudes through the glacial deposits near the Blue Bucket shaft (pl. 1). This limestone, which is in a plate thrust over the slate, is irregularly silicified and dolomitized. The rock exposed at the surface at the old Bella May diggings and farther northwest near the West Contact raise is irregularly silicified and brecciated limestone and crystalline dolomite that stratigraphically is in the upper few hundred feet of the Metaline. Much of the area between the head of the West Contact raise southeast to the Bella May diggings is covered by glaciofluvial debris. High hills consisting of Ledbetter Slate extend south and southeast from near the head of the West Contact raise for nearly a mile (pl. 1). Bedrock is very poorly exposed in this area, except at a few places along some of the old bulldozed roads. The Ledbetter of this area is chiefly black slate and argillite which locally contain beds of black argillaceous limestone and limy argillite. About 800 feet southwest of the Blue Bucket shaft a badly weathered lamprophyre dike is poorly exposed in an old roadcut.

The mine workings expose both Metaline Limestone and Ledbetter Slate. Plate 4 shows the major divisions of these two formations, and plate 5 shows, in addition to this, the main types of altered rock of the Metaline that are found in the northern part of the Blue Bucket workings and in part of the main haulage level. The first 1,850 feet of the main haulage adit from the portal to the Blue Bucket fault (pl. 1) is in the bedded dolomite unit of the Metaline. This rock contains some bands and streaks of black-and-white-spotted dolomite which are especially common in the first part of the adit. Most of the rock is a creamy to gray fine-grained bedded dolomite. It grades into patches of medium- and, rarely, coarse-grained rock at some places, especially near faults and west of the junction of the South crosscut. This bedded dolomite unit, at least in very large part, lies stratigraphically below the Metaline rocks cut elsewhere in the mine. Many caves are in the first 700 feet of the adit; some are filled or partly filled with clay, sand, and gravel of the lake deposits that have worked their way down along fractures. West of the Bella May fault the Metaline rocks are chiefly crystalline nonbedded dolomite and some gray limestone. The crystalline dolomite varies greatly in color, texture, brecciation, and silicification within short distances. Bedding planes are rarely recognizable. Some of the rock is light gray and fine grained, but most is medium to coarse grained and medium to dark gray. Near most of the ore bodies the rock averages a coarser grain size than found elsewhere, and silicified breccias are more common. Most of the dolomite is similar to that found at many places in the Grandview and Pend Oreille mines about 2 miles to the north. Gray, relatively unaltered, limestone is cut at many places in all three of the major workings. Much of the rock on the 600 and 800 levels of the West Contact workings is gray limestone, and several areas of gray limestone are cut in the Bella May and Blue Bucket workings (pl. 5). Some of the limestone in the thrust plate of the northern Blue Bucket area is streaked and banded as a result of plastic deformation (fig. 16) during the early period of thrusting preceding the deposition of the ore. All carbonate beds cut in the Metaline mine west of the Blue Bucket fault are believed to be stratigraphically within the upper 500–600 feet of the Metaline Limestone, and most are in the upper 300 feet.

Ledbetter Slate is exposed for a little more than 2,000 feet in the main haulage adit between the Blue Bucket and Bella May faults. In the South crosscut and its northern branch, slate is known to be present for at least 500 feet west of the Blue Bucket fault, and it may continue much farther west in the drifts that were inaccessible to the authors when the mine was last visited (pl. 4). In the West Contact workings slate is exposed for about 175 feet along the western wall of the 800-foot level at the southern end. Throughout the mine the Ledbetter is chiefly a dark-gray to black argillite. In places, especially near faults and strongly disturbed areas, the rock is a slate with a well-developed fracture cleavage. Beds of limy argillite and argillaceous limestone occur locally.

The structure of the rocks in the Metaline mine area is complex. The strata are broadly folded and cut by low-angle thrusts and many steeply dipping faults. Very little structural information can be gained from the meager and poor exposures at the surfaces, but this lack is largely offset by data obtained from the mine workings and the many drill holes.

The broad folds, although cut by many faults, are clearly brought out in section *A–A′*, plate 4, where it can be seen that both the Blue Bucket and Bella May areas are on anticlines and the West Contact area is chiefly in a syncline. These folds probably plunge at moderate to gentle angles south or southwest, but the lack of sufficient data both to the north and south of the mine area prohibits a definite statement. Structure contours drawn on the Metaline-Ledbetter contact that was cut in the drill holes in the West Contact area show that the strata in this area dip south on an average about 30°. Dolomite beds north of the old Bella May surface diggings strike N. 76° W.–N. 85° E., and dip south from 35° to 55°. In the underground workings bedding planes can be recognized at many places in the main haulage adit from the portal west to within a few hundred feet of the Bella May fault (pl. 4), but elsewhere, bedding planes are very obscure. Relatively small northeast-trending folds are common in the southern part of the Blue Bucket workings where both the slate and the Metaline Limestone of the overlying thrust plate are folded.

The mine workings expose hundreds of faults which range in displacement from a few inches or less to 1,000 feet or more. Most of the faults are believed to have minor displacements, although four major faults are recognized with certainty. The faults range widely in strike and dip although most, especially the major faults, trend northeast. Some idea of the extent of faulting can be obtained from plate 5. The faults commonly have smooth and slick surfaces either with or without striae or grooves. Others have two or more surfaces separated by a filling of gouge or breccia, or generally a mixture of the two. At some places disruption of the strata is indicated by an irregular zone of breccia, gouge, and fractured rock that shows no distinct attitude where exposed. Only vague and generally unreliable relations exist between the magnitude of displacement along faults and the width of the fractured or brecciated zone. The presence of slate squeezed into carbonate rock in a fault zone commonly, but not everywhere, indicates a moderate to large displacement. Some insignificant-appearing faults have large displacements and can be traced considerable distances. Generally, strong-looking faults in dolomite appear weak where traced into the gray limestone. Minor faults are difficult to delineate in crumbly and fractured slate, and at many places it is evident that much movement has been accomplished along bedding planes. Faulting occurred before, during, and after the ore deposits were formed.

The four major faults are the Metaline thrust and the Blue Bucket, Bella May, and West Contact faults (pls. 4, 5). The Metaline thrust, which brings Metaline Limestone over Ledbetter Slate, is cut in raises in both the northern and southern Blue Bucket workings, in the main haulage adit 465 feet northwest of raise 56, and in many drill holes, some as far west as the Bella May workings (see drill holes 36, 38, section *A–A′*, pl. 4). The Metaline thrust formed early in the structural history of the region, and at many places it is offset by later faults. In the main haulage adit the sole of the thrust is very well exposed (p. 36–37). The largest known segment of the thrust is in the Blue Bucket workings where all stopes are in this block. In raise 56 the thrust was cut about 100 feet above the haulage level (pl. 5), and in some of the raises off the South crosscut the fault is only about 35 feet above the level of the haulage adit. In the northern Blue Bucket workings the thrust plate of Metaline Limestone is about 300 feet thick (section *A–A′*, pl. 4). The beds in the thrust are those that, stratigraphically, are in the upper part of the Metaline Limestone.

The Blue Bucket fault is cut in the main haulage adit and South crosscut, and its southward extension is known by the line of drill holes shown in section *B–B′*, plate 4. In the haulage adit it strikes northeast and dips about 60° NW., but in the South crosscut the fault branches near the tunnel and the main southward branch dips 80° E., which, however, may be a local variation of a general westerly dip. The Blue Bucket fault is believed, with a reasonable amount of certainty, to be the southern part of the Slate Creek fault (pl. 1), although the last known position of the Slate Creek fault is about 2 miles to the northeast near the Grandview mine road. The throw of the Blue Bucket fault is not known, but it is a minimum of 700 feet. Throughout most of its course it is believed to be a normal fault, although locally, as indicated by the dip in the South crosscut, it is a reverse fault.

The Bella May fault is a normal fault on the southeast side of the Bella May workings. This fault is cut at only one place in the mine, the main haulage adit, where it strikes northeast, dips about 65° SE., and brings Ledbetter Slate on the east against Metaline Limestone on the west. To the southwest of the main adit it apparently either swings to a more southerly strike or decreases in dip or is offset by another fault, because it is not cut in the lower mine workings. Northeast of the main adit its position is fairly well determined between drill holes 23 and 50, as shown on section *A–A′*, plate 4. This section shows that the fault has a dip-slip displacement of about 1,075 feet.

The West Contact fault, information on which comes largely from many drill holes in the western part of the mine, is a normal fault that strikes north and dips west about 30°–50°. The fault, or fault zone, is cut in the main haulage adit a few hundred feet east of the northerly drift to the base of the West Contact raise (pl. 4). Here stratigraphically higher beds of Metaline Limestone on the west are in fault contact with lower beds of Metaline on the east. The stratigraphic throw of the fault at this point is about 200 feet. Data are insufficient to project this fault very far to the north, but on the surface to the south a broken and silicified area high on the slate-covered hills indicates that it continues southward for several thousand feet beyond the mine workings.

The ore deposits are irregular replacement bodies that in a general way conform to the dip of the strata. Many are associated with irregular areas of dolomite breccia, although some ore is in nonbrecciated dolomite or weakly altered gray limestone. Nearly all the ore is massive, but locally there are some cavities lined with crystals of dolomite, quartz, calcite, or sphalerite, and locally in the higher workings, some cavities contain smithsonite or crystals of cerussite. Most of the ore bodies are in a zone 35–200 feet stratigraphically below the Ledbetter Slate. The individual ore bodies range in length from a few feet to several hundred feet, and some stoped ore bodies are as much as 75–100 feet high, although most are 20–40 feet. The irregular distribution of the ore is shown on plate 4 by the outline of the stoped areas. The wide separation of the ore bodies in the Blue Bucket and Bella May workings is obviously accounted for by structures, but in both areas the ore bodies mined so far are more dispersed than in similar areas of mineralized ground in the main parts of the Grandview and Pend Oreille mines. (See pls. 2, 4.)

The ore minerals are sphalerite and galena, and in most ore shoots sphalerite is greatly predominant. Sphalerite is commonly resinous yellow or reddish brown, although a little of it is pale yellow, which in fine grains appears colorless. Crystal faces are rare, and most of the sphalerite is in anhedral grains distributed in irregular streaks and patches. The grains range in size from very fine to coarse. At many places extreme differences in grain size and color occur within a distance of a few feet. Galena is generally more coarse grained than sphalerite. Galena generally is irregularly distributed in the ore shoots, although at some places it is more abundant near the peripheries of the ore bodies. Pyrite is rare in the ore bodies. Minor amounts of cerussite, smithsonite, and anglesite occur locally in the Bella May area at the surface and in the mine workings around stopes 30 E., 30 W., and 209 (pl. 4). A few crystals of wulfenite were reported by Park and Cannon (1943, p. 67) in ore from the upper Bella May area and in the main haulage adit.

The common gangue minerals are crystalline dolomite, light- to dark-gray jasperoid, and calcite. Milky quartz, in places grading into jasperoid, occurs locally. The dolomite ranges from a fine-grained light-gray rock to one that is coarse grained and medium to dark gray, the latter rock being far more common. Jasperoid is widely distributed in varying amounts, and it commonly forms much of the recemented dolomite breccias. The ore minerals are most commonly within the jasperoid, although some ore and scattered sulfide minerals are in unsilicified dolomite and in places in limestone. Calcite, ranging from white to dark gray, is widely distributed in and bordering the ore bodies as grains, irregular patches, veinlets, and crystals lining small vugs. A few large masses of coarsely cleavable calcite occur locally, especially in the upper part of the West Contact workings, but these large bodies, 25–75 feet long, are not nearly so abundant as in the Pend Oreille or Grandview mines. Fine-grained barite is a very rare gangue mineral and has been reported only in some of the ore from the upper Bella May workings.

According to Cline Tedrow, Metaline Falls, Wash. (oral commun., 1955), the grade of the ore produced from the Metaline mine from 1937 to 1947 averaged 1.27 percent lead and 5.28 percent zinc. Unusually high-grade zinc ore (18–20 percent) was mined from stope 29 in the Bella May workings (pl. 4). In the Blue Bucket workings, above-average zinc ore came from stopes 1414 and 1481, and about 700 feet to the southwest, above-average lead ore was mined in stope 1249. High-grade lead ore was found near the bottom of the ore bodies in stopes 279 and 473. In places, the lead ore is underlain by an irregular body of coarse calcite or gray limestone. Ore in stope 1052 and along the west side of stopes 53 and 54 (Blue Bucket workings) is somewhat different from most. Here most of the sphalerite is pale yellow and very fine grained and is in a dense limestone gangue that is unusually low in silica.

The unbroken nature of most of the ore minerals in the breccias and in sheared rock in the thrust plate indicates that the main period of mineralization followed the period of most intense deformation. At many places, however, postore movement is indicated either by fractured ore minerals or displacement of the ore bodies. Polished sections of ore from the northern Blue Bucket stopes show unbroken ore along flow layers of the thrust plate, but ore from this same body, collected a few feet east of the fault located along the western side of the stopes, is badly fractured.

Ore controls in the Metaline mine are just as vague as those in the Grandview and Pend Oreille mines. However, in all three mines the main ore shoots are in the same general stratigraphic position, 35–200 feet below the Ledbetter Slate. In the Metaline mine, ore occurs in a variety of structures—in a thrust plate (Blue Bucket workings), in an anticline (Bella May workings), and, in some as yet undeveloped mineralized ground in the West Contact area in a very broad syncline that plunges south. Ore in the thrust plate is in both flat-lying and folded beds, in places following flow layers in the carbonate rock for short distances. In the Bella May area much of the ore in the anticline is in the east limb, which dips into the Bella May fault. In many of the stopes there are northeast-trending faults that are similar in a general way to those shown on plate 5 in the northern Blue Bucket workings. Most of these faults cut the crystalline dolomite and in places offset the ore bodies; but other faults fade out in mineralized ground, and some of these may have been minor feeding channels for the ore solutions. Likewise, some of the faults that cut the crystalline dolomite and are presumably younger than the ore may be premineralization faults on which there has been movement following ore deposition, and they also may have originally been feeders for the ore solutions. A general feature worthy of note is that both the Blue Bucket and Bella May ore bodies are elongated northeast roughly parallel to two major faults, the Blue Bucket and Bella May. These faults may have been important feeding channels. It is likely that ore solutions migrated up and along the Bella May fault and were finally concentrated in the footwall side of the fault where the bedding planes dip toward the fault. A similar theory is applied by the authors to the concentration of ore along the Grandview fault (p. 78).

ORIOLE

No attempt was made to examine or obtain the latest information concerning the Oriole mine, which lies about a mile west of Metaline. The mine workings, in the upper part of the Monk Formation, are west of the Flume Creek fault and beyond the main region studied for the present report. The location of the mine, however, is shown on plate 1 where it can be seen that it lies only a few hundred feet from the Flume Creek fault. The interested reader is referred to the description of Park and Cannon (1943, p. 76–77) for the geology and underground workings as of 1937. Since their visit, the mine has been worked intermittently on a small scale. In 1955 the property reportedly was held by local people, among whom is Edward Dressel, of Metaline Falls.

PEND OREILLE

The Pend Oreille mine, the largest and most productive mine in the Metaline district, is about 1½ miles north of Metaline Falls. It is owned and operated by the Pend Oreille Mines & Metals Co., of which Jens Jensen, Spokane, Wash., is president, and Lynn Kinney is general manager of the mine and mill at Metaline Falls. The Pend Oreille mine is on one of the early discoveries in the district. In 1906 the property was acquired from C. W. Clark by the late L. P. Larsen who, as president and principal owner of Pend Oreille Mines & Metals Co. for many years, can be largely credited with the expansion of this company. The Sullivan Mining Co., Wallace, Idaho, acquired a considerable financial interest in the Pend Oreille Mines & Metals Co. in 1946.

Mining was on a small scale during the early history of the Pend Oreille mine. It started on the Josephine claim on the west side of the Pend Oreille River about 1910 and was carried on intermittently for about 18 years. A program of extensive diamond drilling from 1928 to 1930 disclosed ore bodies to the northeast of the older workings. In anticipation of treating this ore a flotation mill was completed and mining resumed in November 1930 and continued intermittently until 1937. In September 1937, a powerplant on the Pend Oreille River was completed, the mill was overhauled, and production was increased to about 600 tons a day. From that date to the present (1956) the mine has yielded ore continuously. By 1950 the workings had been carried so far to the northeast beyond the Pend Oreille River that it was considered expedient to transfer mine operations to the east side of the Pend Oreille River. The first unit (800 ton) of a new mill on the east side of the river was completed in December 1950, and the ore bodies that were then being mined were, in large part, reached more directly by a new adit and incline a short distance from this new mill. At about this time, mining methods were in large part radically changed so that more rock could be handled and a lower grade of ore could be profitably mined. A conveyor belt was installed to carry ore from the lower mine workings to the mill, and haulage of ore from many stopes was done by truck (trackless mining) instead of by train. The second and third units of the mill were completed in 1952 and 1954, respectively. The old mill on the west side of the river, however, continued to be used periodically from 1950 to 1952.

The lead and zinc concentrates are trucked to Metaline Falls and shipped by rail to the Bunker Hill and Sullivan smelters at Kellogg, Idaho.

The Pend Oreille mine ranks first in total output of ore from the district. Table 6 (p. 58) shows the yearly yield and totals from 1917 through 1956. Throughout the history of the mine considerably more zinc has been produced than lead, although in 1954 and 1956 lead exceeded zinc.

The Pend Oreille mine workings, as of 1955, extend from the zero level, high on the slopes on the west side of the Pend Oreille River, northeast for 8,400 feet to the 1300-foot level at the base of the Main incline on the east side of the river. The vertical distance between these two areas is about 1,250 feet (pl. 2). The principal mine development, which has progressed northeastward, has been carried on in the western workings through the Josephine shaft (inaccessible for many years), the Cascade, or 500-foot level adit, and the West shaft, and on the east side of the river through the Main incline and the 2200-foot level adit (pl. 2). A long drift under the Pend Oreille River connects the eastern to the older abandoned western workings. The Main incline, as of August 1955, extends northeast for a horizontal distance of about 3,750 feet and drops about 875 feet to its northeast heading.

The upper part is inclined 17° and the lower part beyond the 1600-foot station 12°. A system of conveyor belts brings ore from crushers in the lower levels to the surface where it is fed into the mill located a few hundred feet north of the head of the incline (pl. 1). The principal workings connected to the incline are the 1900-foot and 1700-foot levels. Entrance to the higher eastern workings is through the 2200-foot level adit 950 feet northeast of the incline. This adit bears southeast into the workings off the 2200-foot level, and the ore from this area as well as that in stopes that extend northeast and downward to the 2000-foot level is trucked to the mill through the 2200-foot adit level. Inclines, in part stoped out, extend from the 2200-foot level to the 2000-foot level and from the 1900-foot level to the 1700-foot level (pl. 2). Many raises connect stopes and drifts, and in addition large areas of the eastern workings are reached by truck roads through stopes or by large drifts that were driven especially to accommodate the ore trucks. In 1955 about 99 percent of all ore was being handled by truck.

Several other workings that are not connected to the Pend Oreille mine have been made on the property (pl. 2). On the west side of the river these include the Yellowhead mine one-fourth mile north of the West shaft, the Hidden Falls and Old Cascade adits on Flume Creek about 1,200 feet southwest of the West shaft, the Josephine glory hole a few hundred feet south of the Josephine shaft, and the Sullivan glory hole about 1,000 feet southwest of the Josephine glory hole. On the east side of the Pend Oreille River are the old diggings and adits known as the Morning and Mammoth, or M. and M., which are about 1,000 feet southwest of the Main incline. In addition to those given above there are many cuts, pits, and short adits scattered over the property, chiefly on the west side of the river.

The country rock is Metaline Limestone overlain by Ledbetter Slate. On the surface above the mine workings a very large part of the Ledbetter and some of the Metaline is concealed beneath Quaternary lake deposits that range in thickness from a thin veneer to 200 feet or more. This glacial covering is especially extensive east of the Pend Oreille River (pl. 1). Rocks of the Metaline Limestone are well exposed at several places on the west side of the Pend Oreille River. Strongly fractured and irregularly silicified dolomite and dolomite breccia can readily be seen along the river banks from Dead Man's Eddy (pl. 2) north almost to the Yellowhead fault. Limestone as well as dolomite is exposed in the steep walls of the valley of Flume Creek between the Cascade adit and Hidden Falls and in the area from the Sullivan and Josephine glory holes south to the mine road. A mass of coarse calcite at least 75 feet long is exposed in the limestone cliff northwest of the bridge over Flume Creek. The Ledbetter rocks are very well exposed along the banks of the Pend Oreille River, especially on the west side during the latter part of the summer when the water is low. Bedding planes are readily seen in these black argillites, which contain numerous limy members. Some of the Ledbetter rocks above the Cascade adit and along the west bank of the river 500 feet south of the Yellowhead fault are very thin bedded platy shale that contain abundant graptolites.

The rock cut in the mine workings consists of limestone and dolomite of the Metaline and, to a lesser extent, the Ledbetter Slate. Most of the exposed Metaline rocks lie stratigraphically in the upper 200 feet of the formation. The Pend Oreille mine workings afford the most extensive exposures in the district of this important part of the formation which contains the main ore bodies. Most of the carbonate rock is medium- to dark-gray crystalline dolomite, commonly having a medium- to coarse-grained texture, but some very fine grained gray limestone is exposed at many places in both the eastern and western mine workings. Some dolomite is creamy, light gray, or black, and locally the grain size is very fine. The uppermost 25 feet of the Metaline commonly contains irregular zones of dark-gray to black crystalline limestone, although at other places all rock in this position is dark crystalline dolomite. Black shaly partings and some shale lenses a few inches thick are locally present in these upper rocks. At many places altered rock is in the form of irregularly-shaped masses of dolomite breccia that range widely in size and grade imperceptibly into nonbrecciated dolomite. Many of the breccias contain angular and subangular fragments of light-gray fine- to medium-grained dolomite; at a few places some of the fragments are slightly altered gray limestone. Light-gray to black jasperoid, locally grading into milky quartz, irregularly fills much of the matrix of the breccias. Some breccias, as well as nonbrecciated dolomite and in places limestone, are almost entirely silicified. Calcite in grains, pods, stringers, and masses 50 feet or more in length is irregularly contained in the dolomite, dolomite breccia, and, to a somewhat lesser extent, in the gray limestone. At many places the dolomite and dolomite breccia are bordered or underlain by coarse cleavable bodies of calcite and calcite stringers and short veins a few inches wide. Dolomite, calcite, and quartz locally form small crystals that line vugs.

As a very general statement it can be said that the uppermost 150 feet of Metaline Limestone in the Pend

Oreille mine area is a crystalline dolomite that overlies gray limestone, although at places gray massive limestone is found 50 feet or less below the slate. Crystalline dolomite also occurs locally beneath gray limestone and repetitions of limestone and dolomite are common. Some of these irregularities between the larger bodies of crystalline dolomite and limestone are shown in the drill holes along the sections shown on plate 3. In the western and higher parts of the mine workings, especially along the 300-level drifts, much of the country rock is a fine-grained gray dolomite that locally grades into limestone and coarsely crystalline dolomite. These drifts in particular clearly show some of the irregularities of alteration as well as the different physical characteristics of dolomite found within relatively short distances.

The most prominent structural features of the Pend Oreille mine area are broad open folds cut by dominantly northward- or northeastward-trending faults. The major structural features are clearly brought out on the structure contour map (pl. 2) and the accompanying sections (pl. 3). This map also shows the structures of the Grandview and Yellowhead mines area and their relations to the Pend Oreille mine. It is probable that the much older Washington Rock thrust extends beneath the mine workings and is preserved between the Slate Creek and Flume Creek faults. In view of these major structures it is not surprising that hundreds, or perhaps several thousand, faults are present in the mine workings. Some idea of the shattered character of the ground can be obtained from the fact that 42 brecciated and faulted zones from 1 to 50 feet thick were recognized in drill hole U.S. 24 shown on section *C–C′*, plate 3. Most of these zones probably represent minor displacements of a few inches to several feet. By far the greatest number of faults seen in the mine workings are clean sharp breaks, and the surfaces are generally smooth, slick, and, in places, polished. Striations and grooves occur on many fault surfaces; most of them plunge nearly parallel to the dip of the fault plane. Other faults have two or more sharp surfaces separated by breccia or gouge and breccia; locally, many of the fragments of the fault breccia are subrounded. Fault contacts between Ledbetter Slate and carbonate rock are commonly irregular zones with much slate squeezed into the carbonate rock, and the local strike and dip obtained in a small exposure along a drift may not reflect the overall attitude of the fault. In places, slate has been forced several hundred feet into carbonate rock. An interesting locality to observe this phenomenon is along the valley of Flume Creek near the Hidden Falls adit. Here a band of black slate about 2 feet thick clearly lies between 2 sharp and polished fault surfaces on dolomite, and at one place a nearly perfectly preserved graptolite was found in the slate.

The principal faults that have been recognized are shown on plate 2. The largest of these is the Chickahominy, which separates the mine into the main eastern and western workings. The Chickahominy is a normal fault dipping 55°–80° NW.; it has a stratigraphic throw of 350 to 500 feet. It is well exposed in the old 1000 drift (now the 1700 level) where Ledbetter Slate on the west is faulted against Metaline Limestone on the east. A few hundred feet north and at a lower altitude it is also cut in the 1500 level of the western workings. Southwest of the old 1000 drift the position of the Chickahominy fault is determined by drill holes and surface exposures, and the fault apparently splits into several branches all of which are downthrown on the northwest as shown on plate 2.

The Yellowhead fault, which lies on the northwest side of the western mine workings, strikes northeast and dips 40°–90° NW., although near its southwestern end a local and steep reversal of dip was observed. This fault, which is normal throughout most of its extension, reaches from the 300-level workings northeast for about 4,000 feet where it joins the Chickahominy fault (pl. 2). The throw of the fault increases to the northeast; it is about 50 feet where cut in the old 300-level stopes and about 200 feet near its junction with the Chickahominy fault. Another fault of major structural significance lies 300–700 feet north and roughly parallel to the Yellowhead fault. This fault has been named the Y.A. fault—an abbreviation for Yellowhead adit—because it is well exposed in this adit at a point 360 feet from the portal where the fault is vertical and brings Ledbetter rocks on the east against Metaline rocks on the west. About 1,800 feet to the southwest this fault is exposed in the northern drift on the 300-level workings where it cuts Metaline dolomite and dips 80° NW. The Yellowhead and Y.A. faults bound a graben as shown in sections *A–A′* and *B–B′*, plate 3. In the line of section *A–A′* the dip slip along the Yellowhead fault is 335 feet, and along the Y.A. fault it is a minimum of 450 feet.

In the eastern mine workings the Grandview fault is cut in stopes and drifts that extend from the southern end of the 2200-level workings northeast to stopes off the 2000 level, a distance of about 1,200 feet. The fault cannot be traced with certainty northeastward of the 2000-level stopes. It is possible that it may be offset by other faults at its northern end, and the fault that is cut by drill hole 868 and dips 65° NW. may be the northeastern extension of the Grandview fault. Dips commonly range from 50° to 65° NW. in the workings along the 2200 level to the 2000 level. A dip of 35° recorded along the old truck drift on the 2200 level is interpreted by the authors to be either a minor local variation of a steeper dip or caused by a later and relatively minor displacement of the Grandview fault. In one stope, about 500 feet northeast of where the 2200-level truck drift enters stoped ground, the Grandview fault forms a brecciated zone consisting of large and small fragments of slate and dolomite. Here both sphalerite and galena clearly cut the breccia, thus showing that the Grandview fault existed before the ore was deposited. Additional features of the Grandview fault as it is traced southwest into the Grandview mine are included in the description of the faults of this mine.

In addition to the multitude of small faults and the principal ones that have just been described, there are many that extend 1,000 feet or more and have displacements of only 10–50 feet. In both the eastern and western mine workings most of these are normal faults that strike north-northeast and are downthrown on the west. At one place in the eastern workings on the 1900 level about 300 feet south of drill hole 867, a northwestward-trending fault has been offset a short distance by a northeastward-trending fault. In the western workings a few hundred feet south of the West shaft, the north-northeastward-trending faults terminate against or are offset along northwesterly faults.

At most places the relative ages among the faults and their age relations to the ore deposits cannot be determined with certainty, although the Grandview fault is preore and many of the minor faults, especially those of the north-northeast-trending group, offset the ore. The Chickahominy, Yellowhead, and Y.A. faults are tentatively believed by the authors to be postore in age, because no visible bodies of jasperoid or ore cut across the faults. Some of the minor faults are definitely preore and some postore. The preore faults are indicated by local fillings of ore minerals, which in places extend into both the hanging-wall and footwall sides of the fault, and elsewhere faults traced into ore bodies have been obliterated by the products of the ore solutions. Most of the dolomite breccia associated with the ore is healed by silica and ore, and the movement that caused the brecciation is therefore definitely presilica and preore. The minor postore faults, of which there are many, clearly cut silicified crystalline dolomite and ore, and at many places the ore minerals are strongly fractured.

Bedding planes are recognized at several places in the Metaline rocks of the mine workings, chiefly in the little-altered gray limestone that underlies the ore bodies. Generally, bedding attitudes are so widely spaced and separated by so many faults that they afford only limited structural data. Planes that are unequivocally bedding planes are extremely rare in the main mineralized ground in and bordering the stopes. Bedding planes were originally probably very poorly developed in these massive rocks, and the later intense alteration, brecciation, and faulting has nearly obliterated them. By far the greatest aids to structural interpretations are the logs and cores from thousands of feet of drill holes. Many of these holes, drilled from both underground and surface locations, have cut the only reliable stratigraphic marker known to be present near the ore zone, the contact of the Metaline Limestone and Ledbetter Slate. Even this contact, as seen in many cores, is often subject to various interpretations, because movement along it is very common and the brecciated zone and slate forced into the carbonate rock can be interpreted as having resulted from movement along bedding or along normal or reverse faults. Likewise, seams or thin beds of dark shale occur locally in the upper part of the Metaline; these are easily confused with Ledbetter Slate because nearly everywhere some movement has taken place along these seams, and this dark shaly material is commonly squeezed into carbonate rock. Some underground drill holes have been stopped when they have penetrated a short section of Ledbetter Slate, and it is not definitely known whether a continuation of the hole would show a repetition of slate and carbonate rock along a fault zone; not infrequently, other holes that have been drilled moderate distances beyond the first showing of slate have cut repetitions of limestone and slate.

The ore forms irregular replacement bodies that range widely in size, shape, and tenor. Some are only a few feet in largest dimension, whereas others have been mined over a length of several hundred feet. The thickness of the ore commonly averages 20 feet, although this also is variable and in the western workings one ore body (stope 7–19) was mined through a thickness of 115 feet. In the eastern workings some ore bodies mined off the 2200 level (22–9 area) were 90 feet thick and the average was 60 feet. The replacement bodies follow in a very general way the dip of the strata as can readily be seen on plate 2 and the sections on plate 3. The depth of the ore below the Ledbetter Slate commonly ranges from 35 to 150 feet, although this is not constant and at places some ore is 20 feet or less from the slate and elsewhere nearly 200 feet below it. Some mineralized rock in the vicinity of the western workings of the Pend Oreille mine is known to be beneath the gray limestone, for drill hole U.S. 24 (section *C–C′*, pl. 3) cuts sphalerite-bearing dolomite about 1,100 feet stratigraphically below the Ledbetter

Slate or about 900 feet beneath the base of the main ore zone.

The ore minerals are sphalerite and galena which occur in varying proportions, although on the average sphalerite is dominant. Sphalerite ranges in color from pale yellow to brownish red, but most of it is either reddish brown or resinous yellow. Several colors may be present in an ore shoot, and very commonly in a single specimen the reddish-brown and yellow grains are intimately associated. Most of the yellow sphalerite partly or completely borders the red, but a few red grains have yellow irregular centers. The grains, which are very largely anhedral in shape, range widely in size from minute specks to a centimeter or more, although they are commonly 0.1–5 mm across. Both large and small grains are generally present in a single ore shoot. Coarse-grained sphalerite is especially common in the 300- and 500-level workings on the west side of the Pend Oreille River. Galena likewise occurs in a wide variety of sizes and shapes. The individual grains range in size from tiny specks in "steel galena" to an inch or more across; these occur as isolated grains, pods, patches, and stringers, some several feet or more in length. Some of the fine-grained galena is streaked and banded. Well-developed crystal faces are rare. Galena and sphalerite do not form an intimate intergrowth; however, both are very commonly present in the same ore shoot, although they vary greatly in relative amounts. Galena is more abundant in the eastern than in the western mine workings, and it is especially abundant in some of the southern stopes off the 1700-, 1900-, and 2200-level workings. Ore mined in 1954 from part of this area carried such high values in lead that for the first time in its history the Pend Oreille mine yielded a greater yearly tonnage of lead than zinc. Unusually rich shoots of galena are commonly associated with abundant gray jasperoid and sparse sphalerite; in position, many of them occur at or near the base of the ore zone.

The gangue ranges considerably in color, texture, mineral and rock content, and degree of brecciation. Most of the ore occurs in a gangue of irregularly silicified dolomite and recemented dolomite breccia (figs. 26–28), although some ore is in coarse cleavable patches or masses of calcite, and a little is in relatively unaltered gray limestone. The dolomite of the gangue ranges widely in the grain size and color, but most of it is a gray to dark-gray medium- to coarse-grained rock. It grades within short distances from a strong breccia of recemented fragments to dolomite that shows little or no brecciation. Many breccias contain subrounded to angular fragments of light-gray fine- to medium-grained dolomite in a matrix of silicified coarse-grained dolomite. White to dark-gray calcite is present in much of the gangue as grains, patches, and stringers, and locally as masses 50 feet or more long. Most of the silica is in the form of jasperoid, which at many places grades within an inch or less from light to dark gray, and locally passes into milky quartz. Some large masses of rock associated with the ore are entirely silicified, although usually the jasperoid is irregularly distributed in the dolomite and dolomite breccias. Milky quartz occurs as stringers and irregular patches. In general, ore and jasperoid are closely associated—and most of the sulfide minerals are in the irregular jasperoid stringers and masses within the dolomite. However, some fairly large bodies of silicified rock contain little or no ore. The variable age relations among the principal minerals of the ore bodies—sphalerite, galena, dolomite, jasperoid, and calcite—have been described on pages 63–64. Several stopes off the 1900-level drift in the eastern workings near drill holes 870, 872, and 875 (pl. 2) yielded ore contained in a gangue consisting almost entirely of coarse calcite surrounded by gray limestone. These ore bodies are of special interest because generally gray limestone is the footwall of the ore, and here drilling has shown that gray limestone lies above the ore for considerable distances.

Most of the ore is massive, but vugs and caves, described below, are present here and there. Locally, in the massive ore are minor amounts of paligorskite, carbonaceous buttons, small blotches and stringers of black shaly material, and fairly common patches and bands of zebra dolomite. Park and Cannon (1943, p. 74) report a little greenockite on dump material at the Josephine shaft, and some tetrahedrite(?) from the 700-level workings. Some smithsonite is found in the shallow oxidized zone in the high western mine workings.

Caves are widely distributed throughout the mine workings, occurring a short distance beneath the surface in some of the western workings and as much as 600 feet or more below the surface in parts of the eastern workings. They range widely in size. Some are little more than large vugs, whereas one cave on the 1900 level is about 275 feet long and averages 30 feet wide and 20 feet high; at one place this cave reaches an estimated height of at least 50 feet. Most of the caves are along fractures and several in the eastern workings are clearly along faults—in places, individual caves are irregularly spaced along a fault for several hundred feet. The caves are described further on pages 49–51. Many contain calcite and ore, and in one cave a pyrite crystal had formed between fragments of cave breccia. Locally, small crystals of barite are present (fig. 18). Paligorskite (fig. 25) is commonly found dangling from fractures in the caves.

The structures that localized the ore shoots are, at most places, vague. Reference to plate 2 shows that the ore bodies in the western workings plunge gently northeast along the eastward-dipping strata. In the eastern workings ore occurs on the nose and on both flanks of the main northeast-plunging anticline, and also in the relatively flat trough of the plunging syncline a few hundred feet north of the head of the main incline. The Grandview fault (p. 44) has, however, localized the ore in part of the workings along the 2200 level to the 2000 level. Among the northeast-trending group of faults many cut the crystalline dolomite and, in places, offset the ore. Others in the 500, 700, and 800 levels of the western workings are discontinuous along strike, although they are alined roughly parallel to the trend of the ore bodies. It is probable that these faults were premineralization in age and were local feeding channels for the ore solutions, which in large part replaced and obliterated the faults. It is likewise probable that some of the northeasterly faults that cut the crystalline dolomite and are presumably younger than the ore, represent premineralization feeding channels along which there has been movement following the deposition of the ore.

The grade of the ore varies greatly within short distances, but during the past 25 years, when the mine has been most active, the mill heads have commonly been between 3 and 6 percent combined lead and zinc. According to Loren Billings, mine superintendent (oral commun., 1955), the ore from the western workings has had a zinc-to-lead ratio of about 4 to 1, whereas ore from the eastern workings has had a ratio of about 2½ to 1.

Outlying workings.—Many small mine workings and prospects are scattered around the principal workings of the Pend Oreille mine. The most extensive of these is the Yellowhead mine, containing an unusually high percentage of pyrite in association with the ore, which is described separately on pages 100–102.

The Hidden Falls adit (fig. 38) was driven northwest about 500 feet. It is in an area of considerable structural complexity. When mapped in 1944, water had backed up to waist and shoulder depth; so only the main geologic features were observed. About midway the adit crosses a reverse fault that strikes N. 27° W., dips 53° SW., and brings dolomite of the upper part of the Metaline on the west against Ledbetter Slate on the east. The adit ended in gray limestone, which near the face is cut by two northward-striking and westward-dipping faults of unknown displacement. To the east the gray limestone is separated from the crystalline

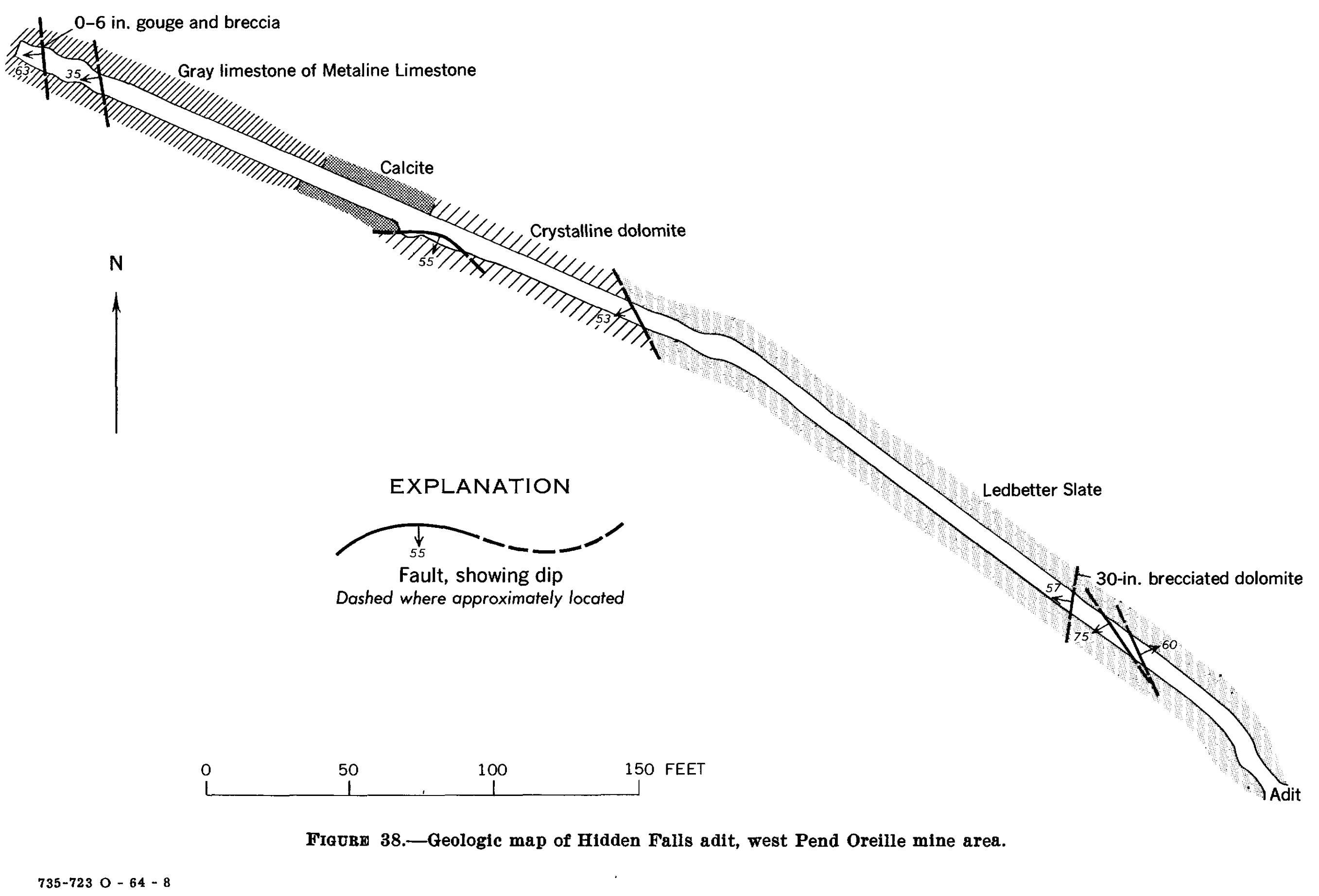

FIGURE 38.—Geologic map of Hidden Falls adit, west Pend Oreille mine area.

dolomite by a mass of coarsely cleavable calcite 40 feet thick.

About 150 feet southeast of the Hidden Falls adit, the Old Cascade adit has been driven several hundred feet south into the hill (fig. 39). This adit follows a fault that strikes irregularly north and dips 60°–90° E. Along most of the adit gray limestone on the west is faulted against crystalline dolomite on the east. The fault is probably normal and has a displacement of less that 50 feet. Sphalerite is scattered in parts of the dolomite. Many small caves are present near the face.

The Sullivan and Josephine glory holes, dug many years ago, are less than 200 feet in diameter and are 75 feet in depth. Some tunneling has been done beneath the Sullivan glory hole. Both these diggings afford excellent exposures of ore associated with irregularly silicified crystalline dolomite or dolomite breccia, and calcite. Bodies of gray massive limestone occur locally in, or a short distance from, the glory holes. Stratigraphically, these rocks lie within the upper 50–200 feet of the Metaline Limestone.

The principal workings on the east side of the Pend Oreille River that are not connected to the mine are those about 1,000 feet southwest of the Main incline, known as the M. and M., or Morning and Mammoth. Most of these workings, consisting chiefly of southerly and easterly drifts, have been largely inaccessible for many years. The property was one of the earliest explored in the district (Adair, 1909), although it is not known to have yielded any ore. A badly caved shaft, collared in a small patch of Ledbetter Slate, lies above the workings, and it is reported to be about 400 feet deep. Brinsmade (1916) reports levels at 80, 200, and 400 feet in addition to 2 adits. The outline of these workings as shown on plate 2 was obtained from old maps in the possession of the Pend Oreille Mines & Metals Co. The workings are in the upper few hundred feet of the Metaline Limestone, and structurally they lie on the west flank of a gentle northward-plunging syncline cut by two northeastward-trending faults of minor displacements. Sphalerite and galena are reported in some of the old workings.

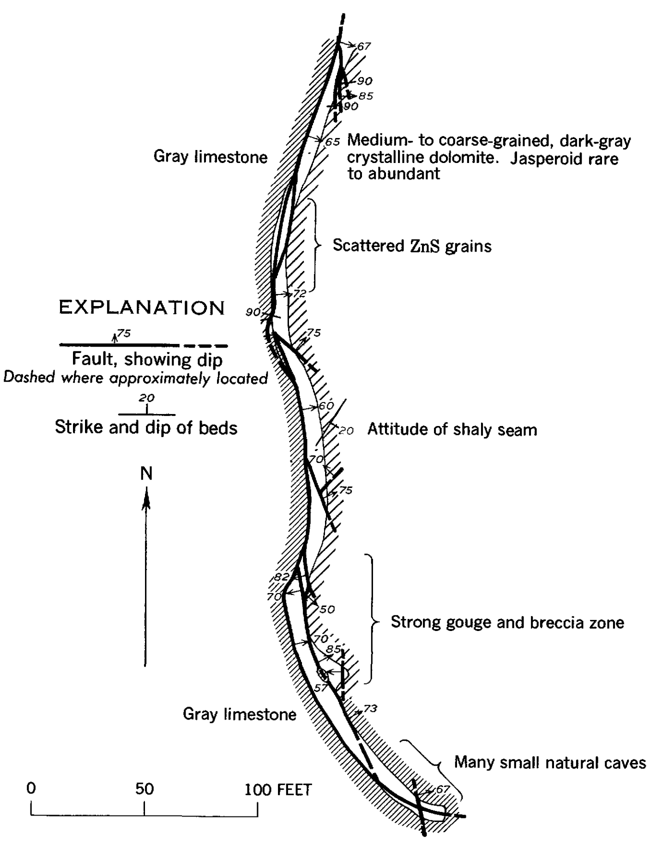

FIGURE 39.—Geologic map of Old Cascade adit, west Pend Oreille mine area. Geology by M. G. Dings and C. L. Rogers, November 1944. All workings in Metaline Limestone or dolomite.

RIVERSIDE

The Riverside mine is one of the oldest workings in the district, but very little development has been done for many years. The principal diggings are in a nearly vertical cliff about 75 feet above the water on the east side of the Pend Oreille River and about 1,500 feet southwest of the mouth of Slate Creek (pl. 1). These workings have been inaccessible for many years, because most of the ladder down the cliff has long since disappeared.

The country rock is a strongly fractured and sheared fine- to coarse-grained mixed dolomite, conspicuously stained with limonite. Very little rock is exposed on the terrace above the mine, and the cliffs for a long distance are inaccessible; so very little specific information that resulted from close observation is available. The old mine diggings and country rock can be clearly seen from the cliffs along the west side of the Pend Oreille River. From this vantage point the most noteworthy feature observed on the cliffs of the Riverside property is a very strong and wide shear zone that strikes N. 55°–80° E. and dips nearly 90°. In many places the shear planes strongly resemble bedding planes, but 500–1,000 feet south along this cliff the shear zone fades out and the moderate to low west and southwest dip of the dolomite beds becomes evident. The dolomite is part of the overthrust plate of the Lee thrust that has been preserved south of the mouth of Slate Creek. (See pl. 1.)

According to Bancroft (1914, p. 50–51), the Riverside deposit is a fissure vein in dolomitic limestone that is exposed for a vertical distance of 250 feet and trends N. 55° E. and dips 70°–80° NW. Bancroft states that the fissure filling is chiefly pyrite and a little galena, both associated with much gossan. He also noted radial pyrite with a little galena arranged in concentric bands, and mentions that steel galena and chalcopyrite were identified in tunnels in the cliff. Calcite, gypsum, and a little native sulfur have also been reported from the mineralized area.

SANBORN

The Sanborn prospect, about two-thirds of a mile south of the Canadian border, is at an altitude of about 4,550 feet on the west slope of the long ridge that extends north from Lead Hill. The prospect can be reached during part of the year by a steep bulldozed road, shown as a trail on plate 1, that continues south from the end of the road past the Bailey property. The Sanborn property consists of four unpatented claims (King Tut, King David, Solomon, and Moses) held (1955) by Mrs. Pearl Sanborn, Metaline, Wash. The last work of any significance was done by lessees in 1954. A little hand-cobbed lead ore has been taken from the property. The developments consist of several shallow pits, a short adit that was caved when visited, and two benches a few hundred feet long and about a hundred feet wide that have been bulldozed to expose bedrock.

The country rock is the bedded dolomite unit of the Metaline Limestone, which in the immediate vicinity of the prospects lies about 1,000 feet below the Ledbetter Slate. The dolomite is a creamy to light-gray fine-grained crystalline rock that contains sparse irregular patches and veinlets of white quartz, which generally follow bedding planes. Some bands and streaks of black-and-white-spotted dolomite occur locally. Bedding planes are exceptionally well developed in the rock of this area, and the attitude of the beds averages N. 35° E., 42° SE.

Small irregular patches, pods, and veinlets of galena are sparsely scattered through the dolomite. The galena is commonly associated with milky crystalline quartz and, rarely, calcite, but at some places galena borders the fine-grained dolomite. The mineralization is too scattered and poorly exposed to establish a dominant trend. The most recent diggings, however, have been made for a length of about 15 feet on the upper bench along an irregularly fractured zone, 1–12 inches wide, that on the average strikes north and dips about 40° W. Stringers of galena and quartz are somewhat discontinuous along the fracture and pinch out locally, but, in places, the galena attains a maximum thickness of 3 inches. The fine-grained dolomite wallrock, although fractured, shows no increase in grain size near the mineralized ground.

SCANDINAVIAN

The Scandinavian property is on Timber Hill about one-half mile west of York Lake. Part of the area can be reached during the summer months by a dirt road that leaves the road to the Schierding placer about one-fourth mile west of Crescent Lake (pl. 1). The property, reportedly consisting of 38 claims, is organized under the name of The Scandinavian, Inc., the principal interests of which are held by Charles Barker, Newport, Wash., and Tim McCarthy, Pasco, Wash. The only workings are a few shallow pits, cuts, and small bulldozed areas south and east of the mine cabin. The principal diggings northeast of the cabin are in a fracture zone that strikes N. 50°–80° W. and dips steeply north.

The country rock is fine-grained creamy to light-gray dolomite that locally contains small areas of coarse-grained dolomite and patches and stringers of coarse white calcite. East of the prospected area the beds strike north and dip about 30° W. Most of the prospecting has been done in a zone of the dolomite that lies 150 feet or less below the base of gray limestone (pl. 1).

The mineralization reportedly consists of sparse galena. Insofar as it could be learned, no ore has been shipped.

TEDROW (HIDDEN TREASURE)

The Tedrow prospects on the Hidden Treasure group of 10 unpatented claims are in the northeastern part of the mapped area about three-fourths of a mile northeast of Lead Hill and a mile south of the international boundary (pl. 1). The prospects can be reached by a bulldozed road, shown as a trail on plate 1, that branches from the road to the Slate Creek Lookout at an altitude of about 4,900 feet. The prospected ground, which lies within a fairly large area of few outcrops, extends about 1,600 feet along or close to the contact of the Metaline Limestone and Ledbetter Slate. The developments consist of a series of shallow bulldozed strips (shown as prospects on pl. 1), ranging from 50 to 200 feet wide, that extend west from the bulldozed road nearly to the crest of the ridge. Several shallow pits have been dug in some of the strips. Most of the work was done a few years after World War II. No ore has been shipped.

The strips chiefly expose light-gray fine-grained crystalline dolomite that lies stratigraphically within the uppermost 100 feet of the Metaline Limestone. Ledbetter Slate is well exposed for nearly 2,000 feet along the bulldozed road north of the strips. The slate is dark gray to black, largely noncalcareous, and contains some thin lenses of black quartzite and, locally, a bed of gray crystalline dolomite. Bedding planes could not be recognized in either the dolomite or slate. A slaty cleavage that strikes north and dips 65°–90° W. is conspicuous in most exposures of the Ledbetter. The stratigraphic contact of the Metaline and Ledbetter is everywhere concealed. The contact is offset a short distance by minor faults at two places along the bulldozed road (pl. 1).

A little coarse brown sphalerite was seen at a few places in several of the strips. Generally it is associated with coarse-grained dolomite, but at a few places small amounts occur in fine-grained dolomite. Irregular patches and stringers of white to gray quartz, patches of coarsely cleavable white to gray calcite, and poorly developed zebra rock are commonly associated with the coarse-grained dolomite. A few minute pyrite crystals, largely altered to limonite, occur locally in fine-grained dolomite.

TOM CAT

The Tom Cat prospect is in the northwestern part of the mapped area about a mile south of the Canadian border and three-fourths of a mile southeast of Gardner Cave (pl. 1). In 1955 the property was held by Day Mines, Inc., Wallace, Idaho, although for many years it was held by E. O. Dressel, Metaline Falls. The main development work consists of a shallow shaft and several small pits, cuts, and trenches on the hillside about 600 feet east of the road to Russian Creek. About 125 feet lower and 600 feet southeast of the shaft, the Champion adit bears west for about 25 feet into the hill. Most of the prospects can be reached by either steep poor roads or trails. No ore has been shipped from the property.

The diggings are in an area which is largely concealed by glacial lake deposits, especially to the south and west. The country rock, as scantily exposed in isolated patches in the glacial debris, is irregularly silicified dolomite and gray limestone that lie stratigraphically within the upper few hundred feet of the Metaline Limestone. Although bedding planes cannot be recognized in the immediate area, it is probable that the strata strike west or northwest and dip about 35° S. Diamond drilling has shown that Ledbetter Slate lies beneath the glacial deposits a few hundred feet south of the prospects. The slate probably rests conformably on the Metaline Limestone. Insofar as it could be determined, no faults of major displacement are in the immediate vicinity of the mineralized area, although the larger area lies within an upthrown block bounded on the north by the Monument fault and on the south by the Gorge fault (pl. 1).

The ore minerals, sphalerite and galena, are erratically and sparsely distributed in a gangue of coarse-grained gray dolomite, medium- to dark-gray jasperoid, and some calcite and white quartz. Sphalerite occurs in disseminated grains 0.1–10 mm long in jasperoid, dolomite, and white quartz. Color grades from reddish brown to yellow; the irregular core of many sphalerite grains is yellow. Galena, which is subordinate in quantity to sphalerite, occurs in scattered coarsely cleavable grains, some as much as an inch or more across. Galena is commonly associated with very small sphalerite crystals in white quartz. Some small iron-stained cavities may represent leached sphalerite grains. No mineralization was seen in the dolomite in the immediate vicinity of the lower or Champion adit.

The most favorable area for exploration is west and southwest of the Tom Cat shaft where the uppermost part of the Metaline Limestone very likely is in normal contact with the Ledbetter Slate. Day Mines, Inc. has put down a diamond-drill hole 496 feet deep, 470 feet S. 16° W. of the Tom Cat shaft. A generalized log shows 145 feet of glacial material, 66 feet of Ledbetter Slate, 260 feet of dolomite containing scattered showings of sphalerite, and 25 feet of irregularly altered gray limestone.

UNCAS GULCH (UPPER DUMONT)

The Uncas Gulch prospects, formerly known as the upper Dumont group, are on the steep slopes north of Uncas Gulch and about one-half mile south of Slate Creek. The property, consisting of 13 unpatented claims, Eureka 1 to 6, Viola 1 to 3, and Flodoro 1 to 4, is held (1955) by Robert May, Metaline Falls, Wash., and three associates. Most of the prospecting was done at least 20 years ago. No ore is known to have been shipped from the property.

The prospects are many and are widely scattered, although, in general, they extend northeast up the slope from an altitude of about 3,100 to 3,450 feet. Prospecting has been done in 13 shallow cuts and 2 adits which bear northeast into the hill for about 40 feet.

The country rock in the vicinity of the diggings is the lower bedded limestone unit of the Metaline Limestone that lies on the south, or upthrown, side of the Slate Creek fault. North of the fault, Ledbetter Slate is very poorly exposed on the hillside, except along a short road that has recently been bulldozed in this area. The lower limestone unit consists of a wide variety of rock types that include light-gray to black limestone, dolomitic limestone, dark-gray to black phyllite, and limy phyllite. The black phyllite, especially on weathered surfaces, is similar to parts of both the Ledbetter Slate and Maitlen Phyllite, a factor which can lead to much confusion in determining local stratigraphy and structure. The limestone beds are irregularly altered to dolomite, both on a fairly large and a small scale.

The dolomite ranges markedly in texture and color, in places within a distance of a few feet. It ranges in texture from fine to coarse and in color from light gray to black; locally, a little of the typical black-and-white spotted dolomite is exposed.

The Uncas Gulch area lies a short distance south of the Slate Creek fault, which here has a throw of at least several thousand feet. The beds of the lower limestone unit strike northeast and are either vertical or dip steeply southeast. Strong northeast-trending fractures cut most of the rocks, and these in combination with local diversely trending fractures, breccia zones, and dolomitization have largely obliterated bedding planes. At many places closely spaced fractures in small outcrops cannot be distinguished with certainty from bedding planes. About 1,500 feet northeast of the prospected area the lower limestone beds have been cut off by the Slate Creek fault (pl. 1). On the hill 2,000 feet east of the diggings, Maitlen Phyllite is in fault contact with the Ledbetter Slate.

A little sphalerite and galena occur in the area, and in the upper diggings some tetrahedrite and copper carbonate stains occur in dolomite in association with abundant and irregular stringers and patches of white quartz and calcite. This area shows only weak mineralization in the rocks that are exposed and is unique in that the mineralized ground is in the lower, rather than the upper, part of the Metaline Limestone.

WEHNERT AND MEYERS GROUP

The Wehnert and Meyers group of claims is about 2,000 feet northwest of the Slate Creek Bridge, and lies across a small valley west of the Dumont property (pl. 1). These properties are described together because although they are under different ownerships, they adjoin and have much the same geologic features. Three unpatented claims, Gilt Top 1 and 2 and Wesley, have been held since 1928 by George Wehnert and Harry Peters of Metaline Falls; the Sphalerite claim is held by Wayne Meyers of Kennewick, Wash. Dirt roads, periodically accessible to vehicles, reach most of the prospected area. No ore has been shipped from the Wehnert claims, and probably none from the Sphalerite claim.

The exploratory work on the properties consists of many shallow diggings and a few areas that have been bulldozed to bedrock. Most of the work has been done on the summit and southern and eastern slopes of a hill about 125 feet high that extends from the highway to Canada northeast for 2,300 feet to a swamp. The hill is surrounded by glacial material.

The country rock is principally an intergrading mixture of fine- to medium-grained crystalline dolomite of the Metaline Limestone. On the southwest slopes of the hill are a few outcrops of gray limestone and dolomitic limestone, and on the northern side of the hill the rock passes into fine-grained light-gray bedded dolomite which continues for a long distance to the north.

The main structure of the area is the Lead Hill fault which brings slate on the south against dolomite on the north. The fault is concealed beneath the glacial deposits, except in a small bulldozed area at the side of the road about 500 feet south of the swamp (pl. 1). There the fault is exposed for a few feet; it strikes N. 65°–80° E. and dips 65°–85° S. The black slate of the Ledbetter on the south side of the fault has a well-developed slaty cleavage that strikes N. 60°–70° E. and dips 70°–90° S. North of the fault the crystalline dolomite is strongly silicified.

Sphalerite and a little galena are scattered throughout the prospected area. The sphalerite is reddish brown and resinous yellow, and occurs as small grains or irregular patches, and, at places, as a conspicuous network of small stringers in dolomite. The gangue is chiefly dolomite that ranges greatly in color and also in texture from very fine to coarse. Jasperoid, quartz, and calcite are irregularly distributed, and some of the rock near the top of the hill is very strongly silicified and contains irregular patches of dolomite breccia.

Future exploration should be done by surface diamond drilling a short distance south of the Lead Hill fault to explore for possible ore bodies that might lie beneath the Ledbetter Slate.

WHOOPIE

The Whoopie prospects lie north of the road to the Slate Creek Lookout and far down on the south slope of La Sota Hill. A dirt road leads to the principal diggings (pl. 1) and beyond this a steep road, shown as a trail on plate 1, has been bulldozed to connect with the main road on the La Sota Hill properties. The Whoopie prospects are in claims held by the estate of the late Ira S. Troyer, Metaline, Wash. No ore has been shipped from the property.

The principal development work has been two short adits, both inaccessible when visited, and several shallow diggings on the slopes north of the adits. All diggings are within a large area covered by glacial material and only in a few scattered places are there small outcrops of bedrock. The Lead Hill fault passes between the two prospect adits, for Ledbetter Slate was cut in the eastern adit and Metaline Limestone in the western adit. The rock on the dump at the western adit is very fine grained gray limestone in large part altered to coarse-grained gray dolomite. A few hundred feet to the north and also to the west of the adit are several small exposures of fine-grained bedded dolomite, in places irregularly altered to coarse-grained dolomite. At one place, 900 feet northwest of the cabin, a short spur of bulldozed road exposes dolomite that strikes N. 38° E. and dips 40° SE. The dolomite there is fine grained and creamy white and contains a few narrow bands and streaks of black and white dolomite and some coarse grained dolomite.

No ore was seen in any of the dump material or at any of the scattered exposures, although a little mineralization reportedly occurs in the area.

WOLF CREEK

The Wolf Creek property is 2½ miles south of Metaline Falls near the mouth of Wolf Creek. It is an old property on which most of the prospecting was done at least 15 or 20 years ago. The principal development work is an inclined shaft, reportedly inaccessible for many years, that enters the hill on a northeast bearing. Several shallow diggings have been made in the hillside northwest and east of the shaft. No information was obtained regarding the extent of the workings off the inclined shaft or the quantity of ore mined, if any. Judging from the size of the dump, the mine workings off the incline probably do not extend more than a few hundred feet.

The country rock is chiefly gray crystalline dolomite, ranging in texture from fine to coarse. Locally, it passes irregularly into small areas of mixed dolomite, especially near the railroad tunnel 1,000 feet northwest of the inclined shaft. Throughout most of the area from the inclined shaft to the railroad tunnel the dolomite is fractured, locally brecciated, and contains irregular patches and stringers consisting of variable amounts of chert, jasperoid, calcite, and white and gray quartz.

The stratigraphic position of the beds north of Wolf Creek is not known, but they are probably within the upper 1,000 feet of the Metaline Limestone. The rarity of bedding, the absence of stratigraphic markers, and the outlying position of this area within thick glacial deposits make reliable stratigraphic and structural interpretations difficult. The only place in the entire area north of the inclined shaft where bedding planes could be recognized with certainty is near the railroad tunnel. Here the beds strike north and dip 35°–45° W. (not shown on pl. 1), but they are within a strongly faulted and fractured zone and the attitudes may be of only local significance. At a few places in other parts of the Wolf Creek area, indistinct parting surfaces of the dolomite faintly suggest bedding planes. All of these strike northwest and dip at moderate angles to the southwest, which conforms, in strike at least, to the beds on the west bank of the Pend Oreille River opposite the Wolf Creek area (pl. 1). About half a mile south of Wolf Creek and just east of the road, a vertical drill hole went through 56 feet of glacial deposits and 1,395 feet of black shale (Ledbetter Slate) before reaching the Metaline Limestone. The Ledbetter rocks, however, are missing from the Wolf Creek area, and those cut in the drill hole are in a structurally low block south of the Wolf Creek fault; so they are of no help in the determination of the stratigraphic position of the rocks of the mineralized area north of Wolf Creek.

On the dump at the inclined shaft the dolomite country rock contains galena, some reddish-brown sphalerite, quartz, calcite, some pyrite and limonite, and fairly common carbonaceous buttons. A few pseudomorphs of limonite after pyrite were seen. Rock along the hill to the northwest as far as the railroad tunnel is sparsely mineralized.

YELLOWHEAD

The Yellowhead mine is on the west side of the Pend Oreille River about 1½ miles north of Metaline Falls (pl. 1). The entrance to the mine is one-fourth mile north of the West shaft of the Pend Oreille mine at an altitude of about 2,130 feet (pl. 2). The property is on a large group of claims held for many years by the Pend Oreille Mines & Metals Co. In 1938 the Yellowhead adit and raise were driven west into the hill to undercut and explore at depth ore bodies found at the surface and further indicated by many churn-drill holes. Shortly after World War II a long trench connecting to a short (about 35 ft) adit was made through the overburden on the hillside 1,250 feet west of the adit. The ore taken out of the Yellowhead mine and this short adit has probably totaled about 12,000 tons. Some of this ore has been mixed with the ore from the Pend Oreille mine in an attempt to mill it on a profitable basis, and part of it has been stockpiled. An unusually large amount of pyrite is associated with sphalerite and galena, and therefore this ore requires a different type of milling from the ore produced in the Pend Oreille and other mines of the area. When the principal operations of the Pend Oreille mine were moved to the east side of the Pend Oreille River and a new mill was erected, it was planned by the Pend Oreille Mines & Metals Co. to convert the old mill on the west side of the river near the Yellowhead mine into one that would handle Yellowhead ore exclusively. A decline in metal prices, however, delayed this plan. The Yellowhead area contains a substantial body of relatively undeveloped ore that remains as a reserve supply for the future.

Surface exploratory work consists of many churn-drill holes, shallow cuts, pits, and a short adit, all situated in an area about one-fourth mile north of the old Josephine shaft (pl. 1). The area prospected lies at an altitude of about 2,550 feet on a glacial-covered terrace where little bedrock is exposed. The drill holes show that over most of the area the glacial debris ranges in thickness from 10 to 50 feet. The underground workings of the Yellowhead mine consist of an adit driven N. 79° W. for about 650 feet to an inclined raise that connects, about 140 feet above the adit level, with an irregular stope about 200 feet long, a maximum of 100 feet wide, and an average height of 10–15 feet. The stope lies between altitudes of about 2,270–2,320 feet, about 250 feet below the surface at a point about 700 feet northeast of the outcrop area in which most of the pits and cuts have been dug.

The country rock is fine-grained light- to medium-gray bedded dolomite (Metaline). Part of the rock is so fine grained that it approaches a lithographic dolomite. Chemical analyses of specimens of the country rock are given below in table 9. The analyses show that the rock is a dolomite with a composition not far from that of theoretically pure dolomite. The insoluble material is mostly jasperoid. The stratigraphic position of the dolomite beds within the Metaline is not known with certainty, and this subject is discussed in more detail in following paragraphs.

TABLE 9.—*Chemical analyses of dolomite country rock from the Yellowhead mine and vicinity*

[Analysts: J. C. Crampton, samples 78 and 101; C. M. Collins, sample 27, Metaline Falls, Wash.]

Sample No.	Insoluble	$CaCO_3$	$MgCO_3$	Total
42 D 78	2. 11	53. 13	42. 18	97. 42
42 D 101	1. 09	53. 40	43. 37	97. 86
54 D 27	. 69	54. 91	44. 04	99. 64

42 D 78. South wall of adit about 440 ft from portal, Yellowhead mine.
42 D 101. Western part of stope, Yellowhead mine in nonmineralized ground.
42 D 27. Short adit at end of trench on hillside 1,250 ft west of portal to Yellowhead mine.

The strata of the Yellowhead area strike N. 20°–30° E. and dip 15°–35° E. The prospected area lies on the northwest, or upthrown, side of the Y. A. fault. This fault, which is cut in the Yellowhead adit 360 feet from the portal, is vertical and brings Ledbetter Slate on the east against dolomite of the Metaline on the west. The stratigraphic throw of the fault is at least 450 feet and possibly as much as 1,300 feet. Much of the dolomite is fractured, and several faults, probably of minor structural significance, were cut in the mine workings. The faults and fractures are generally steeply dipping and strike northeast or northwest. The Ledbetter Slate in the adit is distorted and sheared, but, at places, indications of bedding suggest gentle but variable east dips.

Sphalerite and pyrite occur in widely varying proportions, in places associated with smaller amounts of galena. The abundance of pyrite is a conspicuous feature of the Yellowhead ore—the name Yellowhead was given to this ore body because of the abundance of pyrite and the presence of some yellow sphalerite. The sulfide minerals are contained in a gangue of fractured fine-grained dolomite, cut and replaced by coarse-grained dolomite, calcite, and, locally, a little quartz. Sphalerite most commonly occurs as small grains less than 0.5mm long, although some are as much as 10 mm. Sphalerite is pale yellow, resinous yellow, or pale to dark brownish red. The yellow sphalerite is conspicuous, but the brownish-red type is more abundant. Galena occurs sparingly, usually as grains averaging slightly larger than the sphalerite. The pyrite is very fine grained, averaging a smaller grain size than either sphalerite or galena. No well-developed crystal faces were seen on any of the pyrite. Pyrite tarnishes readily to a deep brownish bronze that somewhat resembles the tarnish of chalcopyrite; however, the mine operator reports no copper in the assays of this ore.

Recrystallized dolomite and some calcite are associated with much of the ore, although at many places the metallic sulfides are found in considerable quantity in the dense country rock. The crystalline dolomite is commonly in coarse grains and is white to light gray. Rarely, it forms crystals that line small vugs. White to light-gray calcite occurs as veinlets and more commonly as small irregular patches less than 3 inches long. A very light gray almost colorless quartz is irregularly and sparingly distributed. In places, gray jasperoid grades into milky quartz, and at other places there are small and isolated irregularly shaped patches of milky quartz. Calcite, quartz, and coarse-grained recrystallized dolomite are much less abundant in the Yellowhead ore than in the ore of the Pend Oreille, Grandview, or Metaline mines.

The sulfides are in a wide variety of forms. In the Yellowhead mine some of the ore follows irregularly along bedding planes, part is in a breccia filling locally surrounding fragments of the fine-grained dolomite country rock (fig. 21), and some is in sharply defined veinlets or irregular pods and thin lenses. Some mineralized rock from the short adit on the hillside above the tunnel shows concentrically banded pyrite and dolomite in ovals as much as 2 inches long; other rock shows pyrite filling right-angle joints and irregular fractures. Pyrite in the fractures is commonly, but not everywhere, associated with coarse-grained dolomite; some of these fractures show pyrite bordered by dolomite, and others show dolomite in the central part of the fracture and pyrite on one or both sides. Although sphalerite and pyrite are closely associated at many places, they are not intergrown, and much pyritized rock contains little or no sphalerite or galena. In general, the age relations suggest that pyrite, sphalerite, galena, and coarse-grained dolomite are closely related genetically, although a large part of the pyrite crystallized before sphalerite and galena. Most of the coarse-grained dolomite formed contemporaneously with or following the pyrite, although a little dolomite is earlier than some pyrite. Calcite formed at a late stage.

The main ore body, as indicated by the churn-drill holes, extends about 1,000 feet S. 65° W. from the Yellowhead stope and averages about 400 feet in width. According to the Pend Oreille Mines & Metals Co.'s estimates, a mill analysis of 500 tons of ore taken from the Yellowhead stope sometime before 1943 ran 10.5 percent zinc, 0.58 percent lead, and 14.4 percent iron.

Stratigraphic position of Yellowhead ore body.—For many years speculation and mild controversy have been carried on, chiefly among the local mining men, regarding the stratigraphic position of the beds that contain the Yellowhead ore body. The uncertainty is due to the fact that the Ledbetter Slate has been entirely removed by erosion from this area. Furthermore, the rocks are separated from the ore deposits of known stratigraphic position in the Pend Oreille mine by the Yellowhead and the Y.A. faults. The stratigraphic throw of the Y.A. fault is at least 450 feet and might possibly be as much as 1,300 feet—in other words, determination of the throw of this fault depends upon the stratigraphic position of the Yellowhead rocks. The country rock—very fine grained bedded dolomite—of the Yellowhead area is markedly different from the massive crystalline dolomite and gray limestone of the Pend Oreille mine area. The pronounced difference in rock types can be explained by postulating that the Yellowhead strata are lower stratigraphically, or that they occupy an area in which dolomite locally formed at a relatively high stratigraphic position, or both. Lastly, the abundance of pyrite in the Yellowhead ore is in sharpt contrast to the relatively iron-free ore of the Pend Oreille mine. Pyrite is known to be locally abundant in bedded dolomite strata that lie 1,000–1,500 feet below the Ledbetter Slate, and for this reason some geologists and mining engineers assume that the Yellowhead ore is in this lower stratigraphic zone. Evidence advanced in support of this supposition is cited in drill hole U.S. 24 put down in the west Pend Oreille mine workings, where pyritized dolomite containing some sphalerite was cut about 1,075 feet stratigraphically below the slate. (See section *C–C′*, pl. 3). Also, a comparison is made with the pyritized bedded dolomite strata at the Lucky Strike mine (p. 85) which probably lie 1,000–1,500 feet below the slate. However, there are no diagnostic physical features in any of the dolomite strata mentioned above which would serve as a reasonable basis for correlation. Moreover, it is hazardous to assume that iron-rich ore solutions would everywhere select a certain stratigraphic zone for depositing pyrite in areas that contain many small premineralization faults. The authors, nevertheless, slightly favor the interpretation that the Yellowhead ore body lies in beds somewhat below those that contain the ore bodies in the Pend Oreille and Grandview mines, possibly even as much as 1,000 fet below the slate. If the beds are 1,000 feet below the slate, then the Y.A. fault would have a throw of about 1,300 feet (section *A–A′*, pl. 3), and would be a major structure which would probably extend much farther north under the glacial covering than shown on the regional geologic map (p. 1).

Z CANYON

The Z Canyon property is on the east side of the Pend Oreille River just north of Z Canyon (pl. 1). The property, which is held by the Pend Oreille Mines & Metals Co., can be reached during the summer months by a narrow road that leaves the road to the Schierding placer about 1,000 feet west of the Galena prospect. Little work other than for assessment has been done at the mine for many years. The only record of ore produced is a small shipment in 1926 (Gerry, 1929, p. 468).

Most of the development work has been done in two relatively short adits in the northern part of a sharp knob of dolomite that forms the northern part of the Z of Z Canyon. This knob lies within a highly faulted and fractured area between the Z Canyon fault on the west and strong northeast-trending faults on the east. (See pl. 1.) Bedding planes have been obliterated by the intense fracturing and dolomitization in the prospected area, and the attitude of the strata within the immediate mine area is not known, although from a regional study it is evident that the rocks lie on the much faulted southeast limb of a syncline that plunges 20°–35° SW. Strongly fractured beds of Ledbetter Slate lie along the riverbanks north of the western side of the cliff of dolomite that composes the sharp knob. Two small patches of Ledbetter Slate occur east of the Z Canyon fault. One is at the extreme southwest end of the dolomite knob along the riverbank, and the other is 1,000 feet to the northeast where a small patch of slate near the water level has been preserved between the series of strong northeast faults. (See pl. 1.) The relation of these patches of slate to movement along the Z Canyon fault has been discussed under the heading of faults. The approximate throw of the Z Canyon fault at this locality is not known, although it is probably at least 200 feet.

The country rock (Metaline Limestone) is light-gray to black medium- to coarse-grained dolomite, and to the south and east it is strongly sheared limestone and dolomitic limestone. Stratigraphically, the strata are probably within the upper 200 to 400 feet of the Metaline Limestone, because about 750 feet of gray limestone lies to the east and beneath these rocks before the bedded dolomites of Timber Hill are reached (pl. 1); the assumption is made, of course, that no folds or faults which would repeat or cut out part of the section are concealed in this eastern area.

The ore minerals are reddish-brown and yellow sphalerite and patches and stringers of galena that are irregularly and sparsely distributed through a gangue of dolomite, jasperoid, and, locally, some calcite and white quartz. Part of the ore is in concentric bands as noted previously by Park and Cannon and described by them (1943, p. 50, 76, pl. 26). Some of the ore near the surface contains small amounts of limonite, smithsonite, and a greenish-yellow stain that may be greenockite.

Drill holes west of the Z Canyon fault through the Ledbetter Slate to the top of the Metaline Limestone might reveal ore-grade mineralization in the upper part of the Metaline.

QUARRIES

Several quarries in the district have furnished various types of rock, chiefly limestone and shale (slate), to the Lehigh Portland Cement Co.'s plant at Metaline Falls. The manufacture of cement started in 1910 and has been one of the most stable industries of the region.

The principal source of limestone and shale has been Quarry Hill, about a mile southeast of Metaline Falls, although many years ago most of the shale was obtained from the Sand Creek quarry about 3½ miles to the south (pl. 1). On Quarry Hill, limestone from near the base of the Metaline Limestone has been obtained in large tonnages for many years, chiefly from the Main Lehigh quarry (pl. 1); the Lower quarry has been abandoned for more than 20 years. The Shale quarry, a few hundred feet northeast of the Main Lehigh quarry, furnishes the shaly material also used in the manufacture of cement. An aerial tram connects the main quarry to the plant at Metaline Falls.

The limestone beds at the Main Lehigh quarry strike north and dip 25°–35° W. The limestone used principally is fine grained and light gray to medium gray, locally grading along strike into dark gray. Calcite flecks and veinlets are locally abundant. Beds range in thickness from a few inches to 20 feet. Quarrying operations commonly extend irregularly over a stratigraphic thickness of about 65 feet, depending upon the purity (calcium carbonate content) of the rock. Rock from the Shale quarry, which is about 200 feet lower stratigraphically than that of the main quarry, is thin-bedded dark-gray limy phyllite and phyllitic limestone.

The Sand Creek quarry is in the southern part of the district, a short distance from the railroad (pl. 1). The quarry, although little used for many years, formerly furnished shaly rock to the Lehigh cement plant at Metaline Falls. The rock quarried is dark-gray to black Ledbetter Slate, part of which contains graptolites. The quarry is in an area extensively covered by Tertiary lake deposits. The Sand Creek fault, separating Ledbetter Slate on the west from Maitlen Phyllite on the east, lies beneath the surficial deposits about 1,000 feet east of the quarry (pl. 1).

Certain types or grades of cement have utilized other material found in the district. Many years ago limonite was obtained from several small deposits in the area (Park and Cannon, 1943, p. 78), and within the past few years siliceous rock of the Gypsy Quartzite has been quarried near the base of the steep slopes a few thousand feet southwest of the Sullivan glory hole near Flume Creek.

PLACER DEPOSITS

Several sand and gravel deposits have been worked intermittently for many years in a small way for placer gold. Most of these workings are along the banks of the Pend Oreille River from the mouth of Slate Creek north to Canada. A small amount of gold has been recovered.

HARVEY PLACER

The Harvey gold placer deposit is on the east bank of the Pend Oreille River about three-fourths of a mile south of the mouth of Lime Creek (pl. 1). The property is held by Mr. Getchel, of Metaline Falls. The deposit has been worked intermittently for at least the past 25 years during periods of low water and has been mostly a one-man operation. A small amount of gold has been recovered. The deposit consists of sand, gravel, cobbles, and a few boulders that rest on an uneven surface of fine-grained well-bedded dolomite.

SCHIERDING PLACER

The Schierding gold placer is on the east side of the Pend Oreille River about one-half mile south of the international boundary. The property can be reached during the summer months by a road that branches from the main highway to Canada on the south side of Crescent Lake. Apparently, very little work has been done for many years on the property, and the equipment left near the diggings is in poor condition.

The deposit is on a large gravel bar that contains well-rounded sand, gravel, cobbles, and a few boulders. The smaller particles are largely quartzite, phyllite, and black slate, and many of the larger cobbles and boulders are quartzite and various types of igneous rock. The bar rests on an uneven and pockety surface of well-bedded fine-grained light-gray dolomite. Park and Cannon (1943, p. 78) visited the deposit in 1937 and examined several pans of black sand reported to have been recovered from a test run. They state that all samples showed numerous small specks of gold and were flat with well-rounded edges as if the gold had traveled long distances. One nugget of about 2 pennyweight was reported to have been recovered from the bar.

FUTURE OF THE DISTRICT

Continued output of zinc and lead ore from the Metaline mining district seems assured for many years; precisely how long is somewhat a matter of personal opinion and speculation and the results of future exploration in this irregularly mineralized region. However, the district, when compared with most other base-metal camps, is relatively young. Substantial output did not begin in the district until 1931, and from 1938, following the principal years of the economic depression, to the present (1957), the annual value of the ores mined has exceeded a million dollars. The grade of the ore is low relative to many other zinc-lead districts, but highly mechanized methods of mining, relatively low mining costs, and firm ground partly offset the low grade of the ore.

Much of what at present seems to be the most favorable ground for ore deposits is held by several companies. Exploratory data on the tonnage and grade of measured and indicated ore in this ground are not available for publication. Some large areas of potentially mineralized ground in the district still remain unexplored or inadequately explored by drill. Excluding, of course, unforeseen economic changes, the authors of this report conservatively believe that active mining and substantial output of ore will continue in the district for at least 25 years.

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