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GEOLOGY AND ORE DEPOSITS OF THE METALINE QUADRANGLE WASHINGTON

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GEOLOGY AND ORE DEPOSITS
OF THE
METALINE QUADRANGLE, WASHINGTON

BY

C. F. PARK, JR., AND R. S. CANNON, JR.

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ILLUSTRATIONS

GEOLOGY AND ORE DEPOSITS OF THE METALINE QUADRANGLE, WASHINGTON

By C. F. PARK, JR., and R. S. CANNON, JR.

ABSTRACT

The Metaline quadrangle is in the extreme northeast corner of Washington State. In the northern part of the quadrangle the Pend Oreille Mountains are steep and rugged, but to the south they are more subdued and rounded. The region is crossed by the northward-flowing Pend Oreille River, along which are two well-developed terrace levels. Except for the highest peaks, the region has been covered by the Cordilleran ice sheet, and both depositional and erosional glacial features are abundantly developed.

Pre-Cambrian rocks crop out over a large area in the east-central part of the quadrangle. These rocks include the complex Priest River group, unconformably overlain by about 5,000 feet of Shedroof conglomerate and 5,000 feet of Leola volcanics. Above the pre-Cambrian is 20,000± feet of Cambrian and probable Cambrian rocks that include, in ascending order, the Monk formation of schists, grits, and limestones, 3,800 feet more or less; the Gypsy quartzite, 5,300–8,500 feet; the Maitlen phyllite, 5,000 feet; and the Metaline limestone (limestone and dolomite) 3,000 feet. Overlying the Metaline limestone is about 2,500 feet of carbonaceous Ordovician slate (Ledbetter slate) and 700 feet of Devonian limestone. Above the Paleozoic formations in the Pend Oreille Valley are remnants of poorly sorted semiconsolidated clastic sediments of Tertiary age, the Tiger formation.

The southern half of the quadrangle is underlain by the Kaniksu batholith, a mass consisting predominantly of quartz monzonite of Cretaceous (?) age, which is considered to be genetically related to the Nelson batholith, to the north, and the Idaho batholith, to the southeast. Three facies of the intrusive rock are recognized—a biotite facies, a muscovite facies, and a porphyritic facies. Along the borders the igneous rock is fine-grained and contains large quantities of ferromagnesian minerals, both biotite and amphibole. An igneous metamorphic zone is developed around the instrusive mass. This zone, which is as much as 4 miles wide, consists of an inner ring of hornfels and marbles and an outer ring of crystalline schists and marbles. The igneous metamorphic rocks are of two types—(1) recrystallized and (2) altered to silicate minerals. Silica was the principal material added during the metamorphism, but large quantities of water facilitated the transfer of materials. The metamorphic minerals are iron-poor.

The complex structure of the sedimentary and metamorphic rocks has a prevailing northeastward trend. Folding, which passed into low-angle faulting, was the earliest deformation of which evidence has been recognized. It was followed by steeply dipping northeastward-striking thrust or normal faults and later by northwestward-trending normal faults that may have been caused by intrusive forces. The Pend Oreille Valley, a much-broken block bounded on the east and west by steeply dipping faults, is underlain principally by the Maitlen phyllite, the Metaline limestone, and the Ledbetter slate. The faults to the west, the Flume Creek and Russian Creek faults, have an offset of at least 10,000 feet. The Flume Creek fault trends a little east of north nearly to the Canadian border, where it swings abruptly into the Russian Creek fault a few degrees south of west. Prefault linear structural features, defined as intersections of bedding planes with axial planes of folds, trend at angles of 30°–40° from the Russian Creek fault and persist with the same strike and pitch on both sides of the fault—facts that are interpreted to mean that displacement on this fault had no rotational component. Foliation planes, particularly in the older rocks, cut and obscure the bedding. In many of the phyllitic rocks a pseudobedding or compositional layering is developed.

Lead-zinc deposits were reported in the Pend Oreille Valley in 1869, but it was not until 1928 that large bodies of commercial ore were found. The production from 1906 to 1937, inclusive, is valued at $3,327,331. In late years zinc has been the principal metal produced. Because of the recent development of considerable bodies of ore and the large amount of unexplored but geologically favorable ground, the future of the district seems to be assured for some years. The ores are generally of low grade, containing 5 to 15 percent of combined zinc and lead, and economic success depends in part on efficient handling of large tonnages.

Three principal types of ore deposits are recognized—(1) replacement deposits in carbonate rocks not in the igneous-metamorphic zone, including minor amounts of ore filling open cavities; (2) closely related replacement deposits in igneous metamorphic rocks; and (3) lodes, mined heretofore chiefly for their silver content.

The principal replacement deposits are in the dolomitic Metaline limestone in the Pend Oreille and tributary valleys. The ores are in the hanging-wall blocks of large normal faults, particularly the Flume Creek and Slate Creek faults, although other fault blocks are mineralized. The replacement ores occur generally along minor breaks and in crackle breccia bodies. So far as now known, ore of this type is confined to the upper part of the Metaline limestone, less than 500 feet below the Ledbetter slate. The ores are generally associated with and occur in dark-gray jasperoid; around the jasperoid and ore coarse-grained white calcite and crystalline dolomite are commonly found. The calcite and dolomite were not introduced by the silica and ore-bearing solutions but were removed from the replaced carbonate beds by these solutions and redeposited in more favorable situations. The mineral composition of the ores is simple, sphalerite and galena being the common minerals. Oxidation of the ore is shallow, and in many places sulfides are on or within a few feet of the surface. Numerous caves are found in the largest mine, the Pend Oreille. These caves are in breccia zones along fractures and were probably formed by circulating meteoric waters below ground-water level.

The lode deposits are mostly in the Ledbetter slate and the Monk formation. Silver-bearing tetrahedrite is found in a quartz and carbonate gangue with galena and other sulfides.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Metaline quadrangle is in the extreme northeast corner of Washington and extends about 1½ miles into northwestern Idaho. It covers an area of about 800 square miles between longitude 48°30′ and 49° (international boundary) and latitude 117° and 117°30′ (fig. 1).

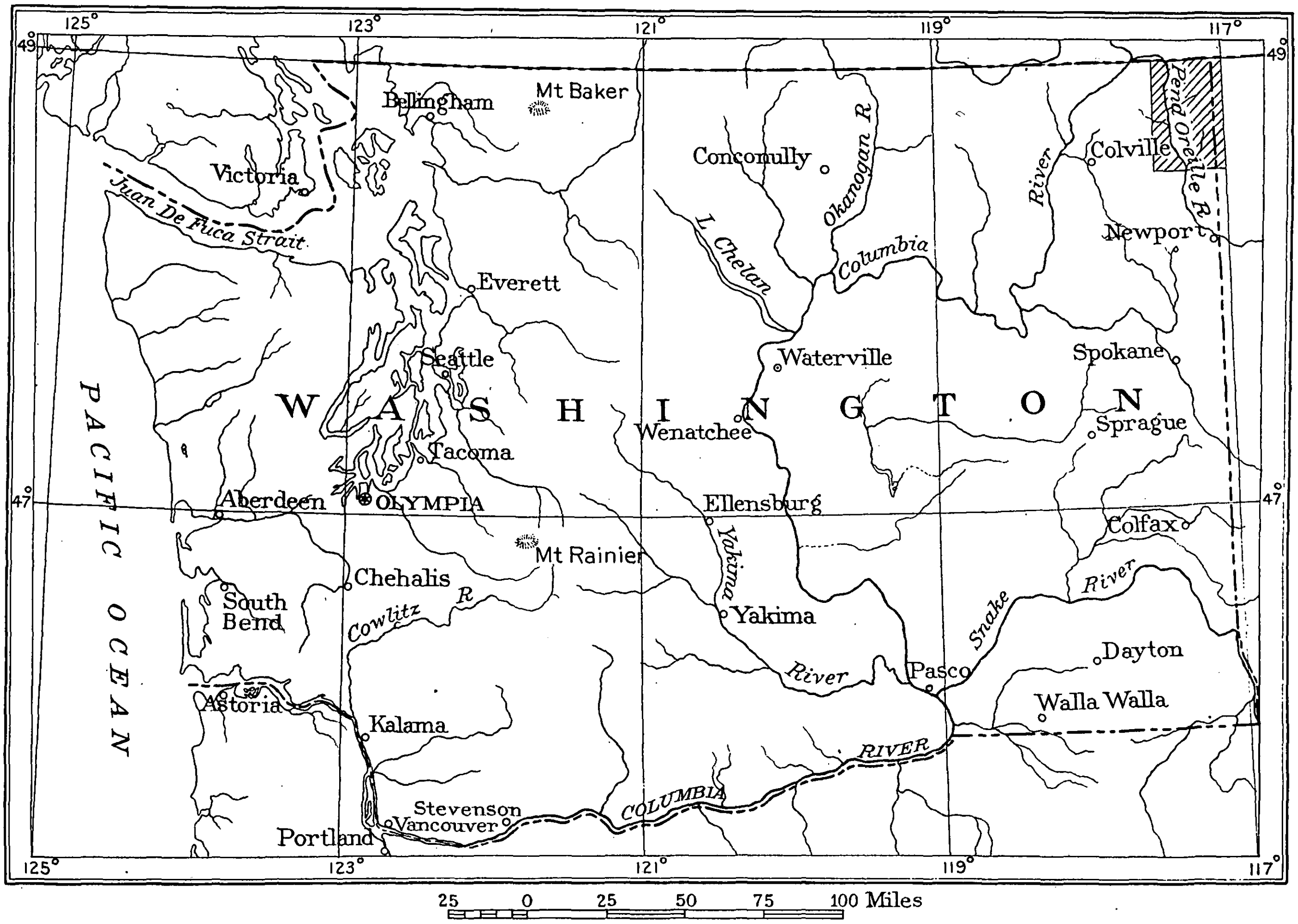

FIGURE 1.—Index map of Washington showing location of the Metaline quadrangle.

A branch line of the Chicago, Milwaukee, St. Paul & Pacific Railroad extends from Newport to Metaline Falls, and daily bus service to Spokane is maintained by the same company. An excellent paved highway extends through Metaline Falls from Spokane northward to the Canadian border. A gravel road to Colville leaves the Pend Oreille Valley at Tiger and is at present the main link with the country to the west. The United States Forest Service maintains and in recent years has greatly extended an excellent system of roads and trails in the Kaniksu National Forest east of the Pend Oreille River. In 1936 and 1937 the United States Resettlement Administration purchased much of the land west of the river and opened several roads and trails into country that was formerly difficult to traverse. A trail up the east slope of Abercrombie Mountain from the center of sec. 32, T. 40 N., R. 43 E., and a road up Russian Creek to the Frisco Standard mine were particularly helpful.

Ione, Metaline Falls, and Metaline are the principal towns, and a few small settlements and farms are scattered along the Pend Oreille Valley. Camps are maintained on Government lands by the Forest Service, Civilian Conservation Corps, and Resettlement Administration, and there are a few temporary lumber camps and small farms here and there along the principal tributaries of the river.

TOPOGRAPHY

The dominant topographic feature of the Metaline quadrangle is the valley of the Pend Oreille River, which flows from south to north through the west center of the area. Rugged highlands that rise from south to north border both sides of the river and are partly dissected by the many tributary streams.

The mountains have been called the Pend Oreille Mountains by Daly,[1] but the name is seldom used lo-

[1] Daly, R. A., The nomenclature of the North American Cordillera between the 47th and 53d parallels of latitude: Geog. Jour., vol. 27, pp. 588, 599, 1906.

cally. Northward they merge into the rugged Selkirk Range of British Columbia. East of the river most of the peaks are named; the highest is Gypsy, at an altitude of 7,318 feet, although many have altitudes over 6,000 feet. The highest point west of the river is Abercrombie Mountain, at an altitude of 7,308 feet, although Hooknose, at 7,203 feet, is one of the most conspicuous landmarks.

Except for the constriction at Box Canyon, the Pend Oreille River south of Metaline Falls is a wide sluggish stream that contains many bars and islands during normal and low-water stages. North of Metaline Falls the river flows turbulently through a series of narrow gorges. Just north of the Canadian border the river swings westward and eventually makes its way into the Columbia. The principal tributary streams from the east are, from south to north, Le Clerc Creek, Harvey Creek, Sullivan Creek, and Slate Creek. West of the river the streams are small and short; the largest is Ruby Creek.

The drainage of much of the eastern part of the quadrangle is tributary to Priest Lake and the Priest River to the east. The principal streams are Kalispell Creek, Granite Creek, Gold Creek, and Hughes Creek. The south fork of the Salmo (Salmon) River flows northwestward through the extreme northeast corner of the area. This stream joins the Pend Oreille River a few miles east of its junction with the Columbia.

Sullivan Lake, 3 miles long and half a mile wide, is the largest of many glacial lakes in the area. It is an easily accessible and delightful summer resort.

CLIMATE AND VEGETATION

Most of the precipitation in the Metaline area falls during the cold winter months as snow. The summers, from June until early September, are generally hot and dry, but during this period thunderstorms are common, particularly in the mountains. Considerable range in temperature is found between the high country and the sheltered valleys, although the nights everywhere are generally cool. The average annual precipitation near Sullivan Lake over a period of 8 years was 26.39 inches.

With the exception of some of the high ridges, burned areas, and the soil-free quartzite slopes, the region is heavily forested. To the south yellow pine thrives in the sandy granitic soil. Farther north white pine, cedar, hemlock, two varieties of fir, and spruce are the most valuable trees, although tamarack, lodgepole pine, birch, white-bark pine, and several other trees and many types of brush are abundant. The most easily accessible and best timber has been logged off, and the dry slashings and dense second growth are serious fire hazards during the dry summer. The Sullivan Creek drainage basin east of Sullivan Lake is the only area in the quadrangle that has been free from disastrous fires. Much of the quadrangle is covered with piles of charred fallen timber, which locally is concealed by alder and young tamarack or lodgepole pine, the combination constituting an almost impenetrable maze. Elsewhere the country has been burned over two or more times and is practically devoid of vegetation. (See pl. 15, *B*.)

FIELD WORK AND ACKNOWLEDGMENTS

The field work upon which this report is based was done from June 1 to October 1, 1936, and from May 15 to October 15, 1937. G. R. Gibson very ably assisted the senior author for 3 months during 1936. Mr. Cannon was assigned to the project in May 1937 and has helped in every phase of the work since then. The study has profited greatly from visits in the field by J. T. Pardee, D. F. Hewett, and W. C. Mendenhall. Mr. Park revisited the district for 2 weeks in October 1938.

It is a pleasure to acknowledge the whole-hearted and generous cooperation of the people of the region, without exception. Particular thanks are due to L. P. Larsen, C. A. R. Lambly, John Currie, and E. H. Miller, of the Pend Oreille Mining & Milling Co., and to H. F. Mills and D. I. Hayes, of the Metaline Mines & Leasing Co. for access to mine openings and diamond-drill cores, as well as for many other courtesies. The United States Forest Service has kindly furnished copies of aerial photographs of nearly the entire quadrangle, and many pleasant and profitable contacts have been made with the Forest Service field men.

Thanks are also due to the members of the Geological Survey with whom the numerous problems that arose during preparation of the report have been freely discussed, particularly J. T. Pardee, A. C. Spencer, James Gilluly, H. G. Ferguson, and T. B. Nolan. Many ideas embodied in the report have arisen from such discussions and any value that the publication may have owes much to this helpful interchange. The photographs of hand specimens and the photomicrographs were taken by N. W. Shupe.

SCOPE OF THE REPORT

The study of the Metaline quadrangle was undertaken primarily as a study of the metalliferous deposits of the area. For this reason the available time, both in the field and in the office, has been largely devoted to consideration of the Pend Oreille Valley, where most of the known mineral deposits occur. The entire quadrangle has been mapped, although outlying areas were not covered in the same detail as the Pend Oreille Valley. For readers interested only in the mineral deposits much of the report dealing with general geology, structure, and development of the topography may well be neglected.

BIBLIOGRAPHY

The principal reports that treat of the Metaline district and nearby areas are listed below, with a few annotations on their contents. No claim of completeness for this bibliography is made, and additional references are found throughout the text. An effort has been made to select the most comprehensive reports and those of pertinent interest to the Metaline problems.

Abercrombie, W. R., Report on the Pend d'Oreille River: Mining, 1896, pp. 245–250. A semipopular account of an exploration of the Pend Oreille River from Pend Oreille Lake to the 49th parallel, conducted in 1885. Mentions lead deposits.

Adair, J. B., Mineral resources of the State of Washington—the Metaline district: Northwest Min. Jour., vol. 7, pp. 54–56, 1909. Describes the general features of the geology. Mentions possibilities of cement industry and gives status of development at the Oriole and Morning and Mammoth properties.

Allan, J. A., Geology of Field map area, B. C. and Alberta: Canada Geol. Survey Mem. 55, 1914. Largely devoted to discussion of igneous rocks. Sedimentary section somewhat similar to that in Metaline quadrangle. Describes Ordovician graptolite shale.

Bancroft, Howland, Lead and zinc deposits in the Metaline mining district, northeastern Washington: U. S. Geol. Survey Bull. 470, pp. 188–200, 1911. A few prospects were visited and described.

——— The ore deposits of northeastern Washington, including a section on the Republic mining district by Waldemar Lindgren and Howland Bancroft: U. S. Geol. Survey Bull. 550, 1914. Contains a reprint of the material in Geol. Survey Bull. 470. Descriptions of properties in neighboring districts are given and a detailed report on the Republic district is included.

Bauerman, H., Report on the geology of the country near the 49th parallel of north latitude west of the Rocky Mountains, based on observations made in 1859–61, Montreal, 1884. Mentions the limestone-shale series and granite on the Pend Oreille and Little Pend Oreille Rivers. Gives the regional setting. Mentions gold deposits on the Lower Pend Oreille being worked in 1858.

Bethune, G. A., Mines and minerals of Washington: Washington Geol. Survey 1st Ann. Rept., pp. 82–83, 1891; 2d Ann. Rept., pp. 128–129, 1892. Earliest known mention of the Metaline district in literature. States that it was called Metaline from the immense amount of metal in sight.

Brinsmade, R. B., Two Washington mining districts: Min. and Sci. Press, vol. 113, pp. 743–745, 1916. The Metaline district is one of the two mentioned. Describes the conditions of the mines and mills in 1916.

Browne, J. R., Resources of the Pacific slope, New York, Appleton, 1869. States (p. 182) that gold was discovered in 1855 near Fort Colville.

Buisman, H. R., The Metaline district: Northwest Mining, vol. 3, no. 8, pp. 3–4, May 6, 1937. A résumé of current developments.

Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, 1909. An excellent reconnaissance report, of value particularly for its stratigraphic data.

Cockfield, W. E., Lode deposits of Ymir-Nelson area, B. C.: Canada Geol. Survey Mem. 191, 1936. Largely mine descriptions.

Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, 1912. Contains data collected during a reconnaissance of the international boundary. Describes the Priest River terrane and assigns it to pre-Beltian age. The Summit series is described: the Irene conglomerate and Irene volcanics are called basal Belt, and the upper members of the series are correlated with the Belt series and assigned to Cambrian age. The Pend Oreille group overlies the Summit series and is separated into two members, schists and marbles. The group was tentatively classed as Carboniferous; no satisfactory section was obtained.

Drysdale, C. W., Ymir mining camp, B. C.: Canada Geol. Survey Mem. 94, 1917. Lithology briefly discussed. No attempt is made to subdivide the Pend Oreille group of limestones and shales. In Addenda I it is suggested that the Irene conglomerate [Shedroof of this report] is equivalent to the Siyeh conglomerate and the Irene volcanics [Leola of this report] to the Purcell lava. The rocks overlying the volcanics are considered Lower Cambrian. Mostly devoted to detailed descriptions of properties.

Fischer, A. H., A summary of mining in the State of Washington: Washington Univ. Eng. Exper. Sta. Bull. 4, 1918.

Geological Survey, Mineral Resources of the United States, 1906, p. 451. Reports shipments in 1906. States on information furnished by L. P. Larsen and Mr. and Mrs. D. D. Birk, that ore was first opened in 1869. Mentions the Mammoth mine.

Hayes, D. I., Zinc company drives 2,000 feet at Metaline: Northwest Mining, Dec. 17, 1936, pp. 1, 4. A brief statement of methods and equipment used in driving the Metaline Mining and Leasing Co.'s tunnel.

Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Cons. and Devel., Div. Geology, Bull. 31, 1924. A report devoted almost entirely to mine descriptions. Contains brief generalization on structure and stratigraphy. Considers the valley of the Pend Oreille (Clark Fork) to be a down-faulted anticline.

Joseph, M. H., Mining in eastern Washington in 1906: Eng. and Min. Jour., vol. 83, p. 185, 1907. Activity confined mainly to Morning and Mammoth mine.

Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, 1926. Short descriptions of the Belt rocks and correlation with nearby areas. Correlates Irene volcanics [Leola volcanics of this report] with Purcell lavas, which are believed to be youngest Belt. Brief discussions of the structure and ore deposits are given.

Larsen, L. P., The Metaline lead-zinc district: Arizona Min. Jour., vol. 16, pp. 5–6, June 15, 1932. A brief résumé of the history of mining in the district and discussion of geology and economic possibilities. A few figures on production and grade of ore in the Pend Oreille mine are given.

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RICE, H. M. A., Cranbrook map area, B. C.: Canada Geol. Survey Mem. 27, 1937. A short but good treatment of an area previously mapped and discussed by Schofield.

——— Preliminary report, Nelson map area, B. C.: Canada Geol. Survey Paper 37–27, 1937. An uncolored map of the eastern half of the map area, with preliminary statements.

SAMPSON, EDWARD, Geology and silver ore deposits of the Pend Oreille district, Idaho: Idaho Bur. Mines and Geology Pamph. 31, 1928. A brief preliminary report of a detailed study. Fossils found in Middle Cambrian limestone and shale. Briefly discusses lithology and ore deposits. States that deformation occurred mostly by normal faults, although evidence of some reverse movement was recognized.

SCHOFIELD, S. J., Geology of Cranbrook map area, B. C.: Canada Geol. Survey Mem. 76, 1915. An exhaustive report on the area northeast of Metaline (east of longitude 16°30′).

TAYLOR, HARRY, Survey of Pend Oreille River, from its source at Lake Pend Oreille, Idaho, to the town of Metalline, Wash.: Chief Eng. Rept., 1898, pt. 4, pp. 3124–3131. A study of the methods to improve navigation on the Pend Oreille River. Mentions lead, silver, and copper mines at Metaline and states that two were working. The district was handicapped by lack of transportation facilities.

WALCOTT, C. D., Cambrian geology and paleontology, V, Pre-Devonian Paleozoic formations of the Cordilleran provinces of Canada: Smithsonian Misc. Coll., vol. 75, no. 5, 1928. A general summary of the stratigraphy of the region northeast of the Metaline quadrangle. Valuable for comparative purposes.

WALKER, J. F., Geology and mineral deposits of Windermere map area, British Columbia: Canada Geol. Survey Mem. 148, 1926. Discusses in some detail the stratigraphy and correlation with surrounding regions. Describes the Glenogle graptolite shale, of Lower Ordovician age. Middle Cambrian strata are absent. Correlates the Windermere series with Daly's Summit series. Detailed descriptions of the mining properties.

——— Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, 1934. Contains a geologic map of the area immediately north of the Metaline quadrangle. Discusses the lithology and correlates the Summit series of Daly with the Windermere series. The Pend d'Oreille group is thought to be late pre-Cambrian. No satisfactory section of this group was obtained. Descriptions of lode and replacement deposits are given. The replacement deposits in dolomite are similar to those in the Metaline quadrangle.

WALKER, J. F., and BANCROFT, M. F., Lardeau map area, B. C., General geology, and Gunning, H. C., Mineral deposits: Canada Geol. Survey Mem. 161, 1929. Mostly devoted to mine descriptions, both replacement and lode types. The stratigraphy is discussed, and a correlation table is given.

WEAVER, C. E., The mineral resources of Stevens County: Washington Geol. Survey Bull. 20, 1920. Contains a geologic map of the county. Formation descriptions appear to be accurate but no attempt at correlation was made. Structure is briefly mentioned. Most of the bulletin is devoted to mine and prospect descriptions.

GENERAL GEOLOGY

PRINCIPAL FEATURES

The Metaline quadrangle contains sedimentary and metamorphic rocks that range in age from pre-Cambrian to Devonian. (See pl. 1.) They are intruded by a batholith, probably of Cretaceous age, that underlies the southern half of the quadrangle. Unconformably overlying both the batholith and the older rocks is a loosely consolidated formation considered to be of Tertiary age. Much of the low country is covered by a thin veneer of Quaternary debris, deposited by waning glaciers and their attendant streams. The total thickness of the Paleozoic section is about 23,000 feet, of which 20,000 feet is Cambrian, 2,500 feet Ordovician, and 700 feet Devonian. The upper pre-Cambrian is a greenstone volcanic formation (Leola), underlain by the Shedroof conglomerate. These two formations aggregate about 10,000 feet and overlie an unknown thickness of metamorphosed sedimentary and igneous rocks.

Detailed correlation of the rocks with those of nearby areas other than to the north is not possible in the present state of knowledge. To the north the continuation of the strata has been mapped by Daly and Walker in the Salmo map area [2], and a table correlating the formations described by them with the strata of the Metaline quadrangle is given on page 6.

Both Daly and Walker correlated the beds in the Salmo map area with strata to the north and east.

The geologic structure (see pl. 1) is similar to that in surrounding areas where Paleozoic and older rocks are tightly folded. Examples of the folds are the Hooknose anticline, the Hall Mountain anticline, and the anticline west of Lost Lake. In places the folds pass into faults, such as the Ridge fault and the low-angle thrusts near the Riverside and Bella May properties. The early deformation, comprising folding and faulting, was followed by a period of additional faulting, during which the prominent Flume Creek and Russian Creek faults were formed.

Other major faults are the Slate Creek and Harvey faults, each with normal displacements, and smaller faults are widely distributed throughout the region. The evidence for faulting is generally stratigraphic offset, although in a few places the actual fault surfaces and gouge and breccia were seen.

[2] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, chart facing p. 178, 1912. Walker, J. T., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 2–10, 1934.

Correlation of formations in Metaline quadrangle and Salmo map area

Metaline quadrangle (this report)

Limestone, 700 feet.	Devonian.
Ledbetter slate, 2,500 feet.	Ordovician.
Metaline limestone, 3,000 feet.	Middle Cambrian.
Maitlen phyllite, 5,000+ feet.	Cambrian.
Gypsy quartzite, 5,300–8,500 feet.	Cambrian.
Monk formation, 3,800+ feet.	Cambrian?
——Unconformity——	
Leola volcanics, 5,000+ feet.	pre-Cambrian.
Shedroof conglomerate, 5,000+ feet.	pre-Cambrian.
——Unconformity——	
Priest River group (?).	pre-Cambrian.

Salmo map area — R. A. Daly, 1912

Pend Oreille group.		Upper Paleozoic.
Lone Star phyllite, 2,000+ feet.	Summit series	Cambrian.
Beehive formation, 7,000 feet.	Summit series	Cambrian.
Ripple quartzite, 1,650 feet.	Summit series	Cambrian.
Dewdney formation, 2,000 feet.	Summit series	Cambrian.
Wolf grits, 2,900 feet.	Summit series	Beltian.
Monk formation, 5,500 feet.	Summit series	Beltian.
Irene volcanics, 6,000 feet.	Summit series	Beltian.
Irene conglomerate, 5,000+ feet.	Summit series	Beltian.
——Unconformity——		
Priest River terrane (?).		

Salmo map area — J. F. Walker, 1934

Pend Oreille group.	Windermere, late pre-Cambrian.
Reno formation, 3,500 feet.	Windermere, late pre-Cambrian.
Quartzite Range formation, 4,400 feet.	Windermere, late pre-Cambrian.
Three Sisters series, 5,400 feet.	Windermere, late pre-Cambrian.
Horsethief Creek series, 4,200 feet.	Windermere, late pre-Cambrian.
Irene volcanic (?) formation (?).	

GEOLOGIC FORMATIONS

PRE-CAMBRIAN ROCKS

PRIEST RIVER GROUP

The name "Priest River group" is applied to the metamorphic rocks stratigraphically below the Shedroof conglomerate. The group was described by Daly as the Priest River terrane, unconformably overlain by basal conglomerate of the Summit series (Irene conglomerate).[3]

The Priest River group is a complex sequence of metamorphic rocks that includes phyllites and schists, limestones, dolomites, quartzites, and volcanics. The beds are generally much distorted and sheared, as shown in plate 2, *A*, and sufficient time was not available to permit a careful study of the group. On the map (pl. 1) rocks of the Priest River group are shown in one color, except that where beds of quartzite and volcanic rocks were traced they are differentiated.

The rocks are predominantly phyllites, derived in part from limy sediments and in part from volcanic rocks. Between Pass Creek and Harvey Creek limestone predominates in exposures but is commonly interbedded with phyllite and quartzite.

The phyllites in general are finely crystalline, and the individual minerals cannot be distinguished without a microscope. They contain widespread and abundant chlorite and sericite, and many of the rocks are similar in degree of metamorphism[4] and in lithologic character to the younger Monk formation and the Maitlen phyllite. Although in general the Priest River group is more metamorphosed than the younger formations, it is somewhat surprising to find metamorphism of so low a grade in rocks that have had so complex a geologic history as these.

[3] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 258–271, 1912.

[4] Knopf, E. B., Retrogressive metamorphism and phyllonitization: Am. Jour. Sci., 5th ser., vol. 21, p. 5, 1931.

SHEDROOF CONGLOMERATE

DISTRIBUTION

A conglomerate of unusual type is exposed in a broad belt that crosses the international boundary at the northeast corner of the Metaline quadrangle. Daly named this the Irene conglomerate formation, which he defined as the basal member of the Summit series, deposited unconformably upon the Priest River group and transitional into the overlying volcanic rocks.[5] The Shedroof conglomerate of the present report, named from the excellent exposures on Shedroof Mountain, refers to the rocks of this belt. Lithologically similar conglomerate occurs also at a higher horizon, at the base of the Monk formation, but for convenience it is described with the Monk.

The Shedroof conglomerate crops out from the northeast corner of the quadrangle south-southwestward for nearly 8 miles. At Thunder Mountain this belt divides into two that continue toward the southwest, where they are involved in the Pass Creek fault zone. Still farther to the southwest the continuation of this zone is presumably represented by the narrow belt of conglomerate which can be traced southwestward across Noisy and Harvey Creeks nearly to the edge of the Kaniksu batholith.

In two areas of greenstone far removed from any known exposure of Shedroof conglomerate the surface is conspicuously strewn with huge angular boulders of the conglomerate. One of these localities is the elliptical greenstone area between Granite Creek and Gold Creek; the other is in an area of poor scattered exposures of greenstone southwest of Tiger. Large quantities of Shedroof conglomerate fragments are also found on the Priest River rocks on the ridge in sec. 22. T. 38 N., R. 44 E.

Shedroof conglomerate crops out moderately well and, indeed, forms the high rugged peaks in the area north of Thunder Mountain. It is noteworthy, nevertheless, that the conglomerate is best exposed where the internal structure (schistosity) of the rocks intersects the ground surface at a large angle. The degree of exposure is presumably controlled by the dominant schistosity of the conglomerate rather than by the extremely inconspicuous bedding. Along the eastern "scarp" slope of the Round Top and Thunder Mountain ridge the conglomerate is well exposed. Along the west side of the same ridge on the long "dip" slope to Sullivan Creek, and particularly in the area surrounding the junction of Sullivan and Pass Creeks, outcrops of the conglomerate are both scarce and poorly exposed. Ledges of the conglomerate tend to break into great angular blocks, and even in areas where the conglomerate is poorly exposed the surface is commonly littered with similar large fragments.

[5] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 141–144, 1912.

THICKNESS AND STRATIGRAPHIC RELATIONS

A close estimate of the thickness of the Shedroof conglomerate is at present impossible. Even the more general structural features remain uncertain because of the scarcity of visible bedding planes in the rock. Nonetheless, the available data are ample to indicate remarkable variation in the thickness of the conglomerate along the strike. In the vicinity of Shedroof Mountain the formation is exposed in a band 3 miles wide. Southeast of Shedroof the basal contact dips about 30° NW. North of Shedroof the upper contact dips about 50° NW. under the Leola volcanics. The few bedding dips that can be seen in this section are generally not steeper than 45°. The maximum thickness computed from these scanty figures would be approximately 11,000 feet. However much in error this figure may be, the absolute minimum thickness of the conglomerate in this section, computed on the basis of the relief at Shedroof Mountain and the assumption of no duplication of strata, is 3,000 feet. In the table the thickness of the formation has been given as ±5,000 feet. The supposed southern extension of this belt south of Hall Mountain, on the ridge between Harvey and Noisy Creeks, has a maximum thickness between 600 and 1,200 feet, which decreases gradually along the strike of the belt toward the southwest. Where this same stratigraphic level reappears between Dry Canyon and the valley of the Pend Oreille southeast of Tiger, the band of Shedroof conglomerate is missing and the Leola volcanics rest directly upon limestone of the Priest River group.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The characteristic Shedroof conglomerate is a coarse, very poorly sorted rock with a dingy gray-brown aspect. Most of the fragments (a term used here to denote particles larger than half an inch in diameter) have diameters ranging between 1 and 8 inches, although many are smaller and a few irregular blocks of limestone have diameters of 5 feet or more. (See pl. 2, *B*.) Fragments of white to reddish-brown quartzite are almost equally abundant with dolomite fragments of similar color, many of which weather buff. A few pieces of black slate or phyllite and a single pebble of granitic rock were seen in the conglomerate. The fragments, which generally constitute 50 to 85 percent of the rock, are embedded in a matrix of gray sandy phyllite, which weathers to a brown pitted surface, as if calcareous.

Several lithologic variations from the dominant type of conglomerate were noted in the field. A gritty sandstone bed is shown in plate 3 *A*, and layers of similar sandstone and gritty conglomerate have been found at several other localities. Thin interbeds of dolomite, which can be traced for only short distances along the strike, occur near the base of the conglomerate on the spurs east and northeast of Thunder Mountain and in the conglomerate layer at the base of the Monk formation.

From the northeast corner of the quadrangle southwestward along Sullivan Creek the upper contact of the Shedroof conglomerate with the Leola volcanics is marked by a zone of transition several hundred feet thick, in which the matrix of the conglomerate gradually changes from gray to green, the proportion and size of fragments is smaller, and the bedding planes are fairly distinct. (See pl. 3, *B*.) This transition rock seems to pass gradually upward into schistose greenstone or green schist without fragments. A similar but narrower zone separates the belt of Shedroof conglomerate from overlying greenstone along the east side of the ridge from Round Top to Thunder Mountain.

A rather similar transition from the dominant type of Shedroof conglomerate to silvery-gray and greenish-gray phyllite or phyllitic schists is thought to occur commonly. This phyllite may correspond to the matrix of typical Shedroof conglomerate, merely lacking the fragments. Although generally a remarkably homogeneous fine-grained phyllite, it is locally sandy and possibly elsewhere limy. Rock of this type occurs principally in the area of poor exposures on the west slope of the Round Top and Thunder Mountain ridge down to Sullivan Creek. Consequently no such transition zones are thoroughly exposed, although the two end members are intimately associated with one another and with intermediate types. In some places—for example, on the Pass Creek road at the mouth of Thor Creek—the areas mapped as conglomerate include some exposures of the phyllitic rock. The wedge-shaped area underlain almost exclusively by the phyllite from Thunder Peak southwest to the headwaters of Stony Creek, in T. 39 N., R. 45 E., has been differentiated on the map.

Visible bedding planes were recognized in scarcely a score of exposures throughout the large area underlain by the conglomerate in this quadrangle. In most of these exposures schistosity crosses the bedding at an appreciable angle, as illustrated in plate 3, *A*. In most outcrops of the conglomerate the fragments have been flattened to triaxial ellipsoids, with a common orientation, as a result of the deformation that produced schistosity. In other outcrops only linear structure and a linear elongation of fragments can be detected. These secondary metamorphic features are found throughout the Shedroof conglomerate and dominate the aspect of the rock. (See pl. 4.) Many fragments are rhombohedral in section, and at least some of these were formed by the breaking and rotating of larger fragments and layers, as shown in plate 2, *C*. The limestone fragments are commonly more angular in outline than adjacent rounded quartzite fragments; this curious difference may have resulted from greater ease of distortion of the limestone than of the quartzite during the deformation of the rock.

The Shedroof conglomerate is readily identified in outcrops by its dingy, rotted aspect; its general lack of bedded structure; the presence of light-colored limestone, dolomite, and quartzite fragments almost to the exclusion of other rocks; the flattened or stretched shape of its fragments; and commonly the greater size and angularity of the limestone fragments.

Microscopic features.—A thorough petrographic study of the Shedroof conglomerate is beyond the scope of this report, and only a few thin sections were examined. The smaller particles of the conglomerate, as seen in these sections, consist principally of quartz-

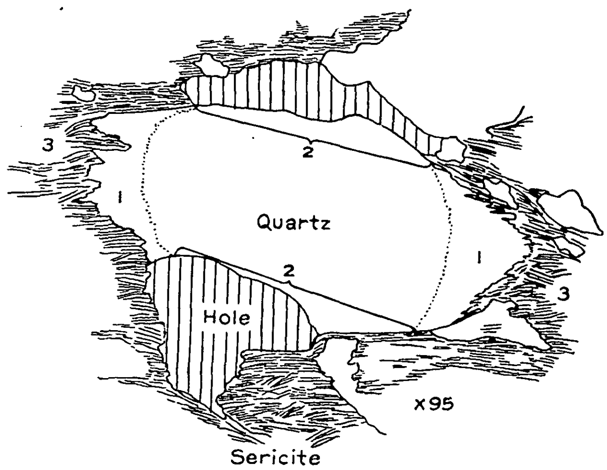


FIGURE 2.—Camera lucida sketch of part of a thin section of Shedroof conglomerate. Shows (1) enlargement on ends of grain, growth of optically continuous quartz into and probably replacing sericite; (2) removal of part of original quartz grains at sides, either mechanically by shearing or chemically by solution; (3) at ends of quartz grain sericite foliation not bending conformably around grain but heading directly into it.

ite, coarse-grained quartz, dolomite, and fragments of sericitic rock, possibly altered shale. Some of the quartzite fragments are fine-grained and contain appreciable amounts of sericite and either microcline or albite. The green facies of the conglomerate is characterized by numerous particles that now consist largely of chlorite.

The matrix is dominantly sericite and fine-grained quartz, with variable amounts of carbonate. Chlorite and biotite are minor constituents. A few rounded grains of tourmaline and zircon are apparently detrital particles.

The schistosity of the conglomerate is shown clearly in thin section by the parallel alinement of sericite, biotite, and chlorite flakes and the long axes of the pebbles. The relations shown in figure 2 indicate that some migration of silica occurred during the metamorphism that caused the schistosity. In specimens containing abundant carbonate the outlines of the pebbles have been largely destroyed owing to the great degree of recrystallization of the carbonate.

CONDITIONS OF DEPOSITION

Daly [6] postulated a great unconformity at the base of the Shedroof conglomerate and considered the debris in the conglomerate to be derived from the underlying Priest River group. In the Metaline quadrangle such an unconformity has not been unequivocally demonstrated, but its presence is indicated by the following evidence: The pebbles in the Shedroof conglomerate have probably been derived from the Priest River group, but wherever the base of the Shedroof conglomerate has been examined the bedding in the Priest River rocks is apparently parallel to the surface on which the conglomerate was deposited. However, the base of the conglomerate from the northeast spur of Thunder Mountain to the east spur of Round Top Mountain is underlain by phyllite of the Priest River group, which throughout this distance contains thin beds of quartzite, whereas the base of all conglomerate southwest of the Round Top fault apparently rests on a limestone bed of the Priest River group and is parallel to the bedding in the limestone.

Judgment concerning the importance of an unconformity at the base of the Shedroof should wait upon a detailed study of the stratigraphy and structure of the Priest River group and a satisfactory explanation of the origin of the conglomerate itself.

The conglomerate may be a fanglomerate, although its origin is not entirely clear, and the wide deposition of such immense quantities of uniformly coarse debris is difficult to explain. Points relating to the origin are:

(1) Its association with and gradation into greenstone is nearly invariable.

(2) Its thickness is extremely inconstant.

(3) The fragments comprise (a) quartzite, dolomite, phyllite, schist, rarely granitic rocks, thought to be derived from Priest River group, and (b) small round quartzite cobbles and pebbles mixed with large angular limestone fragments. Volcanic fragments are absent, except in the transition zones to the Leola volcanics.

(4) The matrix consists of sericite, quartz, carbonate, chlorite, and biotite.

(5) There is a nearly complete lack of sorting; bedding is shown by a few sand and dolomite beds; graded bedding was seen at only one place.

(6) There may be a stratigraphic hiatus below the Shedroof conglomerate.

AGE

The Shedroof conglomerate is assigned to late pre-Cambrian time, as it underlies and is gradational into the Leola volcanics, which are also considered to be late pre-Cambrian.

[6] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, p. 142, 1912.

LEOLA VOLCANICS

DISTRIBUTION

The greenstone and green schist that lie in the belt between the Shedroof conglomerate and the base of the Monk formation are called the Leola volcanics, from the section at Leola Peak, where they are fairly well represented. The extension of this belt north of the international boundary is essentially the Irene volcanic formation of Daly.[7] Although the Leola volcanics include principally altered volcanic rocks, they are discussed here with the sedimentary rocks as an integral part of the stratigraphic sequence.

The Leola volcanics crop out at the top of the Shedroof conglomerate from the international boundary toward the southwest, where they appear to pinch out before reaching Pass Creek. To the south presumably the same belt reappears at the top of the Shedroof conglomerate south of Hall Mountain, extending southwestward and southward around the border of the Kaniksu batholith to Anderson Lake. A few scattered outcrops of poorly exposed greenstone southwest of Tiger and the greenstone(?) inclusion in the batholith 3 miles southwest of Molybdenite Mountain may originally have been parts of this principal greenstone belt.

A continuous band of greenstone similar to the Leola is exposed at the top of the lower belt of Shedroof conglomerate from Round Top to the east side of Thunder Mountain. Small areas of greenstone are exposed elsewhere, possibly interbedded or infolded within the Shedroof conglomerate, especially east of Shedroof and near Mankato Creek. Greenstone also appears at the base of the conglomerate east of Roundtop Mountain. Similar greenstone and green schist are exposed within the Priest River group, notably in a large elliptical area between Granite Creek and Gold Creek and several smaller areas south of Granite Creek.

Although the green schists are in general poorly exposed, the more massive greenstones crop out rather well. The massive rock commonly forms rugged hills and ridges, especially where adjacent to weaker materials. Less commonly than in the Shedroof conglomerate, ledges of greenstone break down to form great blocks and boulders.

THICKNESS AND STRATIGRAPHIC RELATIONS

Estimates of the maximum apparent thickness and of variations in apparent thickness of the Leola volcanics are of the same order of magnitude as corresponding figures for the Shedroof conglomerate. The data on which these estimates are based are even fewer and less reliable than those for the Shedroof.

The Leola volcanics have an apparent thickness of about 4,500 feet on the Salmo-Shedroof ridge. The

[7] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 144–147, 1912.

maximum apparent thickness of this formation is about 9,000 feet in the vicinity of Green Mountain (Prouty Lookout). The thinning and pinching out of the belt south of Green Mountain are due in part to faulting. The supposed extension of this belt from Noisy Creek to Anderson Lake nowhere shows an apparent thickness greater than 5,000 feet, although the upper part of the volcanics is cut off by the Harvey fault, and the basal contact is obliterated by the Kaniksu batholith for a strike distance of 4 miles.

The apparent thickness of the volcanic beds that overlie Shedroof conglomerate from Round Top to Thunder Mountain ranges between 300 and 1,000 feet.

The common transition from normal Shedroof conglomerate through green conglomerate with sparse pebbles to greenstone is described elsewhere (p. 8). An apparent transition from fine-grained chlorite schist of probable tuffaceous origin to schistose greenstone is equally common. Green schist of this type probably underlies nearly one-fourth of the area mapped as Leola volcanics and forms the upper part of the formation underlying the conglomerate at the base of the Monk. Thin beds of dolomite (limestone?), phyllite, and quartzite crop out sparsely within the greenstone areas and are presumably intercalated with the volcanic rocks.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The greater part of the rocks mapped as Leola volcanics consist of typical homogeneous greenstone, such as occurs commonly in series of altered basalt and andesite. The average specific gravity of the typical greenstone is 2.92 according to Daly[8] and is appreciably greater than that of any of the truly sedimentary rocks of the area. The color of the rock is rather uniform dark to grayish green. Most of the greenstone exhibits a distinct schistosity, although in some exposures the rock appears to be nearly or quite massive. In spite of this schistosity and the shearing movements that it implies, certain primary textural and structural features of the rocks can be detected. A mottled aspect of the greenstone can be attributed with fair assurance, at least in part, to porphyritic and even diabasic texture of the original rock. (See pl. 5, *A*.) Exposures of greenstone crowded with small ellipsoidal bodies of crystalline calcite apparently represent amygdaloidal lava. In other outcrops much larger ellipsoidal structures in greenstone, outlined by bands of epidote, have the appearance of sheared pillow structures.

The color, specific gravity, and homogeneity of the dominant type of Leola volcanics distinguish it from any other rock in the area, at least outside the zone of igneous metamorphism surrounding the Kaniksu batholith. The chlorite schists of the Leola, however, cannot be distinguished with assurance from certain green schists or phyllites in the Priest River group, in the phyllite facies of the Shedroof conglomerate, in the Monk formation, and even in the much younger Maitlen phyllite.

Microscopic features.—Thin sections show that the greenstone is essentially a fine-grained felted aggregate of chlorite accompanied by abundant albite, quartz, carbonate, and leucoxene(?). Epidote, iron oxides, sericite, and biotite are variable minor constituents. In some specimens amphibole takes the place of part of the chlorite. The schistosity, which may be fairly conspicuous in hand specimens, is generally suggested only by a tendency toward orientation of the darker minerals, less commonly by wavy layers composed largely of quartz and carbonate.

Some textural features of the original volcanic rocks are preserved in the greenstone, although partly masked by metamorphism. The uniform ground mass of many sections encloses phenocrysts of plagioclase. The plagioclase crystals have been corroded and altered to poikilitic albite crowded with tiny grains of carbonate, epidote, and chlorite. The large plagioclase crystals show random orientation independent of the schistosity of the greenstone and differ in abundance from section to section, suggesting intersertal, ophitic, and even diabasic texture in the original rocks (See pl. 5, *A*). Small sheared amygdules (?) seen in thin section consist of quartz, carbonate, and chlorite.

The tuffaceous nature of a schistose dark gray-green fragmental rock from the upper part of the Leola volcanics along the road above Deemer Creek is evident in thin section. The grains consist of quartz, altered poikilitic feldspar, altered porphyritic basalt, sericitic quartzite, shale altered to sericite, bits of dark minerals altered to chlorite, and possibly remnants of limestone. The matrix is a schistose aggregate of chlorite with subordinate sericite, biotite, quartz, and carbonate. A layering is brought out by an abundance of laths of altered plagioclase in certain layers and by its absence in other layers.

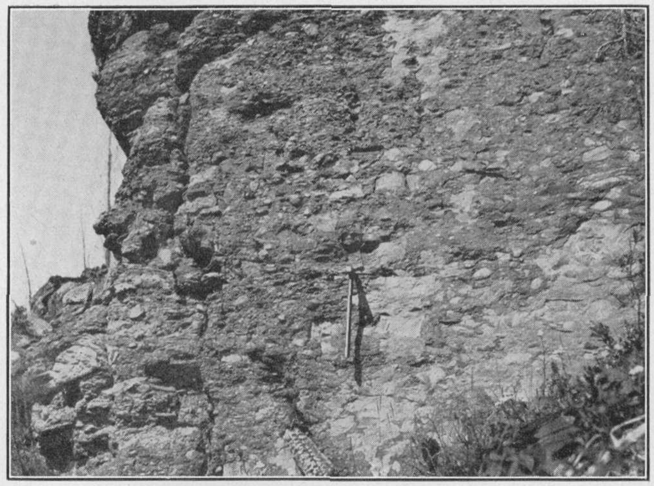
ORIGIN

Daly maintains that the greenstones north of the international boundary are a succession of lava flows with some interbedded sedimentary rocks.[9] Evidence from the Metaline quadrangle supports this view. Sheared amygdaloidal and pillow structures are recognizable in some exposures of relative massive greenstone; also, transitions from greenstone to sedimentary rock through intermediate green facies suggest the contribution of pyroclastic material to nearly contemporaneous sedimentation. However, the field work

[8] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), p. 146.

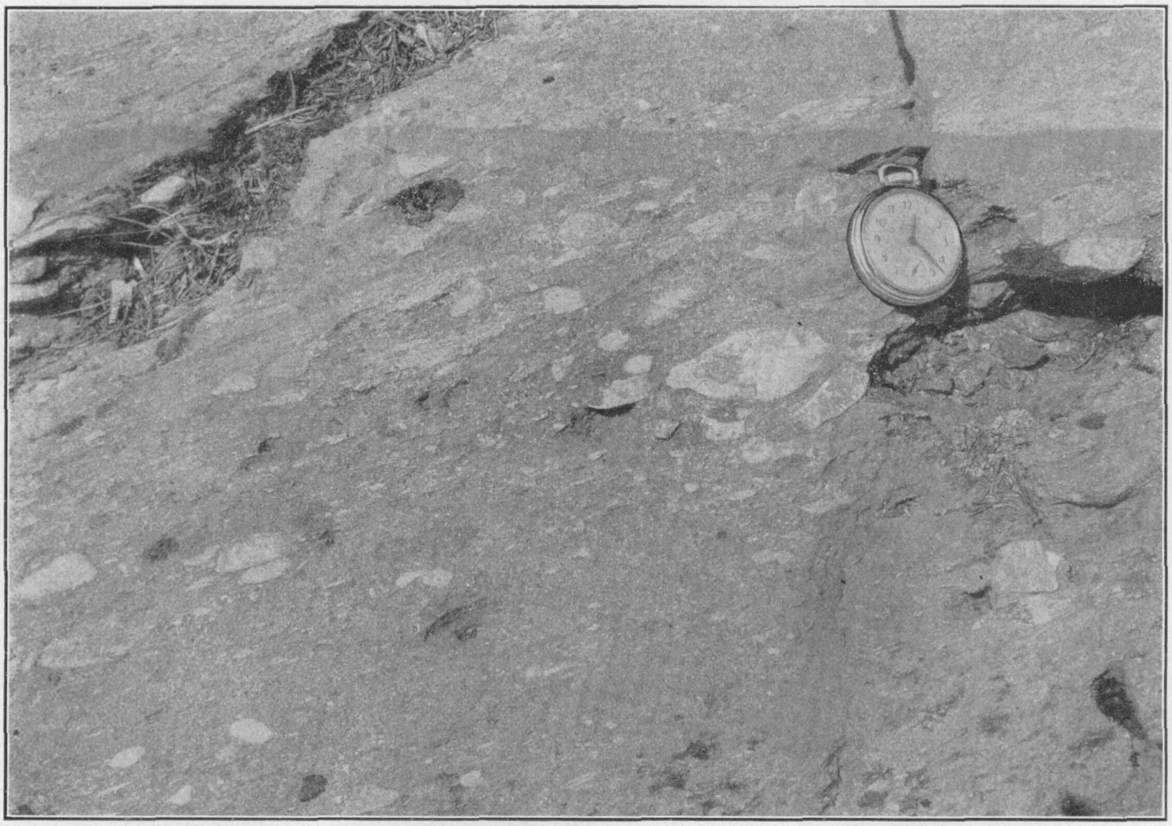
[9] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), pp. 144–147.

A. CONTORTED PHYLLITE IN PRIEST RIVER GROUP.
Road cut east of Pass Creek Pass.

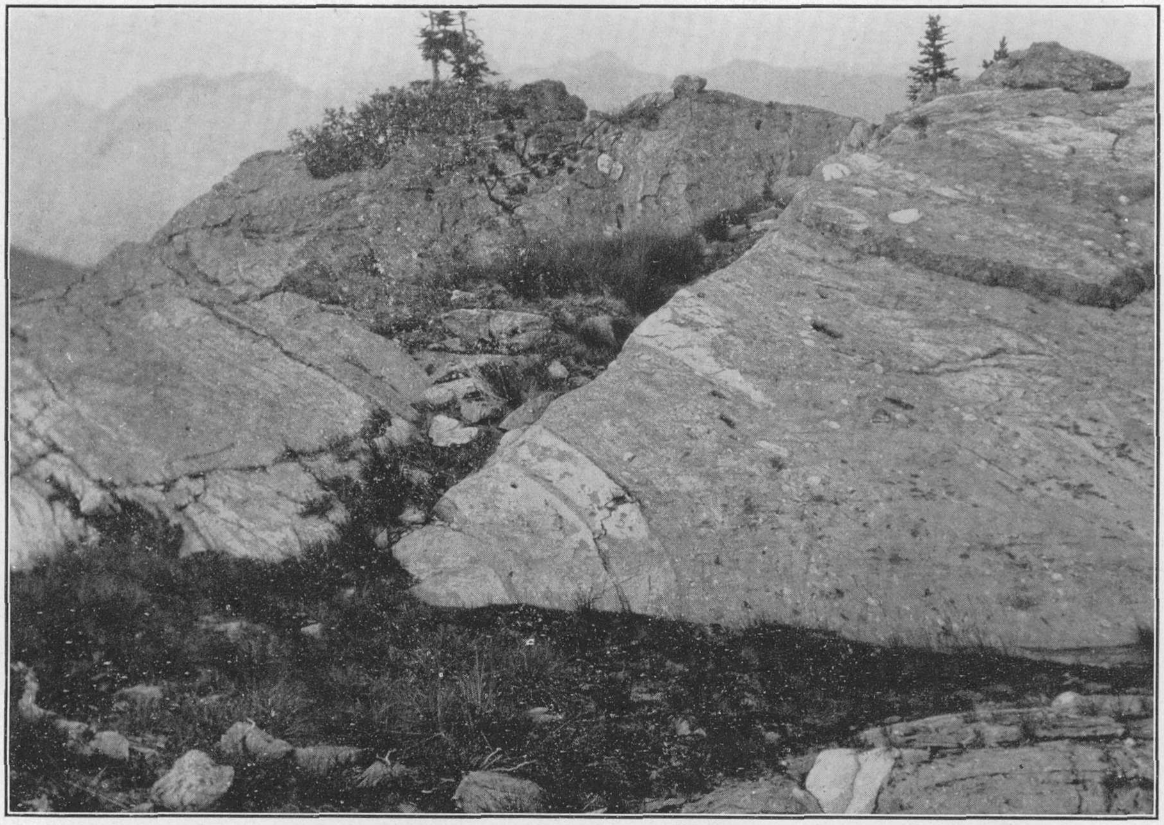


B. SHEDROOF CONGLOMERATE ON RIDGE BETWEEN HALL MOUNTAIN AND GRASSY TOP MOUNTAIN.
Note the large patch of limestone in lower right. Hammer handle is 18 inches long.

C. RHOMBOHEDRAL FRAGMENTS IN SHEDROOF CONGLOMERATE FORMED BY THE SHEARING OF A BAND OF QUARTZITE.
SE¼ sec. 24, T. 40 N., R. 45 E.



A. SANDY BED IN SHEDROOF CONGLOMERATE, SHOWING SHEAR PLANES CUTTING BEDDING AT AN ANGLE OF ABOUT 30°.
Trail forks, southeast corner of sec. 24, T. 40 N., R. 45 E.



B. BEDDING IN TRANSITION ZONE BETWEEN SHEDROOF CONGLOMERATE AND LEOLA VOLCANICS.
Peak at altitude of 6,600 feet, in north center of sec. 25, T. 40 N., R. 45 E.

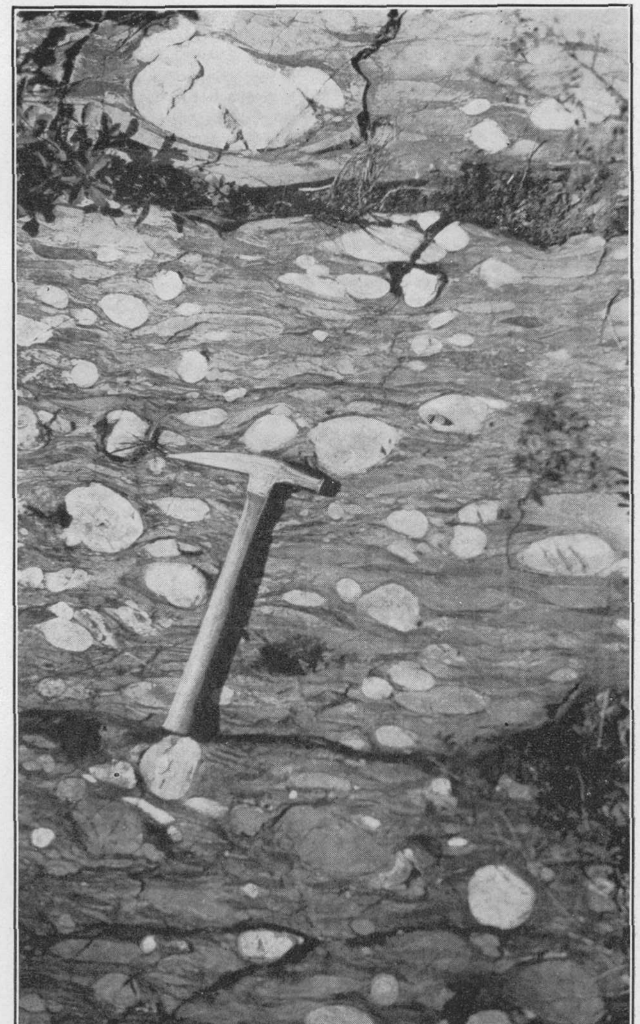
A. SURFACE SHOWING MAXIMUM ELONGATION OF FRAGMENTS.

B. SURFACE SHOWING NORMAL TO MAXIMUM ELONGATION OF FRAGMENTS.
Same outcrop as in *A*.

SHEDROOF CONGLOMERATE ON SOUTHEAST SLOPE OF ROUND TOP MOUNTAIN.

A. PHOTOMICROGRAPH OF GREENSTONE OF LEOLA VOLCANICS, PROUTY LOOKOUT.

Remnants of feldspar suggest an earlier diabasic texture.



B. SHEARED CONGLOMERATE IN GYPSY QUARTZITE.

Slope west of Oriole mine.

did not afford a basis for dividing the volcanics into a series of recognizable flows and tuffaceous sediments.

On the other hand, some of the greenstone in the quadrangle may be altered intrusive sills or even discordant intrusive bodies. This possibility applies particularly to the areas of greenstone within the Priest River group, no one of which has been demonstrated to be extensive at any particular horizon.

SUMMARY

The Shedroof conglomerate and Leola volcanics embrace a succession of conglomerates and greenstones resting upon the older rocks of the Priest River group. In general, the oldest rocks in the succession are conglomerates, but in some places the altered lava rocks lie directly upon the Priest River group. Similarly, the Leola volcanics are in general the youngest rocks in the succession, but in several places the base of the overlying Monk formation rests upon conglomerates.

AGE

The Leola volcanics and Shedroof conglomerate are tentatively assigned to the top of the pre-Cambrian in this quadrangle. An unconformity may intervene between these formations and the overlying Monk formation, of Cambrian (?) age. The base of the Monk appears to rest successively from south to north upon (1) the Shedroof conglomerate due east of Sullivan Lake, (2) the Leola volcanics north of Sullivan Creek, and (3) a layer of still younger conglomerate north of Leola Creek.

CAMBRIAN (?) SYSTEM

MONK FORMATION

DISTRIBUTION

The Monk formation includes those beds that intervene between the older Leola volcanics and the grits at the base of the younger Gypsy quartzite. The formation was named by Daly from Monk Creek, in British Columbia, where the exposures are excellent. As used by Daly [10] the Monk excluded the upper part of the formation as defined in this report. Walker [11] used the term "Horsethief Creek series" for essentially the same beds that are here called Monk. The principal occurrence of the Monk formation is in a belt about 1 mile wide that extends from the international boundary southwestward along the east slope of Crowell Ridge to the east spur of Hall Mountain, where it ends against faults and an offshoot of the Kaniksu batholith.

A narrow belt of the Monk formation crops out at the base of the Gypsy quartzite along the west side of the Flume Creek fault. It extends for nearly 4 miles from the Oriole mine southwestward across Lunch Creek.

This formation is exposed more poorly than any other major stratigraphic unit in the quadrangle. The only section where outcrops are fair across the entire formation is along the crest of the ridge that extends southeastward from Salmo Mountain.

THICKNESS AND STRATIGRAPHIC RELATIONS

South of Deemer Creek the Monk formation occupies a belt about a mile wide. The apparent thickness of the formation in this belt is estimated to be 3,800 feet, measured west of Leola Peak along the trail that bears toward Gypsy Peak. The greater breadth of the belt northeast of Deemer Creek is due largely to the repetition of beds in a shallow synclinal fold in the east half of the belt. Although the best exposures of the formation are along the Salmo-Shedroof Ridge, the information obtained in this section is, nevertheless, inadequate for a determination of thickness.

West of the Pend Oreille River only the upper part of the Monk formation is exposed, representing not more than 1,000 feet of beds.

The top of the Monk formation, where it crosses the Sullivan Creek road 2 miles east of Sullivan Lake, is a band of white sandy marble that grades upward into quartzite and grit. This marble has been traced northeastward for only a few miles. Farther north the contact is placed arbitrarily, so that dominantly quartzitic sediments are put in the Gypsy quartzite, whereas sediments that contain mostly beds of phyllites are referred to the Monk formation.

On the west side of the Pend Oreille Valley the contact between the Gypsy quartzite and the Monk formation is placed at the top of a bed of sandy dolomitic marble.

The base of the Monk formation has been drawn arbitrarily at the base of a conglomerate layer or, where the conglomerate is absent, at the top of the Leola volcanics. This layer of conglomerate is intercalated with limestone and calcareous phyllite and has an apparent maximum thickness of 400 feet. (See section *D–D′*, pl. 1.) The extension of the layer north of Deemer Creek overlies several hundred feet of beds similar to tuffaceous facies of the overlying part of the Monk formation. Although the conglomerate was not seen on the heavily wooded north side of the valley of the South Fork of the Salmo River, both Daly [12] and Walker [13] describe it as a prominent and constant feature north of the international boundary, with an estimated thickness of about 200 feet.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The Monk formation is recognized with confidence only where it can be viewed as

[10] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), pp. 146–147.

[11] Walker, J. F., Geology and mineral deposits of the Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 6–7, 1934.

[12] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), pp. 146–147.

[13] Walker, J. F., op. cit. (Canada Geol. Survey Mem. 172), pp. 6–7.

a whole or in its normal relation to either the Leola volcanics or the Gypsy quartzite. The details of lithology shown by nearly any hand specimen or within a limited area of exposure find their analogs in nearby younger and older rocks, particularly in the rocks of the Priest River group.

The fine-grained phyllites that predominate in the Monk formation contain numerous intercalations of carbonate rocks, quartzite, and grit. The intercalated beds are commonly only a few feet thick, but some of the bands of carbonate rock reach thicknesses of several hundred feet. North of Deemer Creek approximately the lower half of the Monk formation contains numerous beds of carbonate rocks, very few beds of quartzite, and none of grit. In the upper part quartzites and grits increase in abundance toward the top, but relatively few beds of carbonate rocks are present. Along the strike toward the southwest, the grit beds die out and carbonate beds seem to be proportionately more abundant. Consequently, south of the latitude of Gypsy Meadows and Sullivan Lookout there is little perceptible difference in lithology between the upper and lower parts of the formation.

The marble at the top of the Monk contains many rounded quartz grains and is well exposed in the workings of the O. K. mine and on the hill above the mine, where it is interbedded with quartzite layers and grades rapidly upward into quartzite and grit.

A limestone whose maximum thickness is 200 to 300 feet commonly lies in apparent conformity on the conglomerate at the base of the Monk. South of the headwaters of Gypsy Creek the conglomerate is missing, but presumably the same limestone is present overlying greenstone schist and separating it from gray phyllite of the Monk formation.

The phyllites of the Monk formation are not appreciably different from the Maitlen phyllite and from many phyllites in the Priest River group. A uniform light-gray color prevails, but faint greenish and bluish hues are seen and some beds are dark gray or nearly black. The phyllites are thin-bedded, with small differences in the color and grain size of adjacent layers. The phyllites in the lower part of the Monk formation are generally more calcareous than those in the upper part. Some beds near the base of the formation, which are finely fragmental and apparently tuffaceous, resemble the gray-green schists in the upper part of the Leola volcanics.

The limestone members of the Monk formation are white to gray or cream-colored on fresh surfaces and generally buff to gray on weathered surfaces. Those in the lower part of the formation exhibit a conspicuous finely laminated structure and commonly break into flags under the hammer. One such platy limestone exposed in a cut on the Sullivan-Deemer Creek road near the Salmo-Shedroof ridge contains some intraformational limestone conglomerate similar to that in the Devonian (?) limestone near the northwest corner of the quadrangle. Grains of silica are seen in all the limestones, particularly on weathered surfaces. In the massive limestone at the top of the Monk these grains are especially abundant and large, some attaining diameters of 3 millimeters. In hand specimens they appear as rounded grains of opalescent pale-bluish quartz.

The sandy members of the formation range from fine-grained quartzite to coarse-grained grit in which some of the pebbles reach diameters of half an inch. The quartzite beds are commonly light-colored, are generally massive, and show traces of bedding only at their contacts with phyllite and limestone members. Most of the sandy beds are true quartzites, but some contain carbonate as the cementing material and should perhaps be called calcareous sandstones. The color of the grits ranges from light gray to dark greenish gray. The pebbles are mostly quartz, commonly opalescent in shades of blue and lavender, but a few dark-colored slate fragments were seen.

Microscopic features.—Thin sections of the phyllites of the Monk formation show tiny angular mineral particles set in an abundant schistose matrix dominated by fine-grained micaceous minerals. Bedding is indicated by contrasts in the abundance, size, and composition of the particles in adjacent layers. In most sections schistosity cuts the bedding at appreciable angles. The particles are dominantly quartz; a few are albite and resistant detrital minerals such as zircon, tourmaline, titanite, and apatite. Apparently tuffaceous facies near the base contain, in addition, grains altered to aggregates of chlorite or of chlorite with minor sericite, quartz, and carbonate. Some of the chlorite aggregates are apparently pseudomorphs of hornblende or other mafic minerals. The matrix, which is more abundant than the grains, contains sericite, chlorite, and biotite, with intersertal quartz and grains of iron oxides in various proportions. The calcareous phyllites in the lower part of the formation contain abundant carbonate in certain layers.

The limestones examined in thin section are composed largely of calcite with scattered grains of quartz. Sericite, iron oxides, zircon, tourmaline, and apatite make up only a small proportion of the rock. The quartz grains are roughly equidimensional, and their association with grains of zircon, tourmaline, and apatite and the gradation from sandy limestone to quartzite, noted in the field, certainly indicate their detrital origin.

A thin section of typical grit contains many well-rounded pebbles of quartz and several of clusters of altered feldspar crystals, as well as small amounts of iron oxides, titanite, and leucoxene. The matrix is a schistose mosaic of sericite and quartz with minor carbonate. The quartz pebbles consist either of a single grain or of several grains with sutured boundaries. Their appearance suggests that they were derived by erosion from a coarse-grained granite or pegmatite, or from vein quartz, and it was so interpreted by Daly.[14] However, one pebble in thin section preserves fragmentary but rather convincing evidence of relict sandstone texture. This particular pebble has been recrystallized but contains triangular schistose areas that suggest interstitial fillings. The arrangement of dusty particles in the pebble, as well as the schistose inclusions, suggests that the pebble was originally a typical quartzite but has been recrystallized to coarser-grained quartz with sutured boundaries. Possibly many or most of the quartz pebbles in the grits also represent recrystallized quartzite pebbles.

CONDITIONS OF SEDIMENTATION

The great diversity of sedimentary materials in the Monk formation indicates extreme fluctuation and wide range of conditions of sedimentation.

The fact that the character of the Monk changes from north to south but seems to be fairly constant from east to west (Sullivan Creek road and O. K.-Oriole mines) suggests a source of sedimentary debris to the north.

The volcanic fragmental material in the lower Monk may be reworked Leola volcanics rather than a product accumulated during active volcanism. The inference that at least part of the sedimentary beds in the Monk may have been derived from the Shedroof conglomerate and the Priest River group is given some support by the suggestion made above, that the grit pebbles are quartzites rather than single quartz crystals or grains. The numerous quartzite cobbles in the Shedroof conglomerate and the quartzite beds in the Priest River group would seem to offer an adequate source for the grits and quartzites in the Monk, although far inadequate to account for the tremendous volume of the overlying Gypsy quartzite.

AGE

The age of the Monk formation is unknown. It is tentatively placed at the base of the Cambrian, as it is conformable with and grades upward into the Gypsy quartzite which is definitely of Cambrian age.

start

CAMBRIAN SYSTEM

GYPSY QUARTZITE

DISTRIBUTION

The most extensive exposure of the unit here called Gypsy quartzite is a belt 2 to 3 miles wide that forms the core of Crowell Ridge and Gypsy Ridge, and extends from Hall Mountain northeastward into Canada, where it has been traced for many miles by Walker[15] and Rice.[16] Both Daly[17] and Walker[18] subdivide the Gypsy quartzite into several units, the comparative positions of which are shown in the stratigraphic sections of figure 3. For the purposes of the present report it is sufficient to treat the quartzite as a unit. The name is taken from the excellent exposures in the high amphitheaters of Gypsy Ridge. (See pl. 16, *A*.) Three other areas of quartzite are found in the Metaline quadrangle. One extends along the west side of the Flume Creek fault from the Middle Fork of Flume Creek southward about 6 miles, almost to the Kaniksu batholith. This exposure (see pl. 13, *D*) is an excellent place to study the section, as it is nearly devoid of vegetation and is readily accessible. The upper beds of the quartzite crop out on the crest of the Hooknose anticline from the intersection of the Russian Creek and Flume Creek faults southwestward about 6½ miles. A much smaller exposure of the top beds of the quartzite occurs in the Silver Creek Valley southwest of Abercrombie Mountain, in sec. 15, T. 39 N., R. 42 E.

THICKNESS AND STRATIGRAPHIC RELATIONS

The quartzite section on the Crowell-Sullivan ridge is about 8,500 feet thick, but on the ridge west of the Oriole mine the thickness is only 5,300 feet. A comparison of the columnar sections from the two localities is given in figure 3, and shows the reason for the large difference in thickness. The 4,525 feet of grits and conglomerate present at the base of the formation east of the Pend Oreille River are represented by only 1,260 feet near the Oriole mine. The quartzites above the basal grits and conglomerates are surprisingly similar in the two sections.

The Gypsy quartzite grades downward into the Monk formation and upward into the Maitlen phyllite. The limits of the quartzite were placed where quartzite and grit beds predominate over beds of other types. For this reason either boundary of the quartzite may not be everywhere at precisely the same horizon.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The upper contact of the quartzite is placed at the top of a band, 50 to 300 feet thick, of alternating beds of quartzite and phyllite in nearly equal parts. These beds are characterized by fucoidal cylinders and unidentified crooked rods of organic (?) origin, called for convenience "burrows." The "fucoids" are approximately circular in cross sec-

[14] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, p. 151, 1912.

[15] Walker, J. F., Geology and mineral deposits of the Salmo map area, B. C.: Canada Geol. Survey Mem. 172, p. 7, 1934.

[16] Rice, H. M. A., Preliminary report, Nelson map area, B. C.: Canada Geol. Survey Paper 37–27, 1937.

[17] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 141–159, 1912.

[18] Walker, J. F., op. cit., pp. 6–9.

tion, about half an inch in diameter, and generally 2 to 3 inches long, although a few about a foot long were seen. These small cylinders are commonly oriented normal to the bedding and are gently tapering. On casual examination the rock appears to be a conglomerate with peculiar circular quartzite pebbles, and it

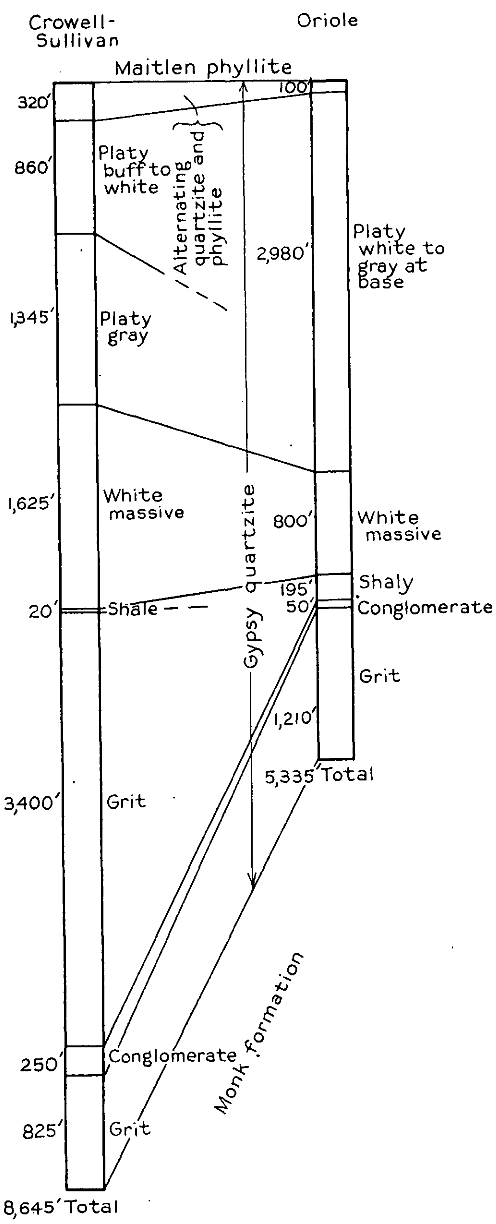


FIGURE 3.—Columnar sections of Gypsy quartzite on the Crowell-Sullivan ridge and on the ridge west of the Oriole mine.

is only where broken across the bedding that the true texture is seen. The "burrows" occur usually in the more shaly layers. They are irregularly distributed, winding and crossing rods a quarter of an inch or less in diameter. They lie along bedding surfaces rather than across them. The value of either the fucoidal cylinders or the "burrows" as horizon markers is questioned by both Bridge and Resser.[19] In the Metaline quadrangle, however, they are found throughout the transition zone between the Gypsy quartzite and the Maitlen phyllite and serve as a convenient reference horizon.

Below the uppermost quartzite beds is about 2,200 to 3,000 feet of thin platy quartzite, in places with shaly layers and a few intercalated limy beds. The beds are generally 6 inches to 1 foot thick, although layers 6 feet thick are not uncommon. The quartzite is gray near the base and becomes white or buff toward the top. It is even-grained and in places is cross-bedded. The beds are commonly separated by sericite-covered planes or by thin schistose layers. Particularly near the top of the platy beds the phyllite layers are more numerous and are similar to those in the overlying Maitlen phyllite.

Below the platy quartzite is a massive white to pinkish cliff-forming quartzite, 800 to 1,625 feet thick. This quartzite is even-grained and sugary; the individual grains can be distinguished with a hand lens. The quartzite is unusually clean in appearance, and besides the quartz the only mineral seen in it consists of a few shreds of silvery-white sericite. Cross-bedding is more noticeable in this massive white rock than at any other horizon in the quartzite formation.

A band of schist 20 to 195 feet thick lies below the massive white quartzite. This schist is in general poorly exposed but is dark green where it crosses Crowell Ridge.

Below the schist and continuing to the base of the quartzite is a sequence of conglomerate, quartzites, and alternating beds of grits. The conglomerate contains well-rounded cobbles as large as 6 inches in diameter. It resists weathering to a remarkable degree and generally stands out in bold relief. For this reason it is a convenient horizon marker, advantage of which was taken by both Daly [20] and Walker.[21] The conglomerate has a maximum thickness of about 250 feet near the Canadian border but thins southward and probably averages less than 100 feet thick in the Metaline quadrangle. On the slope west of the Oriole mine the conglomerate (see pl. 5, *B*) is only about 50 feet thick. Bright-red jasper pebbles are characteristic of the conglomerate from Sullivan Mountain northward but have not been identified west of the Pend Oreille River. The cobbles are mostly quartzite, but schist and vein quartz are common, and in places cobbles of several types of porphyritic rocks are abundant. The matrix in the conglomerate and in part of the grits is commonly a siliceous and micaceous gray to dark-gray material in which small grains of quartz can be seen.

The grits generally are composed of smooth well-rounded quartzite pebbles less than half an inch in

[19] Bridge, Josiah, and Resser, C. E., personal communications, 1937.

[20] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), pp. 153–154.

[21] Walker, J. F., op. cit. (Canada Geol. Survey Mem. 172), p. 8.

diameter. Pebbles of other rocks, particularly schists, are present but in subordinate amounts. The grits are generally light buff or grayish, but some beds are speckled with bright-pink pebbles. Most of the grit beds are a few inches to a few feet thick. They grade into quartzites laterally as well as across the bedding, and some layers change to quartzite within a few feet on the strike. Schist layers alternate with the grit beds near the base of the grits. The schists become increasingly abundant lower in the section, and the formation grades into the Monk.

Many of the quartzites are badly sheared, but in most of them bedding planes and grain outlines can be distinguished.

Microscopic features.—Microscopic study of the quartzites brings out clearly the sheared nature of much of the rock. A general tendency toward elongation exists, and some grains indicate secondary growth. Many of the grain boundaries have thin zones of recrystallized quartz. Most thin sections show quartz and sericite, but a little tourmaline, zircon, and highly altered plagioclase feldspars were also seen. Dusty leucoxene (?) is present in small amount, and in the grain interstices of the less pure quartzites near the bottom and top of the section a little greenish biotite and chlorite were identified. Strain shadows are developed in practically all the quartz.

The purer quartzites, such as the massive white bed above the grits, have no matrix except a few grains of sericite. In the less pure rock the micaceous minerals are more plentiful in the interstices and probably were originally a clayey material now recrystallized.

CONDITIONS OF SEDIMENTATION

The tremendous volume of grits and sandstones accumulated in the Gypsy quartzite can be satisfactorily explained by rapid deposition in a gradually subsiding basin. The source of supply is not known, but the purity of the quartzites suggests that the source was sufficiently distant for the soft and easily weathered minerals to be removed. This may be a function of rate of accumulation, as well as distance from the source. The thinning of the formations to the west and the greater thicknesses given by both Daly and Walker (see table, p. 6) to the north indicate a likely source to the north and east.

The transition to limy and clayey rocks, at both the bottom and the top of the quartzite, probably indicate passage to conditions of deeper sedimentation.

AGE

Several poorly preserved fragments of trilobites in a broken piece of quartzite were found on a ridge at an altitude of 6,250 feet on the west slope of Gypsy Peak, in the NW¼ sec. 18, T. 40 N., R. 45 E. The fossil bed could not be found in place, but the angular quartzite was similar to the bedrock nearby, and it is thought that the fossils had not traveled more than a few feet. Bridge examined the trilobites and said, "The collection is unquestionably Cambrian but is so fragmentary that a more exact determination is not possible at present." The assignment of a Cambrian age to the Gypsy quartzite confirms Daly's earlier determination of his Summit series, based on lithologic evidence.[22] Daly placed the base of the Cambrian about 1,000 feet below the top of his Wolf grits (see table, p. 6), or at the base of the Gypsy quartzite. As no evidence of a stratigraphic break at the base of the Gypsy quartzite is found in the Metaline quadrangle, the base of the Cambrian is tentatively placed at the hiatus below the Monk formation.

MAITLEN PHYLLITE

DISTRIBUTION

The Maitlen phyllite, here named from the valley of the intermittently flowing Maitlen Creek, east of Ione, lies above the Gypsy quartzite and below the Metaline limestone. It is exposed in two large areas—one a belt along the east side of the Pend Oreille River and Slate Creek that extends from the area east of Tiger northeastward to the Canadian border, the other west of the Flume Creek fault and on the flanks of the Hooknose anticline. A third, smaller area is exposed on Boundary Mountain.

The phyllite crops out surprisingly well, considering its character. It is slightly more resistant than the limestones and slates that overlie it, and it forms rounded foothills at the base of the quartzite ridges. On the crest of the Hooknose anticline south of Abercrombie Mountain the phyllite is preserved as a thin cap over the quartzite. The rapidly flowing streams, descending from the quartzite ridges, particularly from the Gypsy-Crowell ridge, have cut deeply into the phyllite, and in these stream canyons exposures are good.

THICKNESS AND STRATIGRAPHIC RELATIONS

The phyllite is much distorted and sheared, and no satisfactory section or estimate of the thickness has been reached. The minimum apparent thickness is about 5,000 feet, taken on the west slope of Sullivan Mountain. The base of the phyllite on Sullivan Mountain and to the northeast is placed about 100 feet below a gray-white limestone band 200 feet thick (not shown on the map). The phyllite is gradational into the Gypsy quartzite, and the contact is placed at the top of a prominent bed rich in fucoidal impressions, where the quartzite becomes subordinate in quantity to the phyllite. On the Hooknose anticline the base of the phyllite is about 200 feet below a limestone band that is thought

[22] Daly, R. A., op. cit. (Canada Geol. Survey Mem. 38), pp. 177–194.

to be the same bed that is exposed on Sullivan Mountain. The Gypsy quartzite beds with the "fucoids" on the Hooknose anticline are mostly included with the phyllites, as they are argillaceous and contain few quartzite layers. No certainty is felt that the base of the phyllite as mapped is everywhere in the same stratigraphic position as fully consistent mapping at this "fucoid" horizon is not feasible. A similar uncertainty applies to the top of the phyllite, where the beds become limy and grade into the Metaline limestone. The contact here is placed where the phyllite predominates over limestone.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The megascopic features of the Maitlen phyllite are extremely diverse. The most common rock type is gray greenish, fine-grained, and conspicuously banded. Quartzite beds, generally less than 3 feet thick, are present in appreciable amounts, particularly near the base of the section. Limestone layers are common, and many narrow layers, in addition to the 200-foot bed near the base, are distributed through the section, particularly in the upper part. In some exposures the phyllite is more correctly defined as a sericite schist, and in other places the rock is greenish and massive and in physical appearance suggests an altered volcanic rock. Pyrite is found in much of the phyllite, and beds are locally spotted with brown iron oxides. On Sullivan Creek just below the Metaline limestone an almost continuous section is exposed. The phyllite near the top is grayish black, slightly recrystallized, and difficult to distinguish from the Ordovician slate. This similarity is particularly confusing in Uncas Gulch, a tributary to Slate Creek, where the upper part of the phyllite and the Ledbetter slate were faulted together.

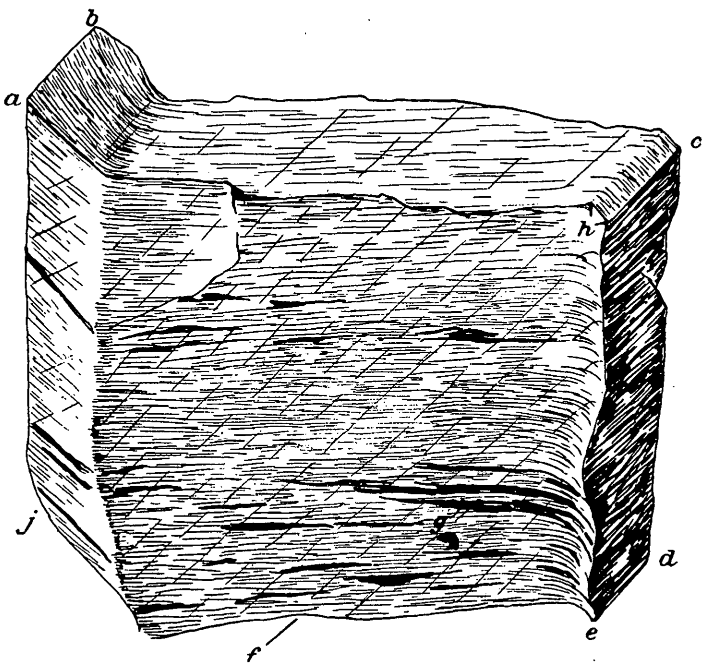


FIGURE 4.—Sketch of a hand specimen of phyllite from south side of Hall Mountain. Natural size. *a b c h*, Poorly defined planar structure; *b c d*, dominant foliation; *c d e h*, late fracture cleavage; *f*, direction of fine hairlike linear structures; *g*, composition banding of unknown origin. Surface *a h e j* is the dominant foliation, broken or bent along cleavage planes parallel to *c d e h*.

The layers in the characteristic phyllite average probably less than 2 inches in thickness. They are compositional, and a few beds of quartzite and limestone can be recognized, although generally the mineral grains are too small to be determined. The 200-foot bed of limestone near the base of the phyllite is largely recrystallized to a dense fine-grained marble, crudely streaked gray and light brown. It is generally much sheared and contains sericite shreds and numerous quartz grains. In places the bed is cut by irregular stringers of white greasy quartz. Other limestone beds weather to a buff color, and all of those tested effervesced freely with cold dilute (1:1) hydrochloric acid.

One of the striking features of the phyllite is its rapid change in degree and diversity of metamorphism. These differences are probably caused by several factors, among which the original nature of the sediments, proximity to the batholith, and the depth of burial at time of metamorphism may be pointed out. In a very small part of the phyllite the deformation is limited to open crumples. Elsewhere the crumples become tighter and fracture cleavage develops. In practically all the formation at least one planar element, other than bedding and jointing, is recognizable, and in some exposures two or even three directions of foliation can be distinguished. One direction is customarily more prominent than the others, and this is the one recorded on the geologic map (pl. 1). It is rather common for the dominant foliation to cut the bedding at angles of 30° or more. The value of recording only the dominant foliation is questionable, as the phyllite—on Hall Mountain, for example—seems to have been subjected to deforming stresses in at least two directions. The evidence for this can best be given with the help of a diagram (fig. 4), which is a sketch of a specimen of phyllite in which the dominant foliation is bent and fractured along a cross cleavage. Toward the top of Hall Mountain the late cleavage planes become more numerous and finally are close enough together to obscure the earlier deformation.

Plate 6, *A*, is a photograph of a polished face of phyllite from the saddle at an altitude of 5,800 feet in the northwest corner of sec. 35, T. 39 N., R. 42 E. It shows two types of layering. The horizontal micaceous layers are formed along shear planes, and the layers *ab* are alternating quartz sericite which probably denote bedding, as suggested by field evidence (see pl. 6, *D*.) In many places the shear banding [23] destroys and is easily confused with bedding.

[23] Balk, Robert, Structural and petrologic studies in Dutchess County, N. Y., pt. 1, Geologic structure of sedimentary rocks: Geol. Soc. America Bull., vol. 47, pp. 709–717, 1936.

Linear structures of several types are recognized. That recorded on plate 1 is the direction and pitch of the intersection of the axial planes of the crumbles with the bedding. In many specimens a very fine hairlike linear structure is conspicuous. Other linear structures are developed by the intersections of the several planar elements, bedding, and shear banding. Mineral elongation does not everywhere coincide with linear structures. The sheared and crumpled nature of the phyllite is obvious on surfaces cut normal to the dominant foliation and the bedding. (See pl. 6, *C*.) The rock, in places, has been more sheared than that in the illustration and is reduced to a mass of pencil-shaped fragments. On Hall Mountain, in the east-central part of sec. 8, T. 38 N., R. 44 E., the siliceous layers have been sheared and rolled in the sericitic matrix to the point where the rock resembles a conglomerate.

Microscopic features.—Microscopically the phyllite consists of quartz, sericite, and calcite, almost to the exclusion of other minerals. Chloritoid and chlorite are both present, although neither is abundant, and their distribution seems to be spotty. Small amounts of detrital zircon and tourmaline have been seen in several sections, and both limonite and other iron oxides are present. No feldspar has been identified in the material examined, but a more extended investigation would probably reveal it. The limestone, particularly near the base of the formation, contains appreciable amounts of sericite and quartz. One specimen obtained west of the Harvey fault on Molybdenite Mountain has about 40 percent of quartz grains embedded in calcite. In most of the material examined the minerals are recrystallized, although individual grains are generally so small as to be invisible without the microscope.

The internal structure of the phyllites is complex. Two directions of foliation can ordinarily be distinguished. Plate 6, *B*, which represents a thin section cut nearly parallel to the face shown in plate 6, *A*, shows both a schistosity and fracture cleavage. The mica tends to recrystallize and concentrate in layers parallel to the fracture cleavage, and at the same time the bedding is not destroyed. Such shear banding might conceivably be formed by close shearing of a bedded rock in which the bedding is gradually rotated and the more mobile material, in this example the sericite, is removed and concentrated along the shear planes. The shear banding may be an incipient stage of "metamorphic differentiation" as defined by Stillwell,[24] Eskola,[25] and Barth,[26] although the high temperatures and pressures usually associated with this process are not found at Metaline. No indication of partial fusion and squeezing out of the liquid material (palingenesis) was seen, although criteria for recognizing this process are vague.

The fine hairlike linear structures so commonly seen on hand specimens are found, microscopically, to be caused by the intersection of an incipient cleavage with other structures, including the shear banding. Generally a few thin plates of sericite are oriented along the incipient cleavage, and individual cleavage planes can rarely be traced across a thin section. The relation of this cleavage to the regional structure is obscure.

[24] Stillwell, F. L., The metamorphic rocks of Adelie Land: Sci. Repts. Australasian Antarctic Exped., 1911–1914, ser. A, vol. 3, pt. 1, pp. 93–121, 1918.

[25] Eskola, P., On the principle of metamorphic differentiation: Soc. geol. Finland Compt. Rend., vol. 5, pp. 68–77, 1932.

[26] Barth, T. F. W., Structural and petrologic studies in Dutchess County, N. Y.: Geol. Soc. America Bull., vol. 47, p. 842, 1936.

CONDITIONS OF SEDIMENTATION

The phyllite, to judge from its generally thin-banded and diverse nature, was deposited on a shallow, oscillating but slowly deepening sea bottom, where conditions ranged from those favorable to the accumulation of quartzite and clay to those in which limy clay and pure limestone were laid down. The "fucoids" and "burrows" near the base also indicate shallow water during the transition from quartzite to phyllite. During the deposition of the upper part of the phyllite conditions gradually changed and limestone accumulated in increasing quantities.

AGE

The phyllite grades downward into the Gypsy quartzite, which is of Cambrian age, and upward into the Metaline limestone, of Middle Cambrian age. It is therefore Lower or Middle Cambrian. No fossils, with the exception of a few fucoidal impressions, have been found in the phyllites.

METALINE LIMESTONE

DISTRIBUTION

The Metaline limestone, here named from the cliffs near Metaline Falls, is exposed in the Pend Oreille Valley from Ione north to the Canadian border. It underlies most of the territory between Slate Creek and the Pend Oreille River and forms the steep-walled gorge of the river north of Metaline Falls. The topography of the limestone area is characteristically pitted and rough.

THICKNESS AND STRATIGRAPHIC RELATIONS

Establishment of a detailed section of the Metaline limestone would undoubtedly be of value to the mining industry, but compilation of such a section is difficult for several reasons. The beds have been masked by dolomitization and other processes related to ore deposition, the brittle carbonate rocks have been much faulted and brecciated, and where exposures are best—in the river gorge—the beds are largely inaccessible. (See pl. 7.) For these reasons no precise estimate of the thickness of the Metaline limestone section is possible at present, although it is thought that with more detailed study such a measurement could be made. The limestone between Slate Creek and the Pend Oreille River, shown in section *D—D'* of plate 1, has an apparent thickness of 5,000 to 6,000 feet. This figure is considered to be too large, as repetition of the strata by faulting is here thought likely. The section east of Metaline Falls, in the relatively undisturbed block being quarried for limestone, furnished what appears to be the most reliable measurements. The total thickness here is about 3,000 feet, in which four members are distinguished, as follows:

Section east of Metaline Falls

Top	*Feet*
Mottled dense gray limestone; few chert nodules	150
Mottled dense gray limestone; many chert nodules	450
Fine-grained cream-colored dolomite, particularly in upper part. Alternating layers of black and white dolomite	1,200
Interbedded limestones and limy shales, locally dolomitic. Grades conformably into Maitlen phyllite	1,200
	3,000

The top of the limestone is sharply defined against overlying black slate. No gradational beds have been seen, and the possibility of an unconformity between the limestone and the slate cannot be completely discarded, although considered to be unlikely. That the beds below the slate are approximately equivalent throughout the district is indicated by the unusual mottling (pl. 8, *A*) and the fine-grained dense character of the limestones, which, about 150 feet from the slate contact, are underlain by peculiar cherty beds (pl. 8, *B*). The base of the Metaline limestone, on the other hand, is a limy phyllite in which limestone beds decrease numerically downward and the formation grades into the Maitlen phyllite below.

LITHOLOGY AND INTERNAL STRUCTURE

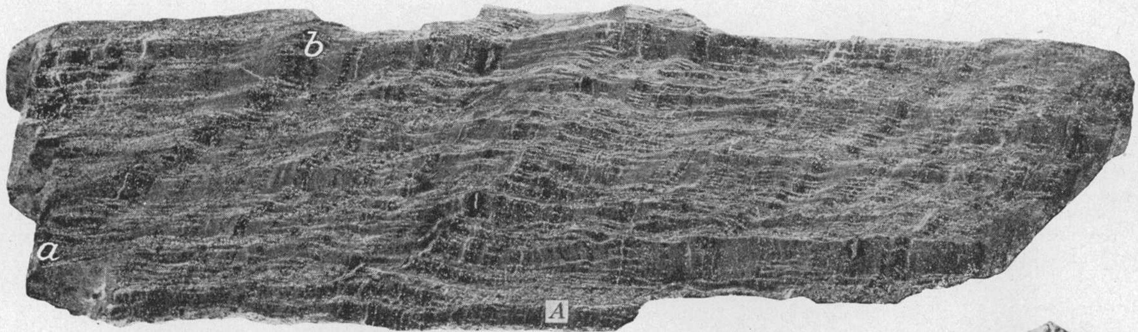
Megascopic features.—The upper 150 feet of the section is a dense, fine-grained soft gray limestone with a peculiar mottled appearance. (See pl. 8, *A*.) The mottling is due partly to the irregular distribution of a small amount of carbonaceous material and partly to the development of stylolites along cracks. The rock is massive, and bedding is generally not seen. A few narrow indistinct parallel layers that appear to be caused by slight concentration of organic material may, however, represent bedding. This part of the limestone seems to have been unusually receptive to ore-forming solutions and is complexly altered to dolomite, jasperoid, coarse-grained calcite, and ore, which mask the original character. A few chert nodules are generally present and the rock passes gradually into a more cherty rock below.

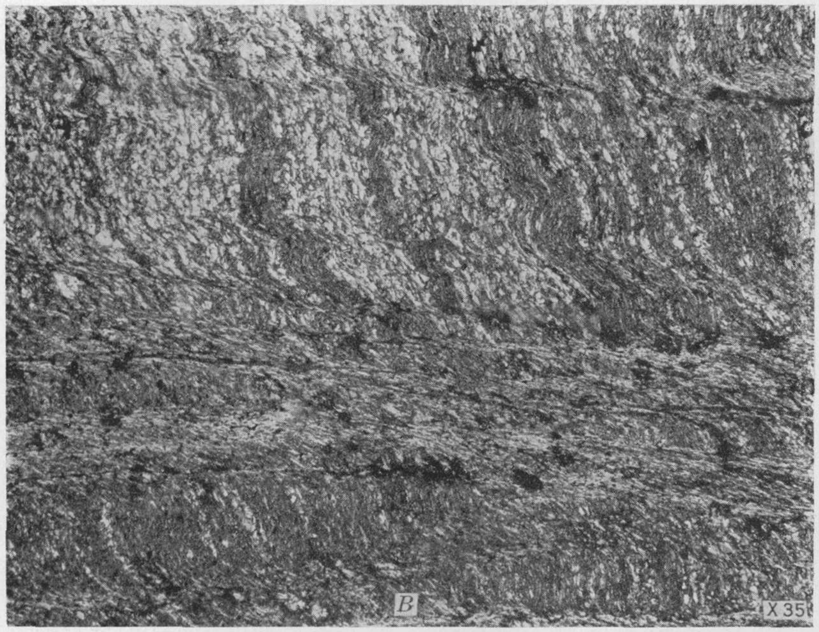
The 450-foot member is similar to the overlying beds but contains numerous chert nodules. (See pl. 8, *B*.) The nodules are generally rounded, crudely spheroidal or ellipsoidal. They average less than one inch in longest dimension and many have hollow centers. The abundance of the nodules differs from place to place, but they appear to be confined largely to this member and a few in beds above. The limestone is similar in mottled appearance and texture to the overlying beds. In some places it is nearly pure limestone and effervesces vigorously with very dilute (15:1) hydrochloric acid. In other places it is altered to a dense fine-grained creamy-gray dolomite and to the materials that accompany ore deposition.

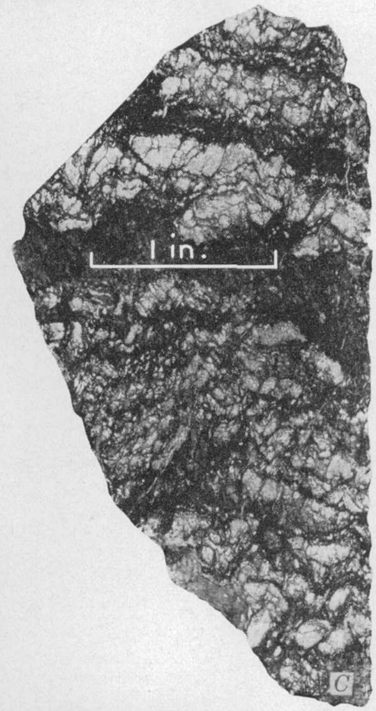
Below the fine-grained limestone is about 1,200 feet of carbonate rock that, wherever seen, is dolomitized. The upper part is generally a fine-grained massive cream-colored to gray dolomite that shows no known diagnostic features. The grain is so fine that cleavage surfaces of individual particles are rarely seen, but lower in the section the rock is increasingly coarser and grains one-sixteenth to one-eighth inch across are present. Intercalated with the fine-grained cream-colored dolomite are a few layers of black dolomite that commonly contain white spots, less than an inch in longest dimension. The black layers are more numerous near the base of the section and in places make up 50 percent of the rock. The thickness of the individual layers is generally less than 4 or 5 feet, but some are much thicker and others are only a fraction of an inch thick. Analyses of the black and cream-colored dolomites are given in the table on page 42. The two rocks are practically identical in composition except for a small amount of carbonaceous material in the black rock. The light-colored dolomite appears to have been formed by recrystallization of the darker layers and the expulsion of the carbonaceous material. For this reason the layering, although in general it agrees with bedding, is in places discordant, and irregular remnants of the black dolomite are isolated in the lighter rock. Plate 9 *A*, shows such a remnant as well as the more usual type of banding. Bedding is better seen near the base of the section than toward the top. It is accentuated by slight textural and color differences. No basis for subdividing this 1,200 feet of dolomite has been recognized, but it is likely that detailed study and possibly an examination of insoluble residues, as developed by McQueen,[27] would establish such a basis.

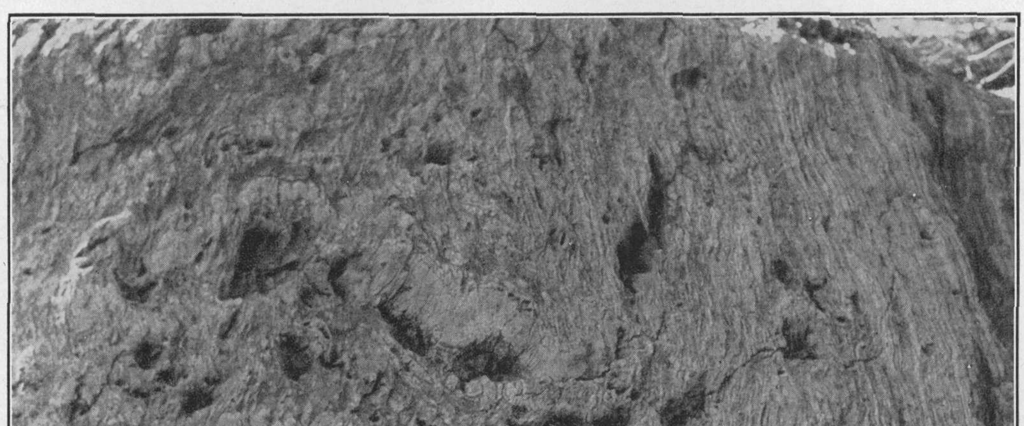
The lowest part of the Metaline limestone, about 1,200 feet thick, is treated as a unit, largely from lack of time to study it thoroughly rather than a lack of recognizable members. Parts of this section are well exposed in the quarries and road cuts east of Metaline

[27] McQueen, H. S., Insoluble residues as a guide in stratigraphic studies: Missouri Bur. Geology and Mines, 56th Bienn. Rept., 1931, reprint of Appendix I, 1930.







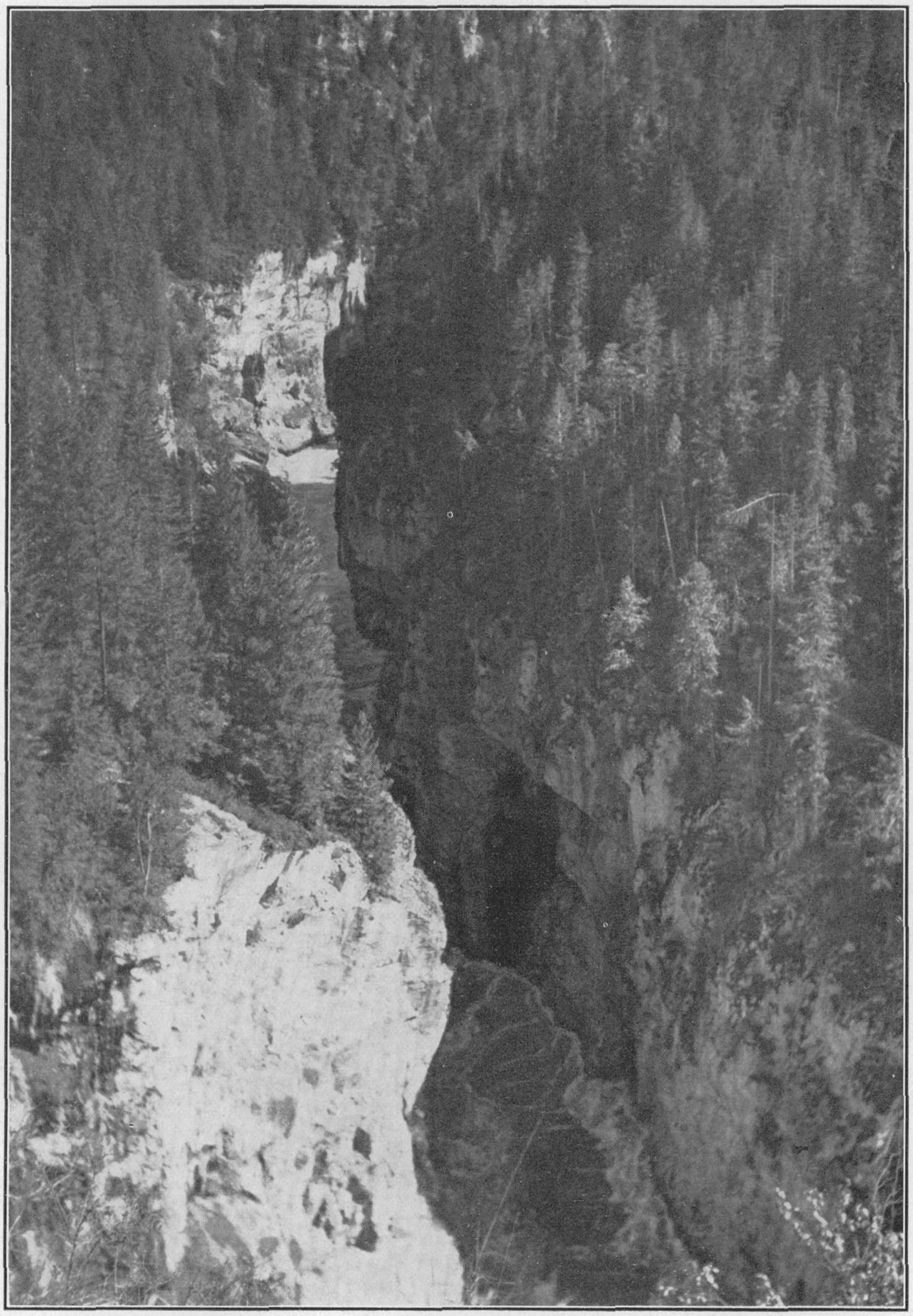


A. MAITLEN PHYLLITE, SADDLE IN NORTHWEST CORNER OF SEC. 35, T. 39 N., R. 42 E., ALTITUDE, 5,800 FEET.
Shear banding is horizontal. Banding *a–b* is bedding.

B. MAITLEN PHYLLITE, PHOTOMICROGRAPH OF THIN SECTION OF ROCK NEARLY PARALLEL TO FACE SHOWN IN *A.*
Schistosity (bedding ?) is cut by fracture cleavage (shear banding).

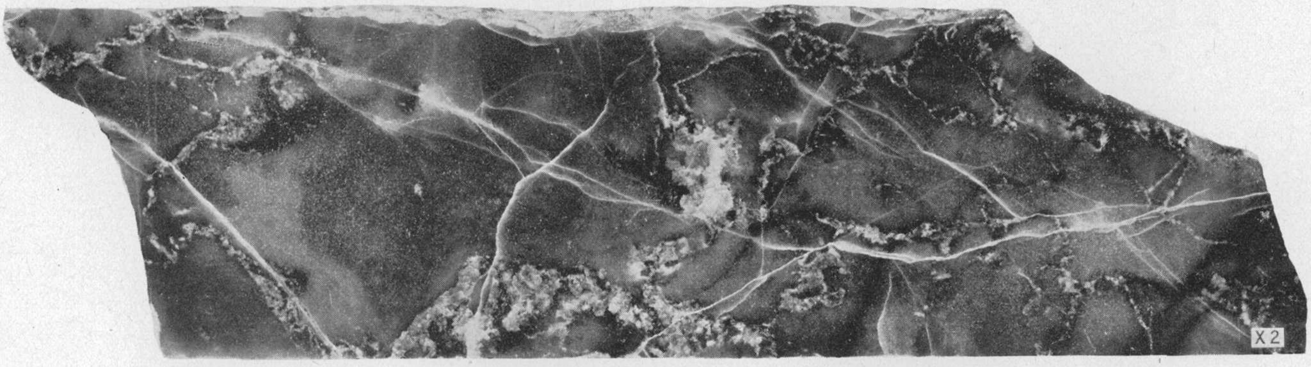
C. MAITLEN PHYLLITE, NORTH CENTER OF SEC. 23, T. 39 N., R. 42 E., ALTITUDE 5,950 FEET.
Polished surface cut normal to dominate foliation and bedding.

D. MAITLEN PHYLLITE, NORTHWEST CORNER OF SEC. 35, T. 39 N., R. 42 E.
Bedding nearly horizontal, shear banding nearly vertical.



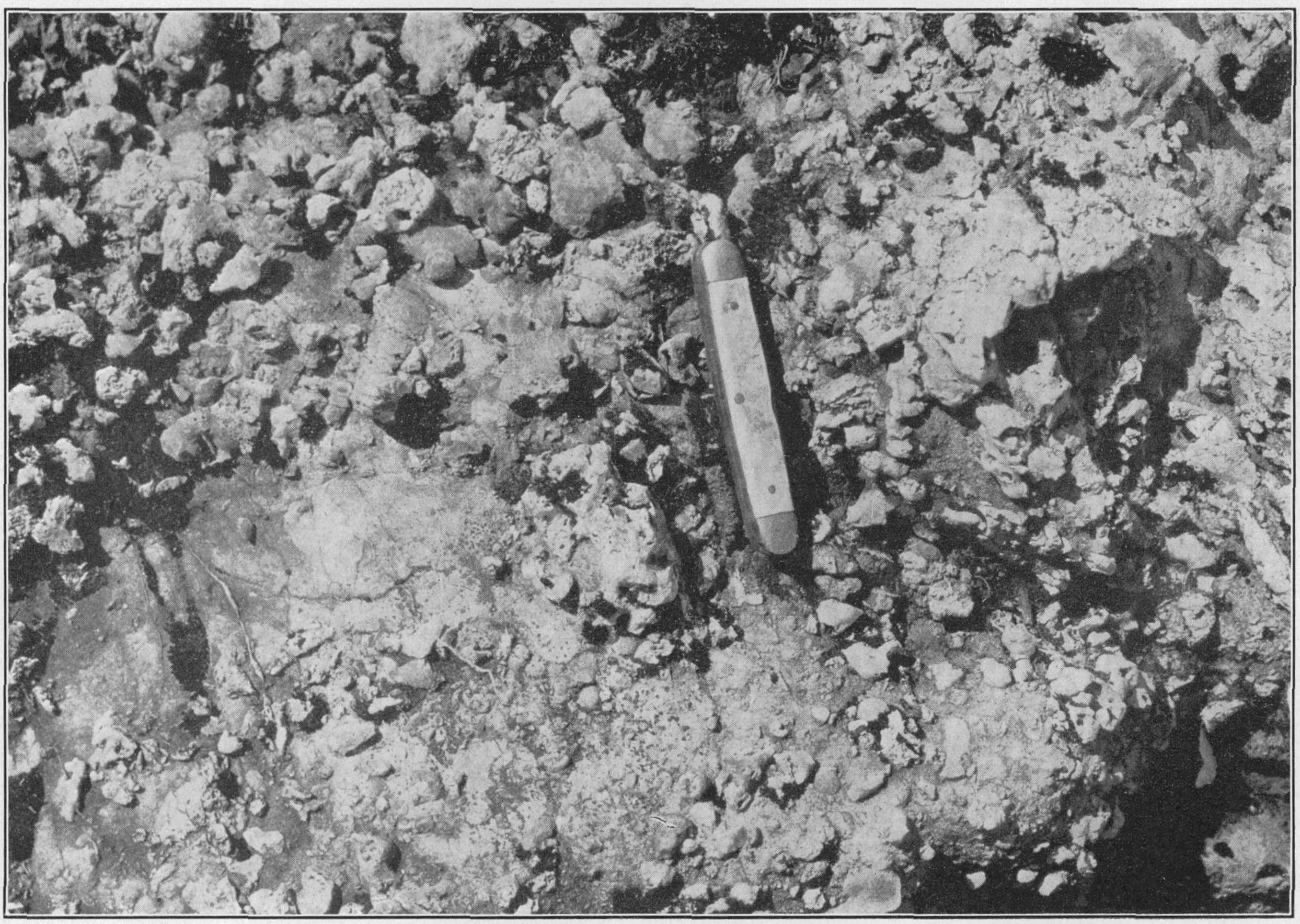
POST-PLEISTOCENE GORGE OF THE PEND OREILLE RIVER.

View south from east bank of the river about ¼ mile southeast of Z Canyon. The river level is about 500 feet below the observer.



A. METALINE LIMESTONE, PEND OREILLE MINE.

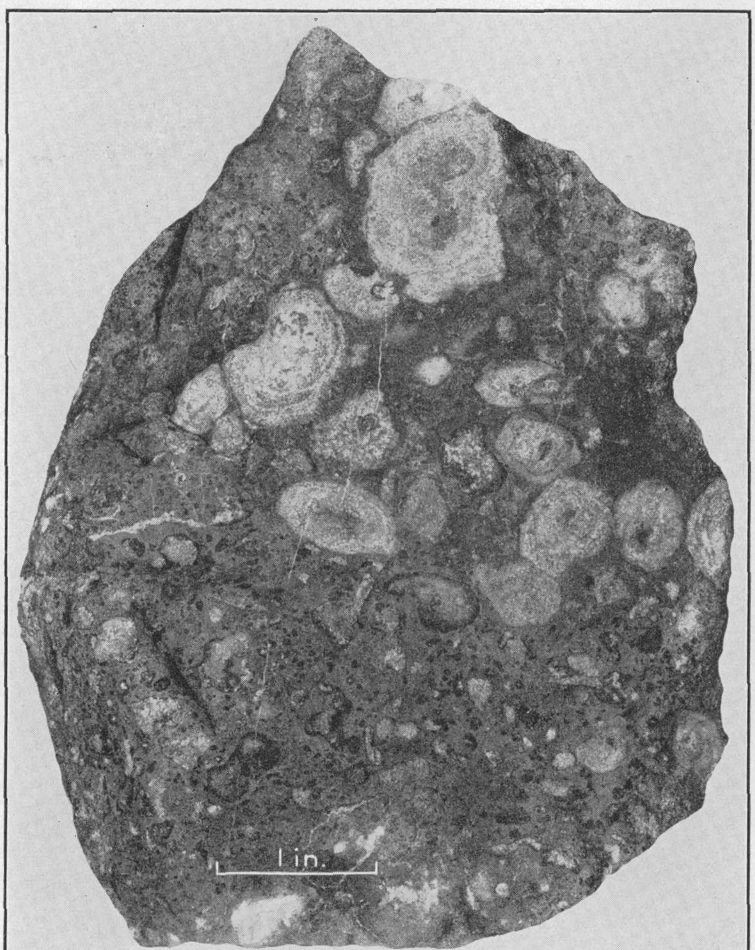
Polished fragment of split drill core, 140 feet below Ledbetter slate.



B. CHERT NODULES ON WEATHERED SURFACE IN METALINE LIMESTONE, LEAD HILL.

A. BLACK AND LIGHT-COLORED DOLOMITE, NORTH SIDE OF CRESCENT LAKE.

Note the residual black remnant in the light dolomite above the hat.



B. ALGAE IN LOWER PART OF METALINE LIMESTONE, ROAD CUT EAST OF UPPER LEHIGH QUARRY.

Falls. Limy shale or phyllite beds alternate with limestones and dolomites throughout the 1,200 feet, but the phyllites are more numerous toward the base. The limestone in the upper part of the section can be seen in the upper Lehigh quarry and in the road cut between the upper quarry and the shale quarry. Limestone, dolomitic limestone, and dolomite are all represented. The limestone is chiefly of two types. One is a smooth light-gray rock speckled with small (less than one-eighth inch) glassy calcite crystals; the other is a smooth dense rock, with a mottled gray appearance, which contains numerous streaks and spots (about 2 inches in longest dimension) of white calcite. The bed below this limestone is slightly dolomitic (less than 10 percent $MgCO_3$) and is of unknown thickness. This bed is conspicuous, as it consists of layers of blue-gray dense limestone, less than 2 inches thick, separated by sharply undulating layers of shaly limestone about a quarter of an inch thick. Some of these undulating shale layers join and leave isolated eyes of the limestone. On exposed surfaces the shaly layers weather brown and contrast with the grayish lime. This contrast is less noticeable on fresh surfaces where the shaly layers are only slightly darker than the blue-gray limestone. Several beds farther down in the section are also characteristic. One bed of dolomite contains many algae such as are shown in plate 9, *B*. Other beds contain numerous small rounded grains that resemble oolites or pisolites. The limestone in the lower parts of the section is thin-bedded and is interlayered with much limy phyllite. Gradations from blue-gray limestone to black limy phyllite are found. The black phyllite is in beds that are 50 feet or more thick, as well as in numerous thinner layers. The thicker beds have in places, particularly in diamond-drill cores, been confused with the closely similar Ledbetter slates. The degree of metamorphism of the two rocks is about the same, but a grayish sheen is noticed on much of the Cambrian phyllite and is generally absent from the Ledbetter slate. Bedding planes are also more conspicuous in the Cambrian rocks.

A section through the Metaline limestone on Boundary Mountain is similar to that east of Metaline Falls, but the rocks are more recrystallized and dolomite is more abundant.

Microscopic features.—No effort has been made to study the microscopic features of the limestone in detail, and no unusual features were noticed in the few slides examined. Much of the rock, particularly the light-colored dolomite, is recrystallized. The black dolomite has a cloudy greasy appearance, probably due to minute spots of carbonaceous material. The black dolomite grains are, on the average, smaller than the grains in the light-colored dolomite. Many crystals between the black and light-colored dolomites are partly cloudy and partly clear.

CONDITIONS OF SEDIMENTATION

The conditions favorable for the accumulation of limestone alternated with and gradually superseded those under which the phyllites were deposited. These conditions must have remained unchanged for a long period of time to permit the deposition of 3,000 feet of limestones. The contact between the Metaline limestone and the overlying Ledbetter slate is sharp and indicates an abrupt change in the conditions that governed deposition—in fact, at least part of the Upper Cambrian epoch intervened between the Metaline and Ledbetter epochs.

AGE

Two collections of fossils of Middle Cambrian age have been taken from the Metaline limestone near the base of the formation. The best collection was obtained from the shaly bed that overlies the limestone in the upper Lehigh quarry, east of Metaline Falls. A few trilobites can also be found in nearby limestone beds. The fossils identified by Josiah Bridge are listed below.

Elrathia kingii.
Neolenus sp.
Kootania sp.
Pagetia sp.
Acrothele sp.

A second fossil locality was found in poorly exposed limy shale at an altitude of 2,800 feet on the southeast bank of Threemile Creek in the SW¼ sec. 12, T. 39 N., R. 43 E. The species identified by Josiah Bridge are the same as those obtained from the Metaline quarry. According to Bridge, the Metaline limestone is approximately equivalent to the Stephen formation of British Columbia [28] and the Middle Cambrian limestone recently found in the Libby quadrangle, Mont.[29]

One specimen of a poorly preserved trilobite was found by John Currie in the silicified limestone of the Pend Oreille mine between the 500-foot and 700-foot levels.

ORDOVICIAN SYSTEM

LEDBETTER SLATE

DISTRIBUTION

The Ledbetter slate is irregularly distributed in the Pend Oreille Valley north of Ione. One belt, from which Slate Creek is named, can be followed from the Pend Oreille River northeastward up the Slate Creek Valley to the Canadian border. Another large area that lies north of the Russian Creek fault is well exposed on the new Russian Creek road to the Frisco

[28] Walcott, C. D., Cambrian geology and paleontology: Smithsonian Misc. Coll., vol. 53, pp. 209–212, 1910.

[29] Gibson, Russell, Geology and ore deposits of the Libby quadrangle, Mont.: U. S. Geol. Survey Bull. (in preparation). Fossils determined by P. E. Raymond.

Standard mine. The name Ledbetter is taken from the outcrops on the slope west of Ledbetter Lake, where the formation can readily be seen. The slate breaks down readily and forms rounded soil-covered hills. For this reason the rock is best exposed in artificial openings, such as road cuts and mine excavations.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Ledbetter slate is much sheared and distorted, and, as a result, the thickness is extremely erratic. The apparent ease with which the slate "flowed" under pressure is indicated by the drag, in places amounting to hundreds of feet, along fault zones. The maximum apparent thickness both on Russian Creek and northwest of Ledbetter Lake is about 2,500 feet. The base of the slate is a sharply defined surface. The upper limit has been seen only on the hill southwest of the United Treasure mine, and here the relations are obscured by an intrusive mass; furthermore, the exposures are poor and definite statements as to the character of the upper slate contact cannot be made.

Except where the contact is a fault, bedding in the slate is apparently parallel to bedding in the underlying Metaline limestone. However, the difference in age, Middle Cambrian of the Metaline limestone and Ordovician of the Ledbetter slate, indicates that a disconformity may exist.

LITHOLOGY AND INTERNAL STRUCTURE

Megascopic features.—The Ledbetter slate is a black, fine-grained, generally homogeneous-appearing rock in which the individual mineral grains can rarely be distinguished. In places a few thin indistinct composition bands, generally less than 1 inch thick, can be identified, and in the Slate Creek section a conspicuous bed of black quartzite about 15 feet thick was recognized. The quartzite was helpful in mapping, as it is resistant to weathering and stands out from the enclosing weaker slate. The quartzite is commonly cut by a network of white quartz stringers. It is even-granular, and the individual quartz grains are readily distinguished with a hand lens. Particularly in the upper part, the slate becomes limy and bedding is more conspicuous. The uppermost known Ordovician beds are black limestones that are well exposed in a road cut on the Spokane highway in sec. 18, T. 38 N., R. 43 E.

The slate is, with the exception of the Devonian and younger rocks, and possibly the phyllite in the lower part of the Metaline limestone, the least metamorphosed of the sedimentary beds. It is neither micaceous nor extensively recrystallized. As the slate is greatly deformed and is involved in the orogenic history, the lack of recrystallization suggests deformation under comparatively light load. A well-defined fracture cleavage is evident in most outcrops, and where the bedding is also recognizable it is generally cut at low angles by the fracture cleavage. In some places, particularly on Russian Creek, the bedding is bent into a series of small tight folds, but fracture cleavage is poorly developed or absent.

Microscopic features.—Microscopic study confirms the field observation that little recrystallization has occurred in the Ledbetter slate. In thin section the slate is streaked with narrow black and transparent bands, parallel to the fracture cleavage. Under a magnification of 500 diameters the boundaries of mineral grains in the light streaks cannot be seen. In part of the rock small quartz grains are identified and calcite is recognized in the limy beds. The black quartzite consists of well-rounded quartz grains that have wavy extinction and generally a small amount of recrystallized quartz on the grain borders. The matrix consists of finer-grained quartz and carbonaceous material.

CONDITIONS OF SEDIMENTATION

The conditions of sedimentation during the deposition of the Ledbetter slate were favorable for the accumulation of large quantities of nearly uniform clay, high in organic material. Enough fluctuation took place for quartz grains to be at times deposited in the sediment. An increasing abundance of limestone in the upper part of the formation indicates a gradual change in the controlling conditions.

AGE

Fossil collections from the Ledbetter slate have been examined by Josiah Bridge, and most of the determinations have been checked by Rudolf Ruedemann. Bridge says:

> The oldest graptolite fauna is of lower Deepkill age. It is * * * from the west bank of the Pend Oreille River north of the Pend Oreille mine * * * and * * * contains the following fauna:
>
> Graptolites:
> - *Tetragraptus quadribrachiatus Hall var.
> - *Tetragraptus similis (Hall).
> - *Didymograptus nanus Lapworth.
> - Dicellograptus sp.
> - *Phyllograptus ilicifolius Hall.
> - Phyllograptus sp.
>
> Brachiopod:
> - Leptobolus sp.
>
> This is a characteristic early Deepkill assemblage and presumably correlates this portion of the Ledbetter slate with the upper part of the *Tetragraptus* zone of the Deepkill shale of New York and with the lower portion of the Glenogle shales of the Windermere, B. C., area. This particular collection seems to fall somewhere in the interval between 730 and 950 feet in Walker's measured section on Windermere Creek [30]—in other words, near the top of the lower half of his lower Glenogle shale. This correlation is based largely on the presence of *Tetragraptus quadribrachiatus* * * *.
>
> The fauna described from the type Glenogle shales near Field,

[30] Walker, J. F., Geology and mineral deposits of the Windermere map area, B. C.: Canada Geol. Survey, Dept. Mines, Mem. 148, pp. 26, 27, 1926.

B. C., is much younger, and it is not known whether this Deepkill fauna is present in that region or not.

The species prefixed by an asterisk in the foregoing list were found by Kirk in a large Deepkill fauna obtained from an isolated outcrop of an unnamed early Ordovician shale in the Wood River region of Idaho,[31] and the correlation between these two areas seems to be well established. This same portion of the Ledbetter slate is also the approximate equivalent of the Saturday Mountain formation of the Bayhorse district, Idaho,[32] which also carries a Deepkill fauna, but there the evidence is less conclusive.

No fauna characteristic of the late Beekmantown or early Chazy (upper Deepkill zones) have been found in any of the collections.

All the remaining collections contain elements of the lower *Dicellograptus* fauna, of Normanskill age. The list of species and their occurrence in the several collections is shown on the attached table. Two distinct subzones are recognizable * * *.

The first group (subzone) is characterized by the absence of *Dicranograptus* and by the presence of *Nemagraptus gracilis*, *Thamnograptus capillaris*, *Dicellograptus sextans*, and other early Normanskill forms. Although the stratigraphic relations of the various collections was not determined in the Metaline area, it is known that strata carrying these forms commonly underlie beds in which various species of *Dicranograptus* are abundant. This is true of the Womble shale of Oklahoma and Arkansas and of the Athens shale of the southern Appalachian region, both of which carry Normanskill faunas.

[31] Umpleby, J. B., Westgate, L. G., and Ross, C. P., Geology and ore deposits of the Wood River region, Idaho: U. S. Geol. Survey Bull. 814, p. 18, 1930.

[32] Ross, C. P., Geology and ore deposits of the Bayhorse region, Custer County, Idaho: U. S. Geol. Survey Bull. 877, pp. 16, 17, 1938.

Fossils from Ledbetter slate

	Pend Oreille River bank northeast of Pend Oreille mine	Pend Oreille River bank north of Morning mine	Entrance to 500-foot adit, Pend Oreille mine	Mouth of Slate Creek	Prospect in SW¼ sec. 30, T. 40 N., R. 44 E.	Highway southwest of Ledbetter Lake	Highway southwest of Ledbetter Lake	West center sec. 2, T. 39 N., R. 43 E.	Whiskey Creek road cut	Prospect dump 1 mile south of old Bella May mine	West center sec. 12, T. 40 N., R. 44 E.	Road cut, NE¼ sec. 22, T. 40 N., R. 44 E.
Graptolites:												
Thamnograptus capillaris (Emmons)		x										
Didymograptus sagitticaulis Gurley	x	x	(?)									
Didymograptus n. sp. aff. D. fasciculatus Nicholson	x	x										
Didymograptus n. sp.				x								
Syndyograptus cf. S. pecten Ruedemann	x											
Nemagraptus gracilis (Hall)		x										
Dicellograptus gurleyi Lapworth		?										
Dicellograptus sextans (Hall)	x	x		x	(?)							
Dicellograptus divaricatus (Hall)					(?)							
Dicellograptus sp.	x									x		
Dicranograptus ramosus Hall						(?)						
Dicranograptus ramosus var. arkansasensis Gurley						x						
Dicranograptus cf. D. nicholsoni Hopkinson	x											
Dicranograptus nicholsoni var. parvangulus Gurley						x						
Dicranograptus aff. D. spinifer var. geniculatus Ruedemann						x	x	x				
Dicranograptus contortus Ruedemann					x							
Dicranograptus sp.									x			
Diplograptus acutus Lapworth				x								
Diplograptus incisus Lapworth	x				x	x	cf.			x		
Diplograptus euglyphus Lapworth	x	x		x	x	x	x			x		x
Diplograptus sp.			x					x			(?)	
Orthograptus sp.						x						
Glossograptus ciliatus Emmons	x	x			x	x		cf.				
Glossograptus whitfieldi (Hall)	x					x				x		
Climacograptus parvus Hall	x	x										
Brachiopod:												
Schizocrania sp.	x											
Crustacean:												
Caryocaris sp.		x	x									

A further reason for considering this subzone to be slightly older is found in the presence of a species of *Didymograptus* which, though not identical with Deepkill species, is more nearly related to Deepkill forms than to any known from the Normanskill. These collections also contain the shells of *Caryocaris*, a form which according to Ruedemann is not known from the Normanskill of New York but which here is associated with characteristic Normanskill forms.

The second subzone is characterized by an abundance of species of *Dicranograptus* and by the absence of many of the forms cited above.

The remaining collections contain none of the diagnostic forms but only species which are common to both zones and hence cannot be as accurately placed.

In general, the fauna corresponds fairly well to that of the main portion of the Pi Kappa formation of the Wood River district, Idaho[33] but no trace of the peculiar, youngest fauna listed from that formation was found in these collections.

The exact relationship of these faunas to those from the upper part of the Glenogle shale on the Kicking Horse and Dease

[33] Umpleby, J. B., Westgate, L. S., and Ross, C. P., op. cit. (U. S. Geol. Survey Bull 814), pp. 22, 23.

Rivers, B. C.,[34] is not definitely established. It has been claimed that these Glenogle faunas are possibly slightly older than the true Normanskill, this claim being based primarily on the absence of dicranograptids and nemagraptids. However, Ruedemann[35] points out that these same elements are lacking in the beds immediately overlying the main *Dicranograptus* subzone and suggests that these high Glenogle faunas may well be slightly younger than the true Normanskill, and therefore younger than the faunas from the Ledbetter slate. I am inclined to hold the same opinion.

DEVONIAN SYSTEM

DEVONIAN LIMESTONE

DISTRIBUTION

A small area of limestone that yielded Devonian fossils is exposed east of the Flume Creek fault in sec. 16, T. 40 N., R. 43 E. A larger patch of carbonate rock, mapped as Devonian but possibly of Cambrian age, lies north of the Russian Creek fault in the extreme northwest corner of the Metaline quadrangle. (See pl. 1.)

THICKNESS

The exposures of the Devonian rocks are poor, and no satisfactory stratigraphic sequence was established. The bedding in sec. 16, T. 40 N., R. 43 E., seems to be nearly horizontal and, if so, the limestone has a minimum thickness of 700 feet, with an unknown amount eroded. The outcrops in the northwest corner of the quadrangle are too poor to permit an estimate of thickness.

LITHOLOGY

The fossiliferous Devonian rock contains a somewhat unusual type of limestone breccia or conglomerate at the base of the exposure. (See pl. 10, *A*.) The fragments or pebbles are mostly limestone, with a few of black slate. The matrix is partly limestone and partly subrounded quartz grains that can easily be seen in plate 10, *A*. Some of the limestone fragments are single fossils but other fragments contain several fossils in limestone. The fragmental nature of the limestone becomes less noticeable away from the base of the formation, and the rock gradually becomes an even-grained grayish-blue limestone. The carbonate rock in this exposure appears to be all limestone; no dolomite was recognized.

The carbonate rock in the northwest corner of the quadrangle is different in appearance from either the known Cambrian or the known Devonian. The most diagnostic member, and the best exposed, is an intraformational breccia shown in plate 10, *B*. This breccia can be traced laterally into the type shown in plate 10, *C*, and finally into typical thin-bedded dolomite with desiccation cracks as shown in plate 10, *D*.[36] Similar intraformational breccia is recognized at the Just Time mine, in sec. 15, T. 40 N., R. 42 E. The rock seems to be completely dolomitized. The fragments are gray to cream-colored crystalline material, and the matrix is a dense dark-gray shaly dolomite. Other carbonate rocks, particularly a dense blue-gray one and a shaly-gray bed, are exposed in isolated patches.

An isolated outcrop on the northeast slope of the hill, at an altitude of 4,400 feet, in sec. 14, T. 40 N., R. 42 E., is a blue-gray limestone that is mottled with tiny spheroids less than one-eighth of an inch in diameter. These spheroids are resistant to weathering and stand out from the enclosing calcite. They weather to a reddish-brown color, which also makes them conspicuous. L. G. Henbest, who examined this material, found no evidence of an organic origin for these spheroids; in his opinion they are probably recrystallized calcareous oolites. In thin section small grains, that have elliptical cross sections as much as one-eighth of an inch on the long axis, are numerous. According to Henbest, these grains are likely algae. Similar limestone with tiny spheroids is found in a layer of Maitlen phyllite west of the Hooknose-Abercrombie ridge.

CONDITIONS OF SEDIMENTATION

The fragmental nature of the rocks near the base of the Devonian formation indicates accumulation in shallow water. The presence of quartz grains in the matrix also suggests near-shore conditions. The intraformational breccia and conglomerate resemble deposits on mud flats, which are hardened and later reworked by currents and wave action. The near-shore conditions gradually changed to those more favorable for the accumulation of normal limestone.

AGE

G. H. Girty reports that the fossil collection is probably of Devonian age, although Bridge, supported by Kirk, Cooper, Ulrich, and Bassler, says that "it is either late Devonian or early Mississippian, presumably the latter."

Girty determined the following species:

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

[34] Canada Geol. Survey Rept., 1886, pt. 2, p. 24d; Mem. 55, p. 101, 1914; Mem. 148, p. 30, 1926.

[35] Ruedemann, Rudolf, Graptolites of New York, pt. 2, p. 25, 1908.

[36] Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 14–15, pl. 5, *A*, 1932.

According to Girty:

> The evidence that would definitely place these faunas in some geologic period is probably not strong. Not so the evidence that would exclude them from the Carboniferous. Aside from the large and numerous crinoid stems, if they have any weight, I do not find a single Carboniferous element in these faunas. For instance, the Producti, which are seldom lacking in any collection of Carboniferous age, are entirely unrepresented. On the other hand, these faunas seem to abound in *Favosites* and related corals, all of which are exceedingly rare in the Carboniferous. There is also the hypothetical *Leptaena*, the like of which does not occur in any Carboniferous fauna known to me. In brief, there is no evidence whatever for identifying these faunas as Carboniferous, and considerable evidence for believing that they are not Carboniferous.

TERTIARY SYSTEM

TIGER FORMATION

DISTRIBUTION

Four areas of Tertiary continental rocks are recognized in the Pend Oreille Valley near Ione. The most extensive exposure is south of Tiger, where the beds form a group of low rounded hills and from which the name is taken. The formation is also well exposed in road cuts along the Spokane highway in secs. 18 and 19, T. 38 N., R. 43 E., and it caps at least two hills west of Ione. The semiconsolidated rock breaks down easily and it is likely that additional patches have been mapped with the unconsolidated Pleistocene deposits.

THICKNESS

The maximum thickness of the Tiger formation is about 1,000 feet in the hills south of Tiger. The character of the beds changes rapidly, however, and the thickness of the deposits is very erratic.

LITHOLOGY

The clastic material that makes up the Tertiary deposits changes strikingly with the underlying rock; it includes conglomerates, sandstones, and clays. In the road cuts in sec. 18, T. 38 N., R. 43 E., the Tertiary is composed mainly of fragments of Ledbetter slate, and on the hills west of Ione, where the formation overlies the Metaline limestone, the debris is mostly limestone. South of Tiger the Tertiary contains mostly granitic rock detritus.

The beds are generally ill defined, and the materials are poorly sorted, although in some places sharply limited thin beds of carbonaceous (lignitic) material and clay and sandstone are found. Plate 11, *A*, shows a cliff of the semiconsolidated beds south of Tiger, and plate 11, *B*, is a close-up photograph of the same exposure, to show the crudely sorted character of the granitic waste. In one place some of the boulders are 3 to 10 feet in diameter.

CONDITIONS OF SEDIMENTATION

The Tertiary beds were deposited under continental (nonmarine) conditions, probably in a valley similar to that existing today. The source of the clastic material must have been near the site of deposition, as its character agrees closely with that of the underlying rock. The crude sorting and the subangular nature of the fragments likewise indicate a nearby source. The lignitic beds indicate swampy conditions, and shallow-water sorting is suggested by the clay and sandstone layers.

AGE

Fossil leaves are plentiful in a few of the finer-grained and carbonaceous beds of the formation. They are poorly preserved, however, owing largely to an indistinct cleavage that crosses the bedding. A collection of leaves made in the road cuts contained only four species, which have been identified by R. W. Brown as *Sequoia* sp., *Quercus* sp., *Trochodendroides* sp., and *?Laurus* sp. Brown says, "This material does not lead me to any definite specific determinations or conclusions as to age."

The beds are thought to be Tertiary for several reasons. They are semiconsolidated (see pl. 11, *A*)—more so than any nearby known Pleistocene beds. The beds are slightly deformed, in places they dip 20°, and an ill-defined fracture cleavage is developed. Three of the four known exposures are well above the highest known Pleistocene deposits, with the exception of scattered morainal debris.

The beds are shown on the State geologic map [37] as Tertiary, but the reason for this assignment is not given in the brief accompanying description.[38] Tertiary Miocene beds that underlie the Columbia River lavas are extensive near Spokane.[39]

QUATERNARY SYSTEM

PLEISTOCENE DEPOSITS

The deposits of Pleistocene age recognized in the Metaline quadrangle are all related to glaciation and the ice-melt waters. For convenience, they are discussed with other glacial features in the section on development of the topography (pp. 35–38).

RECENT DEPOSITS

The Recent deposits are confined to stream bottoms and debris-covered slopes. The wide, flat flood plain of the Pend Oreille River south of Metaline Falls is

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[37] Geologic map of Washington, 1936.

[38] Culver, H. E., The geology of Washington, pt. 1, General features of Washington geology: Washington Dept. Cons. and Devel., Div. Geology, Bull. 32, 1936.

[39] Pardee, J. T., and Bryan, Kirk, Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Wash.: U. S. Geol. Survey Prof. Paper 140–A, pp. 1–16, 1926.

by far the most extensive of the Recent stream deposits. Most of the streams are, however, actively cutting into their bedrock, and the gravel and boulder accumulations along them are in small, generally short-lived areas. Slope wash and soil cover are features of considerable moment in the geologic mapping, as they extend over large areas and obscure the bedrocks.

INTRUSIVE ROCKS

KANIKSU BATHOLITH

DISTRIBUTION

The Kaniksu batholith underlies most of the southern half of the Metaline quadrangle. Small isolated exposures of similar rock, probably satellitic to the main mass, occur on the south side of Hall Mountain and on Snyder Hill between Sullivan Lake and the Pend Oreille river. The name Kaniksu is taken from the Kaniksu National Forest, a large part of which is underlain by the batholith.

In a regional way the Kaniksu batholith lies between two of the major North American batholiths—the Nelson batholith and the Idaho batholith. The Kaniksu mass has many compositional, textural, and structural features in common with each of the other two and at various times has been mapped as part of either. A reasonable interpretation of the evidence is that the three large intrusive bodies and many of the smaller ones are all parts of one great mass. The Kaniksu batholith, on the basis of hasty reconnaissance, is regarded as continuous with the Bayview granodiorite of Sampson and Gillson [40] and the auxiliary mass of the Nelson batholith described by Kirkham and Ellis [41] and shown on the West Kootenay sheet by McConnell and Brock.[42] Daly [43] described the same mass as the Rykert granite batholith, which has a more prominent gneissic character than the intrusive mass near Metaline. In the Salmo map area, immediately north of Metaline, both Walker [44] and Drysdale [45] consider the scattered bodies of granitic rocks to be offshoots of the larger Nelson batholith to the north. Ross,[46] on the other hand, considers the Kaniksu batholith as part of the larger Idaho batholith to the southeast, although the two masses are not known to be connected.

GENERAL CHARACTER

The Kaniksu batholith exhibits a wide variety of compositional and textural features. Three dominant facies prevail, not including the border facies. These are the biotite facies, the porphyritic facies, and the muscovite facies.

The biotite facies is probably the most abundant rock in the intrusive mass. It is commonly a light-gray or pinkish-gray massive crystalline rock in which individual mineral grains are from one-eighth to one-half an inch in longest dimension. Mineral alinement is well shown in a few places but is ordinarily vague. Quartz and two varieties of feldspar, one pink and one white, make up about 80 to 90 percent of the rock. The remainder is mostly biotite, but rarely, as on Molybdenite Mountain, hornblende is found, and sphene can generally be seen.

The porphyritic type of rock is characterized by the presence of pink feldspar crystals, commonly less than an inch in longest dimension, although crystals as much as 3 inches long have been noted. These phenocrysts form generally only a small proportion of the rock, but exceptionally they make up 20 percent or more. The boundaries of many of the crystals are indistinct (see pl. 12, *A*), but others are sharp and are coated with biotite flakes whose basal cleavages are parallel to the feldspar boundaries. Small flakes of biotite and grains of quartz and white feldspar are commonly recognized in the phenocrysts. The groundmass is similar to the biotite facies of the rock. Transitional types, rather than sharp contacts, separate the porphyritic facies from the biotite facies. In several places in the field the white feldspars are coarse and the pink ones are smaller. This particular porphyritic variety is unusual, however, and its field relations are obscure.

The muscovite-bearing rock is an unusual facies that underlies several square miles near Granite Peak and in the valley of the South Fork of Lost Creek. It is recognized also in smaller masses throughout the part of the batholith studied. Texturally the rock is similar to the biotite facies, but in places the feldspars are large and the rock seems to grade into typical pegmatite. Elsewhere the rock is cut by sharply bounded pegmatite dikes in which the mineral constituents appear to be the same as in the surrounding rock. In a few places, particularly northwest of Ione, a strong gneissic structure is apparent. The minerals usually recognized in the hand specimens are quartz, white feldspar, and, rarely, spots of pinkish feldspar, muscovite, and tiny red garnets. (See pl. 12, *B*.) A few of the garnets are relatively large, and crystals as much as half an inch in diameter have been seen. A subgraphic

[40] Gillson, J. L., Granodiorites in the Pend Oreille district of northern Idaho: Jour. Geology, vol. 35, pp. 1–31, 1927. Sampson, Edward, Geology and silver ore deposits of the Pend Oreille district, Idaho: Idaho Bureau Mines and Geology Pamph. 31, pp. 10–11, 1928. Stewart, C. A., A comparison of the Coeur d'Alene monzonite with other plutonic rocks of Idaho: Jour. Geology, vol. 22, pp. 684–688, 1914. Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, pp. 43–46, 1909.

[41] Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bureau Mines and Geology Bull. 10, pp. 35–36, 1926.

[42] McConnell, R. G., and Brock, R. W., West Kootenay sheet, No. 792, Canada Geol. Survey, 1904.

[43] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 284–289, 1912.

[44] Walker, J. F., Geology and mineral deposits of the Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 13–17, 1934.

[45] Drysdale, C. W., Ymir Mining camp, B. C.: Canada Geol. Survey Mem. 94, pp. 33–38, 1917.

[46] Ross, C. P., Some features of the Idaho batholith: 16th Internatl. Geol. Cong. Rept., pp. 369–385, 1936; Mesozoic and Tertiary granitic rocks in Idaho: Jour. Geology, vol. 26, pp. 673–693.

pattern between the feldspar and quartz is commonly developed.

The bodies of muscovite-bearing intrusive rock have vague boundaries where they grade into the more normal biotite type. Their obvious pegmatitic nature is somewhat unusual in large irregular masses, although similar bodies are reported from the Buffalo Hump quadrangle, in north-central Idaho, where Reed[47] thinks they are associated with zones of shearing. The reasonable suggestion has been made that pressure and ease of escape of fluids along joint systems are controlling features in the formation of pegmatites.[48] It is likely that an unusual set of conditions has given rise to the large masses of pegmatitic type, not apparently related to intrusive borders.

PETROGRAPHY

Microscopic examination of the intrusive mass shows it to be predominantly a quartz monzonite that grades into granodiorite, but smaller patches of other rock types are present. The composition agrees closely with that of both the Nelson and Idaho batholiths, so far as is known. Drysdale[49] described the Nelson batholith near Ymir, B. C., as most commonly a grandiorite but ranging from a granite to a diorite and more mafic types. Walker[50] described the Nelson batholith in the Salmo map area as commonly a medium- to coarse-grained light-colored, generally porphyritic granite, but bodies of granite, aplite, granodiorite, quartz diorite, diorite, syenite, and monzonite were also recognized. Ross[51] concluded that the Idaho batholith is a somewhat calcic quartz monzonite. He says that the plagioclase (generally oligoclase-andesine) is commonly in excess of the potash feldspar, although in places the rock grades into granodiorite or granite. Reed's work[52] indicates that the Idaho batholith is dominantly a quartz monzonite, but other types are recognized, particularly near the borders.

The essential constituents of the biotitic and porphyritic facies are quartz, oligoclase, microcline, orthoclase, and biotite. In places albite, andesine, hornblende, and muscovite are present in different proportions. The recognized accessory minerals are sphene, zircon, apatite, and iron oxides, and small amounts of chlorite, sericite, epidote, clinozoisite, and allanite are widely distributed. Oligoclase and potash feldspar are present, generally in nearly equal amounts; together they make up about 40 to 60 percent of the rock. Locally hornblende is present in place of biotite, and andesine takes the place of the other feldspars. In some specimens the plagioclase is zoned from andesine or andesine-oligoclase centers to oligoclase borders. A little albite is present in most samples as small spots or in cracks in other feldspars. Potash feldspar is rarely present to the exclusion of plagioclase, but in some material it is the principal feldspar.

The microcline phenocrysts are thought to have developed late in the formation of the intrusive mass by replacement of earlier constituents, but before the formation of the muscovite-garnet facies. This belief is supported by the fact that many phenocrysts contain ragged remnants of other minerals, principally quartz, feldspar, and biotite, that in places are continuous into the groundmass. The microcline is generally clean and fresh in appearance, even where other feldspars, except albite, are dusty. Contacts of microcline with other feldspars and quartz commonly have a worm-eaten appearance (myrmekite).

The essential constituents in the muscovite facies are quartz, microcline, albite, oligoclase or andesine, and muscovite. Garnet and in places epidote are abundant accessories, and a few grains of tourmaline can generally be seen; pink zoisite (thulite) was found at several places. This rock type appears to grade into the biotite facies. The muscovite-bearing rock is thought to have been formed from the biotitic rocks by late magmatic fluids after crystallization was well advanced[53] (deuteric). Evidence for the alteration of biotite to muscovite is shown in plate 13, *A*, where a small remnant of biotite, oriented the same as the main biotite crystal, can be seen in the muscovite, and the west border of the biotite approximately coincides with the west border of the muscovite. The narrow ragged contact zone between the two minerals is absent in some specimens, and the contacts are sharp. Many muscovite grains contain opaque inclusions oriented along cleavage surfaces; such inclusions are not conclusive evidence of the formation of muscovite from biotite, but they are suggestive. The white feldspars the mainly albite and microcline. A few of the white microcline crystals grade to pinkish microcline in the centers of the grains. In the crosscutting sharp-walled pegmatites the few feldspars examined are principally albite, but some andesine and oligoclase were recognized.

BORDER FACIES

The borders of the batholith are generally finer-grained and darker than the interior of the mass, and foliation is customarily developed. The coarse porphyritic type of rock is absent, although it is not un-

[47] Reed, J. C., personal communication, March 14, 1938.

[48] Grout, F. F., and others, Problems of the batholith, Nat. Research Council, April 22, 1933.

[49] Drysdale, C. W., Ymir mining camp, B. C.: Canada Geol. Survey Mem. 94, pp. 33–36, 1917.

[50] Walker, J. F., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 3, 13–17, 1934.

[51] Ross, C. P., Some features of the Idaho batholith: 16th Internat. Geol. Cong. Rept., pp. 373–374, 1936.

[52] Reed, J. C., Geology and ore deposits of the Florence mining district, Idaho: Idaho Bur. Mines and Geology Pamph. 46, p. 8, 1939.

[53] Harker, A., The natural history of the igneous rocks, pp. 293, 323, New York, 1909.

common to find crystals a quarter of an inch in longest dimension set in a finer-grained groundmass. In many exposures, such as those on Cedar Creek and Jim Creek northwest of Ione, the contacts are sharp and the borders of the intrusive are clearly defined. (See fig. 5.) In other places, such as Indian Mountain, Timber Mountain, and the southeast corner of the quadrangle, the dark border phase of the intrusive appears to grade, without a sharp break, into metamorphosed crystalline sedimentary beds.

Microscopically the border facies is more mafic than the interior of the mass. Quartz decreases in quantity, and the larger feldspars are generally andesine, although albite and potash feldspars are common in the finer-grained rocks. Green hornblende, in places with

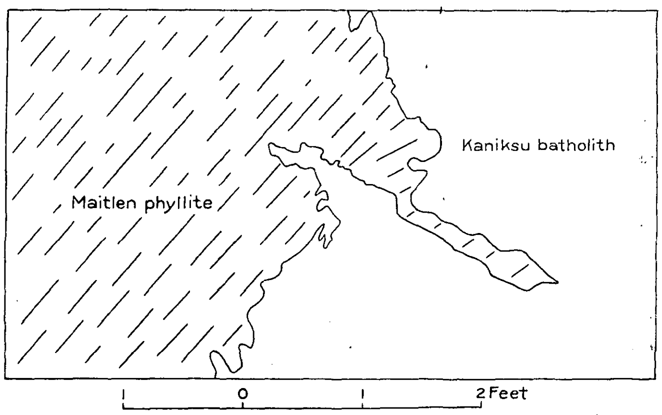


FIGURE 5.—Sketch of contact between Kaniksu batholith and Maitlen phyllite in sec. 11, T. 38 N., R. 42 E. The intrusive cuts sharply across the foliation in the phyllite.

many opaque inclusions (schiller structure), is generally present in appreciable amounts, although in places biotite is the dominant dark mineral. In some specimens the dark minerals constitute 50 percent or more of the rock. Epidote, chlorite, allanite, and clinozoisite are present in small quantities and rarely make up an appreciable proportion of the rock.

AGE

The age of the Kaniksu batholith is uncertain, but the best available evidence seems to point to a Cretaceous, possibly late Cretaceous age. This evidence is based on the assumption that the Kaniksu batholith was intruded at the same time as the Nelson batholith and the Idaho batholith. Walker [54] calls the Nelson batholith post-Triassic and Rice [55] says that the Nelson batholith was probably intruded at some time between the late Jurassic and early Tertiary, possibly during the Cretaceous. Cairnes [56] concluded that the Nelson batholith was Cretaceous or late Cretaceous but based this conclusion on the unsupported assumption that the Nelson batholith came from the same magma source as the Coast Range batholith, of Jurassic age, and as the Nelson batholith is the more siliceous it must, therefore, be later.

Ross [57] summarized the evidence of the age of the Idaho batholith in 1933. He said: "The intrusion of the Idaho batholith * * * could have taken place as recently as Eocene * * * and can hardly have occurred before the Jurassic period." Reed,[58] from a determination of the age of pitchblende obtained in the Idaho batholith at Warren, Idaho, concluded that the age in that region was probably Upper Cretaceous. Tertiary (Miocene and Oligocene?) deposits are reported by both Pardee [59] and Ross [60] to overlie the eroded surface of the Idaho batholith. Lindgren's suggestion of an eastward migration of intrusive activity [61] cannot be summarily dismissed and has much to commend it.

MINOR INTRUSIVE BODIES

GRANITIC MASSES

Small masses of granitic rocks which in physical properties and mineral composition are comparable to the border facies of the Kaniksu batholith are found at several places. Two such bodies occur in the northwest corner of the area, and small exposures of similar rocks are present on Noisy Creek and west of the Flume Creek fault north of Lost Lake. Small granitic masses are particularly abundant in the Maitlen phyllite between Sullivan Lake and the Pend Oreille Valley. Other bodies of similar rocks are common at places near the border of the Kaniksu batholith and have been seen in the Priest River group away from the main intrusion.

The bodies of granitic rocks are generally tabular and sill-like. They appear to be concordant with either the dominant foliation or the bedding.

The rocks are customarily although not everywhere porphyritic. The phenocrysts consist of feldspar, quartz, hornblende, and biotite and are commonly corroded and embedded in a fine-grained matrix, which consists mainly of quartz, orthoclase, and albite, with tiny needles of hornblende and flakes of biotite. The accessory minerals are zircon, sphene, apatite, and iron oxides. Chlorite, epidote, zoisite, calcite, and particularly sericite are common. The feldspar phenocrysts

[54] Walker, J. F., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, p. 3, 1934.

[55] Rice, H. M. A., Preliminary report, Nelson map area: Canada Geol. Survey paper 37-27, p. 11, 1937.

[56] Cairnes, C. E., Slocan mining camp, B. C.: Canada Geol. Survey Mem. 173, pp. 61-75, 1934.

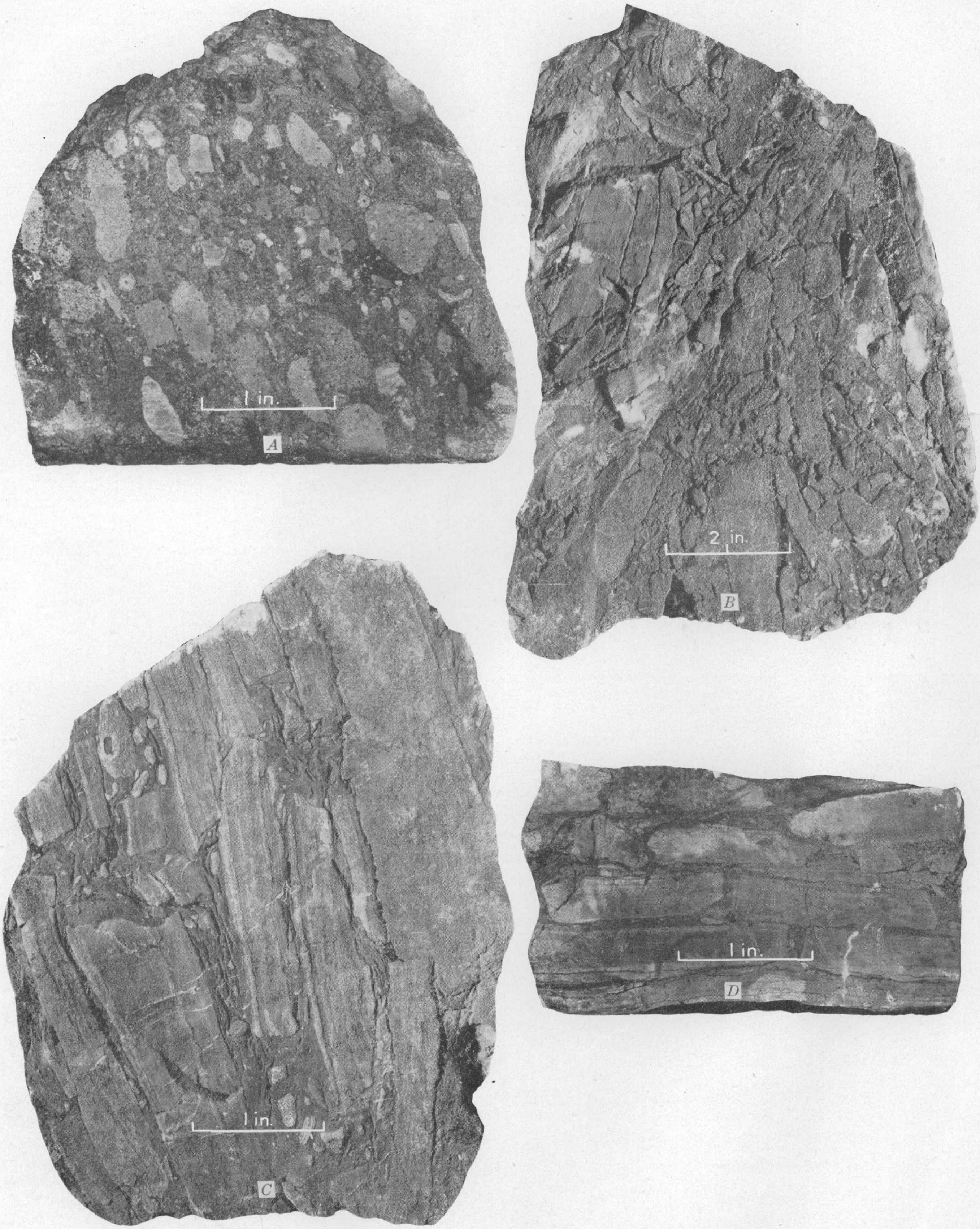
[57] Ross, C. P., Some features of the Idaho batholith: 16th Internat. Geol. Cong. Rept., p. 383, 1936.

[58] Reed, J. C., Geology and ore deposits of the Warren mining district, Idaho County, Idaho: Idaho Bur. Mines and Geology Pamph. 45, p. 8, 1937.

[59] Pardee, J. T., and Bryan, Kirk, Geology of the Latah formation in relation to the lavas of the Columbia River Plateau near Spokane, Wash.: U. S. Geol. Survey Prof. Paper 140-A, pp. 1-16, 1926.

[60] Ross, C. P., op. cit., p. 382.

[61] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems: Problems of American geology, pp. 234-286, 1915.



A. DEVONIAN LIMESTONE BRECCIA, NORTHWEST CORNER OF SEC. 15, T. 40 N., R. 43 E.

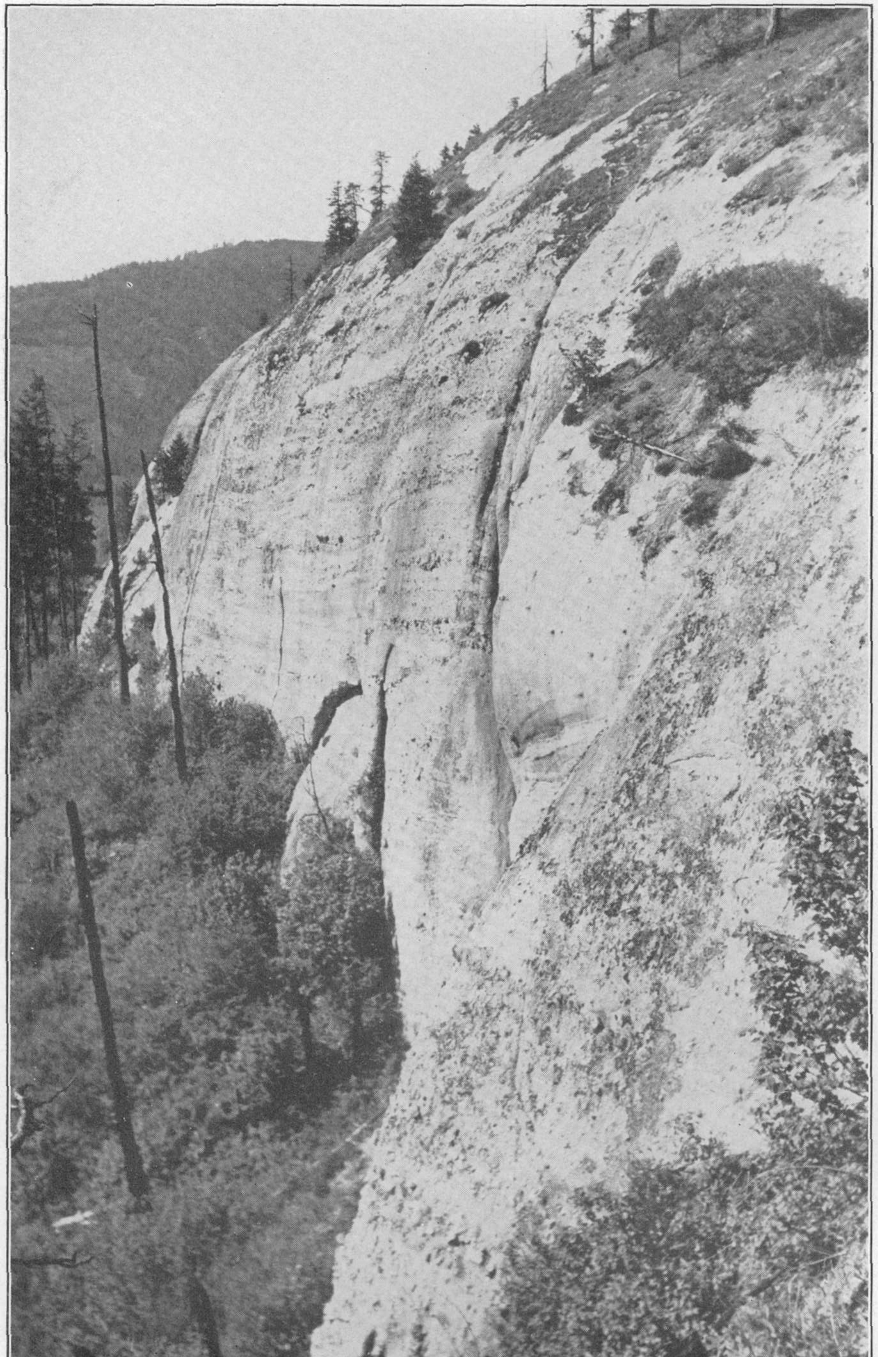
B. INTRAFORMATIONAL DOLOMITE BRECCIA, ROAD CUT IN SW¼ SEC. 11, T. 40 N., R. 42 E.

C. INTRAFORMATIONAL DOLOMITE BRECCIA.

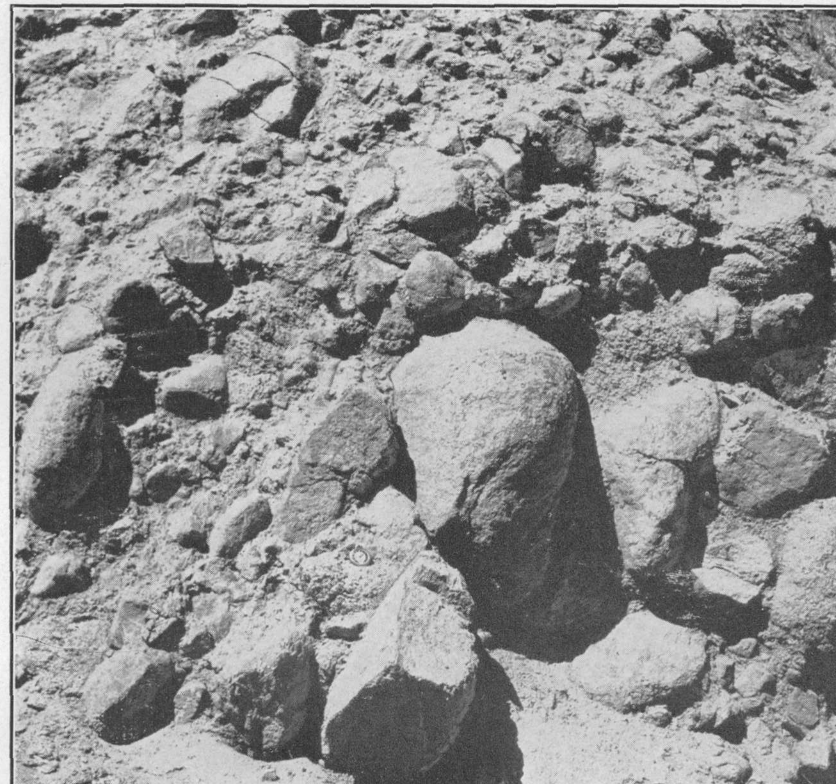
Eighty feet east of outcrop shown in *B*.

D. THIN-BEDDED DOLOMITE WITH DESICCATION CRACKS.

Ten feet east of outcrop shown in *C*.

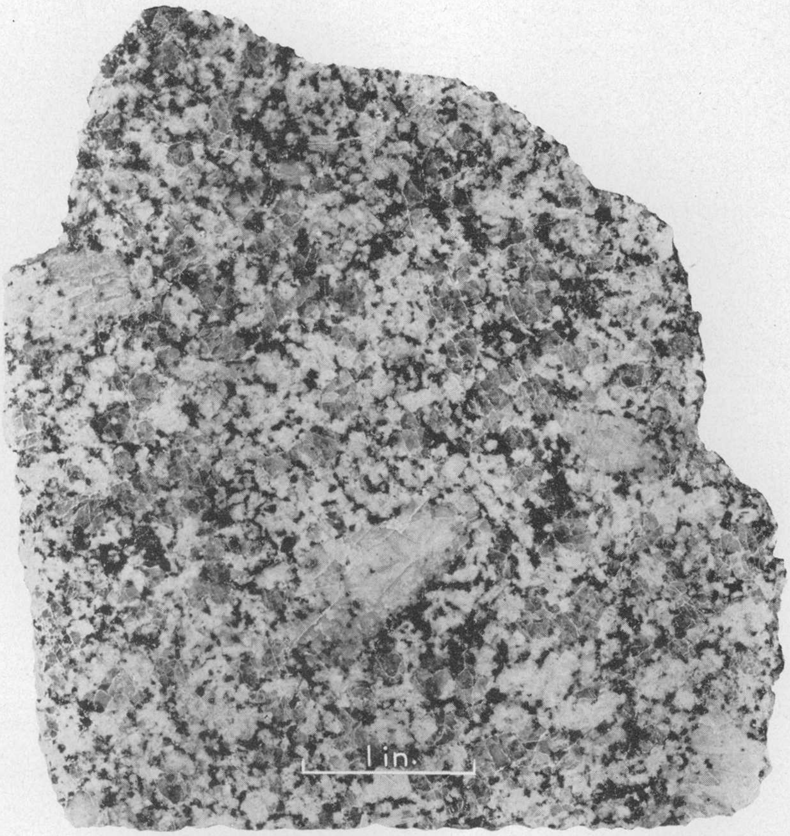


A. CLIFF OF POORLY SORTED TERTIARY SEDIMENTARY BEDS, CENTER OF SEC. 16, T. 36 N., R. 43 E.



B. TERTIARY SEDIMENTARY DEBRIS, SOUTH CENTER OF SEC. 16, T. 36 N., R. 43 E.

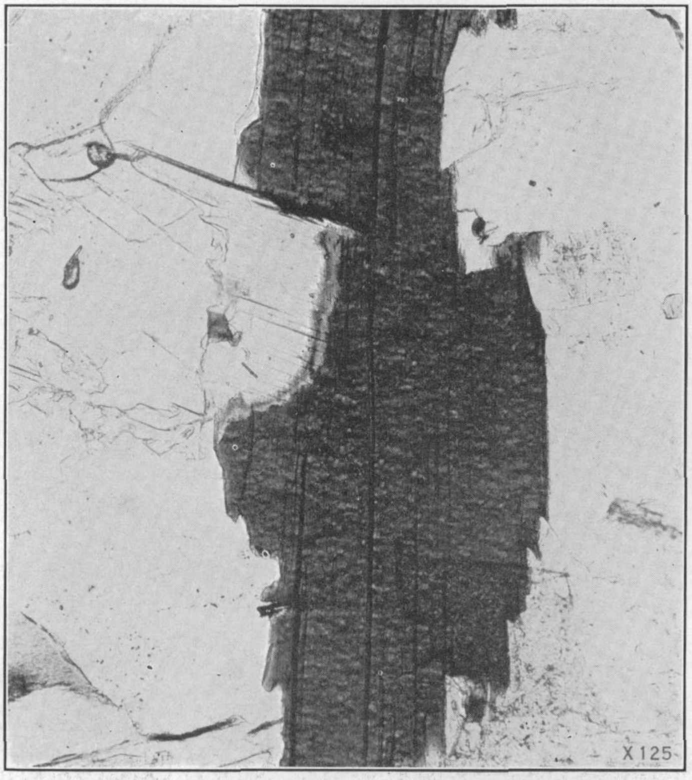
Watch in lower center indicates scale.



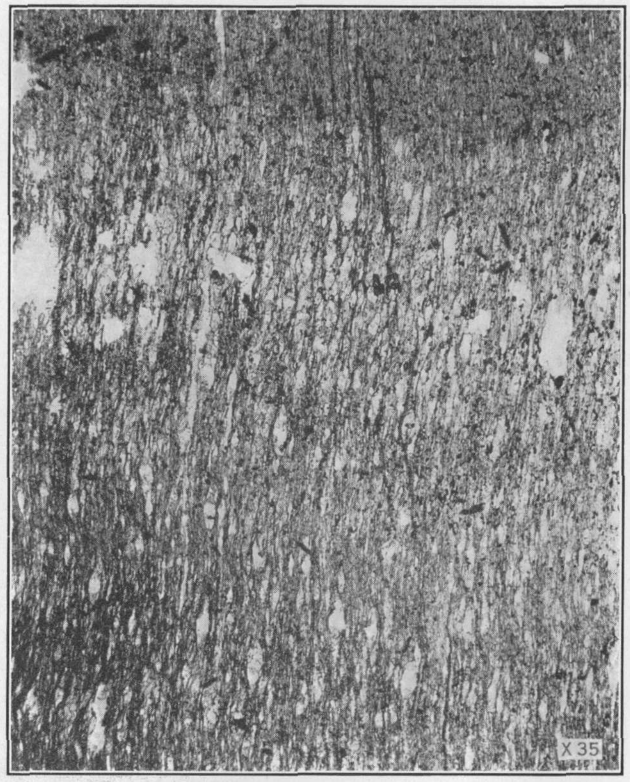
A. POLISHED SLAB OF PORPHYRITIC FACIES OF THE KANIKSU BATHOLITH, SOUTH CENTER OF SEC. 21, T. 35 N., R. 45 E.

B. MUSCOVITE-GARNET FACIES OF THE KANIKSU BATHOLITH, CENTER OF SEC. 1, T. 36 N., R. 42 E.

Light gray is feldspar and quartz. Dark gray booklets are muscovite, and tiny dark spots are garnets.



A. PHOTOMICROGRAPH OF A THIN SECTION FROM GRANITE PEAK LOOKOUT, INTERPRETED AS SHOWING BIOTITE ALTERED TO MUSCOVITE.

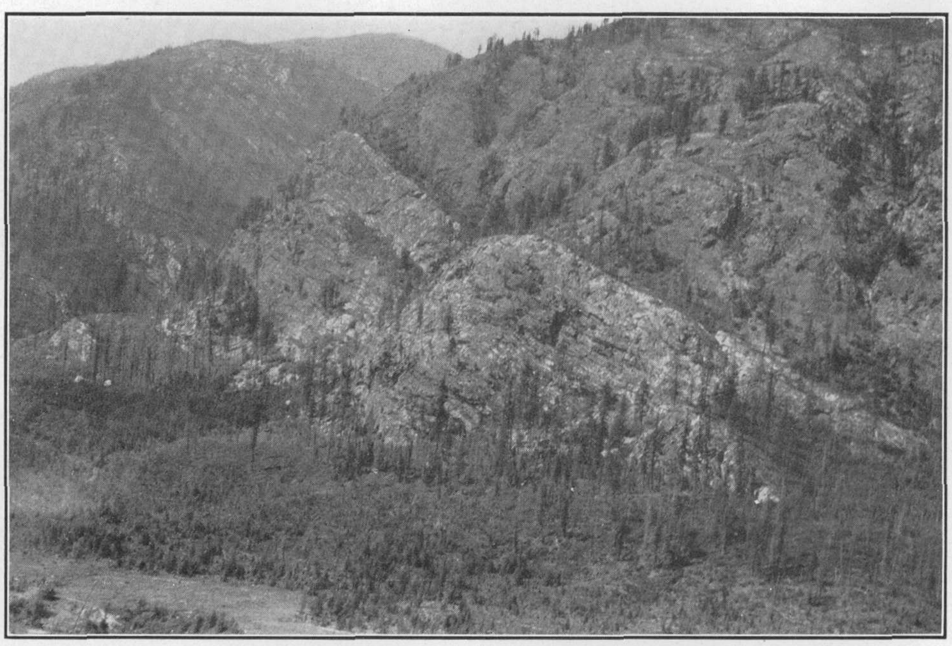


B. DIKELET IN PHYLLITE, SOUTHEAST CORNER OF SEC. 4, T. 38 N., R. 42 E.

On Hall Mountain trail from Harvey Creek, altitude 4,000 feet. Note lack of micaceous minerals parallel to bedding.

C. PHOTOMICROGRAPH OF THIN SECTION SHOWING SHEARING NEARLY NORMAL TO BEDDING.

Feldspar on borders and quartz, tourmaline, and muscovite in the center. Natural size.



D. GYPSY QUARTZITE WEST OF FLUME CREEK FAULT.

View southwestward from a dolomite knob at the Josephine workings of the Pend Oreille mine. Flume Creek fault passes through the lowlands in the foreground.

identified include andesine or more sodic plagioclase, microcline, and orthoclase.

Feldspar

PEGMATITE BODIES

Pegmatite dikes and irregular-shaped masses, other than the muscovite facies of the batholith, are widely distributed through the batholith and to a less extent in the more intensely metamorphosed sedimentary rocks.

A poorly exposed pegmatite body was seen in the metamorphosed dolomite of the Monk formation near the O. K. mine. This body is rather fine-grained and contains but few crystals over half an inch in longest dimension. The rock is white or cream-colored except for scattered crystals of black tourmaline and small bright wine-colored garnets. Much of the rock is cut by seams of soapy material which, under the microscope, is found to be montmorillonite. The bulk of the rock consists of feldspar—microcline, orthoclase, and calcic albite—and quartz. Colorless to pale-blue and dark-blue tourmaline, booklets of clear colorless talc, several irregular grains of topaz about 0.5 millimeter long, and a very few tiny shreds of biotite were also recognized.

The pegmatites vary considerably in texture. A few crystals of feldspar as much as 3 or 4 inches on a face were seen, and the grain size grades downward from this maximum. Graphic and subgraphic patterns are common, particulary between feldspar and quartz. An unusual texture in a narrow dike is illustrated in plate 13, B. This dikelet contains feldspar along the borders and quartz, muscovite, and tourmaline in the center. Such a comb structure arrangement in a quartz-carbonate veinlet would generally without hesitation be attributed to deposition from a fluid, and probably in an open cavity. The specimen shown offers rather compelling evidence of the mobility of the parental fluids.

The mineralogy of the pegmatites is simple. Feldspars, quartz, and muscovite greatly predominate, but garnet and tourmaline are generally present. Exceptionally, coarse-grained biotite and green amphibole are found. The feldspars are principally albite, but microcline, andesine, and oligoclase are recognized.

APLITE DIKES

Aplite dikes are widely distributed through the batholith and the larger outlying intrusive bodies such as that south of the Frisco Standard mine. They have not been seen in the adjoining strata except in the highly metamorphosed areas. The aplites are commonly fine-granular buff to whitish rocks; rarely they contain a few scattered feldspar phenocrysts.

In thin sections the aplites are seen to consist largely of feldspar and quartz, with a little muscovite generally present. The feldspars are dominantly orthoclase, but there is a little microcline and albite-oligoclase. A few tiny flakes of biotite and small scattered spots of epidote and pyrite have also been identified.

LAMPROPHYRE AND RELATED DIKES

Dark-colored dikes are widely distributed throughout the sedimentary beds in the northern part of the quadrangle, and a few cut the more silicic intrusive rocks. These dikes vary widely in texture and appearance, although similar in mineral composition. They are generally less than 4 feet thick, and the walls are clean and sharp.

One of the most common types is found in the My Era adit in the east center of sec. 11, T. 40 N, R. 42 E. In hand specimens it is a fine-grained greenish-gray rock and is liberally sprinkled with flakes of biotite as much as a quarter of an inch or more across. Weaver[62] has described this type as minette. In the Lead King diamond-drill cores and on the ridge about 1½ miles south of the peak of Boundary Mountain another type is a fine-grained dark-greenish rock. In some of this material no minerals can be recognized with a hand lens, but in other places tiny flakes of biotite and rounded spots of calcite a quarter of an inch or less across and a radiating fibrous white mineral can be seen. A third type found at the mouth of Slate Creek and in a shallow adit on the lower Dumont property has a fine-grained dark groundmass spotted with many greenish crystals, some as long as a quarter of an inch. These three types are the most common, but all gradations among them are found. A dike near the center of sec. 1, T. 40 N., R. 44 E., is mineralogically similar to the lamprophyres except that it has a granitoid texture and contains about 50 percent of feldspars.

In thin sections the lamprophyres are found to consist of only a few minerals that differ widely in proportions and grain size. In most dikes the groundmass consists of laths of feldspar that with few exceptions are altered to albite[63] and thomsonite, fresh-appearing tiny automorphic augite crystals, magnetite, and biotite; in places chlorite, serpentine, calcite, and epidote are abundant, and small amounts of quartz, apatite, a white micaceous material, and pyrite are found. In several dikes, such as the one in the canyon at the junction of Lunch Creek and Sweet Creek, green hornblende is an abundant constituent. The feldspars determined are albite and labradorite. The larger phenocrysts in the dikes at the mouth of Slate Creek and on the lower Dumont property are olivine largely altered to a mat of serpentine and other minerals.

OTHER DIKE ROCKS

A few dikes that can hardly be classed as lamprophyres or as granitic bodies have been found but have

[62] Weaver, C. E., The mineral resources of Stevens County: Washington Geol. Survey Bull. 20, p. 304, 1920.

[63] Determination checked by F. C. Calkins.

not been mapped. One such mass occurs in the northeast corner of sec. 16, T. 38 N., R. 45 E. This rock is light gray to white and superficially resembles an aplite. Under the microscope it is found to consist almost entirely of sheafs and nodules of radiating thomsonite. A little fine-grained white micaceous mineral, calcite, and a few grains of much-corroded and rounded opalescent quartz were the only other minerals recognized.

STRUCTURE OF THE PRE-TERTIARY SEDIMENTARY AND METAMORPHIC ROCKS

GENERAL FEATURES

The accompanying geologic map (pl. 1) shows most of the structural features that have a prevailing north-northeast trend, although a few faults, such as the Russian Creek fault and the Pass Creek fault zone, strike more nearly east. The structural history is entirely different from that of the eastern Rocky Mountains, where low-angle thrust faults are common.[64] Folding was the earliest recognized type of deformation and was followed by three periods of faulting. Compressive stresses were dominant during folding and some of the folds broke into thrust faults. Later deformation obscured these thrusts, and their extent, therefore, is unknown; however, in general, they seem to be subordinate features. The folding and thrusting were followed by deformation that produced a series of vertical or steeply dipping faults, which may be attributed either to compression or to tension—the elevation of the footwall or the depression of the hanging wall. The last stage of faulting recognized produced faults of northwest trend, typified by the Pass Creek fault zone.

The deformation of the rocks resulted in the development of conspicuous foliation and linear structure, particularly in the schists and phyllites. As used in this report, the term "foliation planes" includes all planar elements except bedding and jointing. In many of the rocks two and in some of them three directions of foliation are clearly defined, but only the dominant planes have been recorded. These have a prevailing northeast strike with a steep westward dip, but, particularly west of the Pend Oreille River, considerable variation is found. Mica orientation is generally at an angle to the bedding. (See pl. 13, *C*.)

The most constant structural characteristic in the region is the linear structure. The strike is N. 40°–60° E. and the pitch is low, either northeastward or southwestward. The linear structure is defined by the lines of intersection of bedding planes with the axial planes of small folds. The structural features thus defined were established in the same epoch as the folding and are not directly related to the faulting, which they antedated. Other linear structure is evident but is not satisfactorily explainable, and in the field no assurance was felt that the same features were everywhere recognized. For this reason they were not plotted on plate 1.

Gilluly[65] pointed out that linear structure of the type here considered "seems susceptible of only one mechanical interpretation. This is that the lines mark axes along which tension operated during a late stage in the deformation of the rock." Phillips[66] called particular attention to the linear structures in the Moine schist, of the type described here, which are perpendicular to the direction of movement, and contrasted them by means of rock-fabric analyses with grooving or rodding caused by slickensides.

In order to simplify discussion the structure of the quadrangle will be considered in five units, as follows:

1. The Flume Creek-Russian Creek block, bounded on the north by the Russian Creek fault, on the east by the Flume Creek fault, on the south by the Kaniksu batholith, and on the west by the edge of the quadrangle.
2. The valley block, which extends along the Pend Oreille River from the international boundary south to the Kaniksu batholith. On the west it is limited by the Flume Creek-Russian Creek fault block, and on the east the boundary is arbitrarily taken at the top of the Maitlen phyllite. This block, which contains most of the known ore deposits, is depressed about 10,000 feet relative to the adjacent blocks.
3. The Hall Mountain block, defined as the strip between the international boundary on the north and the batholith to the south, bounded on the west by the top of the Maitlen phyllite and on the east by the base of the Monk formation and the Harvey fault.
4. The eastern block, east of the base of the Monk formation and the Harvey fault, bounded on the north and east by the borders of the quadrangle and on the south by the Kaniksu batholith. The outlying bodies of sedimentary and metamorphic rocks surrounded by the batholith are conveniently included here.
5. The Kaniksu batholith, described on pages 24–26.

As the detailed descriptions of these blocks and the interpretations of their origin are necessarily involved, the features of general interest are summarized at the beginning of each description.

FLUME CREEK-RUSSIAN CREEK BLOCK

Nearly the entire area of the Flume Creek-Russian Creek block is underlain by two formations, the Maitlen phyllite and the Gypsy quartzite, with a small

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[64] Clapp, C. H., Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines and Geology Mem. 4, 1932. This pamphlet contains a good discussion and a bibliography on the structure of the Rocky Mountains.

[65] Gilluly, James, Geology and mineral resources of the Baker quadrangle, Oreg.: U. S. Geol. Survey Bull. 879, pp. 68–69, 1937.

[66] Phillips, F. C., A fabric study of some Moine schists and associated rocks: Geol. Soc. London Quart. Jour., vol. 63, pp. 591–594, 1937.

amount of the upper part of the Monk formation exposed along the Flume Creek fault. The rocks are closely folded, on both a large scale and a small scale; the axes of the folds trend about N. 45°–50° E. and are cut off by the great Flume Creek and Russian Creek faults. The somewhat peculiar curved junction of the Flume Creek fault and the Russian Creek fault (see pl. 1), combined with unusually good exposures on the ridges, encouraged a more detailed structural study of this area than was possible for the rest of the quadrangle.

The crest of the highest ridge (Hooknose-Abercrombie ridge) nearly coincides with the medial line of a southwestward-plunging slightly overturned anticline, the Hooknose anticline. (See pl. 1.) The axial plane of this fold and the axial planes of the small satellitic folds dip about 80° SE., which agrees in general with Walker's observations north of the Canadian border.[67] Northeast of Hooknose the anticlinal structure is difficult to recognize, and the beds toward the Flume Creek and Russian Creek faults are steep to vertical. Near the faults the quartzite is brecciated and the phyllite is contorted. The southern part of the Hooknose anticline is complicated by the Ridge fault, but east of the fault there are similar folds, both anticlines and synclines. To judge from the attitude of the small folds the axial planes, with one exception, dip steeply eastward. The Gypsy quartzite exposed along the Flume Creek fault south of the mouth of the middle fork of Flume Creek terminates at its south end in an abruptly broken fold. The axial plane of this fold cannot be located with certainty but is thought to be nearly vertical or to dip steeply west. The phyllite south and east of the point of the fold in the quartzite is overturned and dips under the quartzite, which near this locality is a breccia. Below the base of the quartzite a thin strip of sandy dolomite and schist typical of the top of the Monk formation on Sullivan Creek is exposed.

The Flume Creek fault and the Russian Creek fault together constitute one of the most conspicuous and impressive features in the entire region. Plate 13, *D*, is a view southwestward from a dolomite knob west of the Pend Oreille mine, across the Flume Creek fault and nearly along the strike of the quartzites. It gives a vivid picture of the magnitude of the fault, which has a known vertical displacement of at least 10,000 feet. The attitude of the Flume Creek fault is unknown, as it is nowhere exposed. The comparatively straight trace of the fault indicates that the dip is steep or vertical, and on the cross sections (pl. 1) it is shown as vertical. The Russian Creek fault is more closely located and appears to dip more than +70° N., as computed from different altitudes along the strike.

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. This is interpreted to mean 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. The attitudes of the linear structures east of the Flume Creek fault are in general obscure.

In the part of the Hooknose anticline near the junction of the Flume Creek fault and the Russian Creek fault some distortion of the linear structures is shown. The Maitlen phyllite on the northwest limb of the anticline thins rapidly from about 1,500 feet on the west to about 300 feet where it disappears under the alluvium on the east. This thinning appears to be due

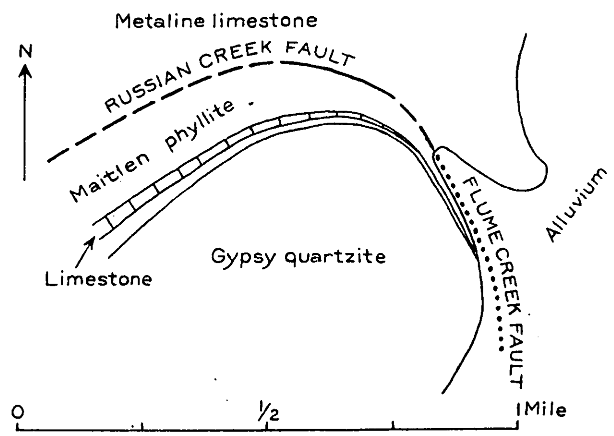

FIGURE 6.—Generalized sketch plan of junction of Flume Creek fault and Russian Creek fault. Shows squeezing and thinning of the phyllite members.

not so much to the cutting out of beds along the fault, although some are cut out, as it is to the squeezing out of individual beds. This squeezing-out process is particularly well shown by the marble layer near the base of the phyllite (see fig. 6); it is probably the result of compression or excessive drag. The rocks in the valley near the fault have been subjected to compressive forces (see pl. 14, *A*), although local compression effects would be expected whether the dominant forces were tensional or compressional.

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.[68] 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

[67] Walker, J. T., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 18–21, 1934.

[68] Nolan, T. B., The Gold Hill mining district, Utah: U. S. Geol. Survey Prof. Paper 177, p. 60, 1935.

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 the 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 trust-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 Ridge fault (see pl. 1) crosses the strike of the bedding at low angles and dips about 60° E., nearly parallel to the dip of the bedding. The fault is not a sharp, well-defined break but is an indefinite zone of intense shearing that grades laterally into less deformed rocks. It cannot be traced northeastward beyond the Flume Creek fault, which probably cuts it off. A bedding fault of this type might be expected in a closely-folded region where the folds have broken during the late stages of the deformation. The Ridge fault is near the thick Gypsy quartzite which would form a rigid buttress and against which the phyllites might readily break and slide. The linear structures on opposite sides of the fault pitch, with a few exceptions, in opposite directions; east of the fault they pitch northeastward, and west of the fault they pitch southwestward. This indicates that the movement on the fault was rotational.

VALLEY BLOCK

In the valley of the Pend Oreille River north of the Kaniksu batholith there is a topographically low area of down-faulted Paleozoic rocks bordered on the east and west by higher areas of Middle Cambrian and older rocks. The structure in the limestones and shales of the valley is exceedingly complex, and the rocks are intricately folded and faulted, both by normal and by reverse faults. Mapping is handicapped by the extensive cover of Tertiary and later formations, but as this block contains most of the known ore deposits it was studied and is described in considerable detail.

The complex structure of the valley block is thought to have resulted from the dropping of a down-pointed wedge between two downward-converging faults, the Flume Creek and Slate Creek faults. As the wedge was lowered normal faults were developed parallel to its sides, and compression against the sides of the wedge was relieved by thrust faulting along the incompetent layers, particularly the Ledbetter slate, and by supplementary tear and transverse faulting. As the wedge was lowered farther the faulting, complicated by folding, continued, and the final result was a complexly deformed and shattered mass.

Jenkins,[69] in his study of the lead deposits of Pend Oreille and Stevens Counties, presented a generalized east-west cross section from Metaline Falls to the valley west of Abercrombie Mountain. He considered the Pend Oreille Valley to be a depressed anticline, bounded on both east and west by normal faults.

The limestones and dolomites generally dip less than 45°—surprisingly little when compared to the older rocks in adjoining blocks. They are, however, intensely brecciated in many areas, and low-angle thrust faults, as well as numerous vertical and normal faults, are recognized, both in the carbonate rocks and in the slates. The slates are generally much contorted and in places are dragged and squeezed along fault zones for hundreds of feet. The contacts between carbonate rocks and slates appear to have been particularly amenable to faulting, and, with few exceptions, the slates near the contacts are reduced to black clay gouge.

The wide exposure of carbonate rocks and slates between Slate Creek and the Pend Oreille River narrows rapidly southward to the mouth of Slate Creek. Considered as a unit, this block is a faulted anticline plunging southward or southwestward. A fault that brings up the phyllite of Boundary Mountain on the west coincides with the Styx Creek Valley and, farther south, with the axis of the fold. The fold axis also seems to merge into a fault exposed in Dumont's lower group of claims, in sec. 30, T. 40 N., R. 44 E., and at the mouth of Slate Creek, where the fault is vertical.

[69] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Cons. and Devel., Div. Geology, Bull. 31, p. 32, 1924.

East of Styx Creek the dolomite dips 45° to 50° E. It is overlain by the much sheared and contorted slate band along the west side of the Slate Creek fault. This slate band, judged by an apparent repetition of its black quartzite member, is thought to be a tightly folded syncline (see section *D–D′*, pl. 1), which can be traced southwestward along the strike as far as Uncas Gulch. Southwest of Uncas Gulch the structure in the slate is obscure. The dip is generally to the southeast, and the slate is thought to be separated from the Metaline limestone by a low-angle thrust that dips southeastward. (See pl. 1.) West of Styx Creek the dip ranges from 10° to 35° W., but the rocks are probably repeated along northeastward-trending faults. The slate west of this anticline forms a syncline that is well exposed in Z Canyon. (See section *C–C′*, pl. 1.) Both the north and south contacts of the slate in Z Canyon are thought to be faults; the northern fault is vertical, and the southern fault, where exposed in the east bank of the river, dips 80°–85° S. The synclinal axis plunges at a steep angle to the west; on the hill east of Z Canyon diamond drilling has failed to show slate in place. Westward the block of Devonian limestone in sec. 16, T. 40 N., R. 43 E., is probably on the trend of the fold. West of the Devonian limestone the syncline is cut off by the Flume Creek fault, which here brings the Cambrian Gypsy quartzite against Devonian limestone. In sec. 29, T. 40 N., R. 43 E., just east of the junction of the Ridge fault and the Flume Creek fault, the synclinal nature of the slate block is again evident. A thin layer of Metaline limestone is exposed along the valley east of Flume Creek. It dips about 20° E., under the slate. On the east side of this slate, near the Lead King and Giant properties, the dips are 30°–40° W. South of Ledbetter Lake the syncline, although it may persist, cannot be recognized.

The slates and limestones north of the Russian Creek fault are structurally part of the terrain to the north and west. They appear to be compressed into a rather open syncline, the axis of which trends about N. 60° E. Knowledge of this structure is meager, and additional work in adjacent areas is needed. Within about 100 to 200 feet of the Russian Creek fault, particularly near the junction with the Flume Creek fault, the rocks are much distorted. (See pl. 14, *A*.)

The Ledbetter slate is well exposed in the canyon at the junction of Slate Creek and the Pend Oreille River. The north contact of this slate and the carbonate rocks is exposed on the north bank of Slate Creek and at the R. E. Lee property, west of the river. Both of these contacts are nearly vertical faults. The south contact of the slate dips about 35° S. under the Metaline limestone. This contact is shown in plate 14, *B*.

The carbonate rocks that are thrust over the Ledbetter slate form a block about a mile across. At only one place in this carbonate block has bedding been recognized; most of the rock is completely shattered. The south side of the thrust block is a nearly vertical fault that is poorly exposed in the river gorge. (See cross section *C–C′*, pl. 1.) The west side of the carbonate thrust block is not exposed and is assumed to be a fault hidden beneath the alluvium near Ledbetter Lake.

A similar but probably larger block of Metaline limestone thrust over the Ledbetter slate is thought to extend from a point north of Metaline Falls southward nearly to the mouth of Wolf Creek. At the base of Washington Rock, in the river valley just south of Metaline Falls, is a small exposure of slate, and north of the falls similar graptolite-bearing slate is exposed at low water on both banks of the river. (See pl. 14, *C*.) At the bottom of the Metaline shaft (150 feet deep) diamond-drill holes directed under the river showed nothing but black slate. The outline of this thrust block is vague because of the thick cover of alluvial material. Extensive diamond drilling at the Pend Oreille mine shows no evidence of slate in depth, and it is probable that the fault surface below the thrust block is concealed below the overburden south of Flume Creek. The eastern and western limits of the thrust block are also hidden under terrace deposits. The eastern limit is thought to be cut off by the southern continuation of the Slate Creek fault; the western limit is assumed to be the fault which, farther south, is known to lie between the old Bella May and the Bluebucket workings. The new Bella May adit south of Metaline and several nearby diamond-drill holes furnish most of the information in the southern part of the thrust block. A fault that dips 45° W. was cut in this adit at about 2,500 feet. (See pl. 30.) On plate 1 this fault is connected with the Slate Creek fault, although the main Slate Creek fault may be under the alluvium farther east. The fault in the adit is normal, with downthrow to the west, and brings Ledbetter slate against Metaline limestone. Overlying this slate is a thrust plate of Metaline limestone exposed in the mine workings and in drill cores. The western limit of this thrust block is along an eastward-dipping fault that lies in the valley east of the old Bella May workings. The thrust block here is seen to be wedge-shaped and is bounded on both the east and the west by normal faults.

The structure south of the new Bella May adit is almost entirely conjectural, owing to poor exposures. A cross fault that extends up Wolf Creek is inferred to explain the apparently uniform slate block south of the thrust block. This fault can be picked up in Wolf Creek where the limestone-phyllite contact is offset. South of Wolf Creek, on the east side of the river, a fault whose dip is unknown brings the slate against the sheared Metaline limestone and, at one place about a mile south of Sand Creek, brings the slate and Maitlen phyllite into contact.

An unusual type of movement for which an adequate explanation is lacking has occurred in the dolomite just north of the slate exposure below Metaline Falls on the west bank of the river. This movement consisted of the formation of low-angle normal faults offset along steeper reverse faults. (See fig. 7.) It can be explained tentatively either as the result of rotational normal faulting or as an unusual expression of tension stresses followed by compression.

The valley block is arbitrarily limited on the east by the top of the Maitlen phyllite, which for much of its trend coincides with the Slate Creek fault. The Slate Creek fault can be traced from the international boundary southwestward nearly to the Grandview mine, where it is concealed beneath alluvium. It is thought to continue farther south and to be an eastern limit to the thrust block of limestone south of Metaline Falls.

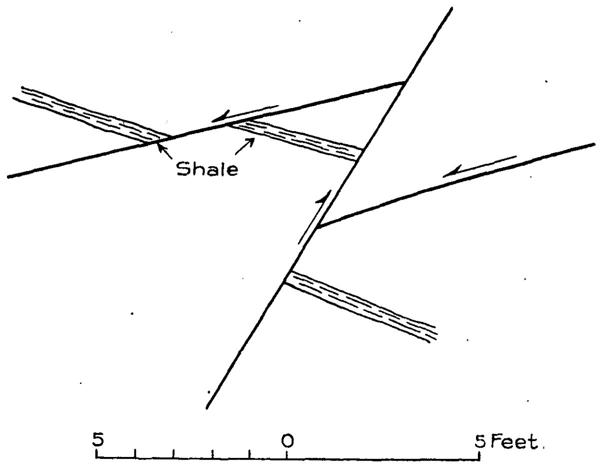

FIGURE 7.—Simplified sketch showing type of movement on small faults in thrust plate of Metaline limestone in Pend Oreille River gorge north of Metaline Falls. Vertical section.

A fault that dips about 45° W. is exposed in the new Bella May adit and may be the southern continuation of the Slate Creek fault. North of Uncas Gulch the trace of the Slate Creek fault has a nearly straight course and therefore is nearly vertical, though it may dip steeply westward. The Ledbetter slate is faulted against the Maitlen phyllite, and on the poorly exposed slopes these two formations are difficult to distinguish. Near Uncas Gulch the exposures are unusually poor and the details of the structure are not known. A cross fault along Uncas Gulch is inferred to offset the Slate Creek fault, as the formations on opposite sides of the gulch do not match. This Uncas Gulch fault probably persists into the Gypsy quartzite to the east, as an offset is indicated on the phyllite-quartzite contact. South of Uncas Gulch the Slate Creek fault is thought to continue southwestward between the Metaline limestone and the Maitlen phyllite. Its course indicates a steeply dipping or vertical fault.

HALL MOUNTAIN BLOCK

The Hall Mountain block of steeply dipping beds has its structure dominated by the thick series of Gypsy quartzite. In the valley of the south fork of the Salmo River, near the international boundary, the quartzite is nearly vertical or dips more than 70° W. Toward the south the westward dip persists but gradually decreases; on Gypsy Peak it is about 60° W., on Crowell Peak about 50° W., and on Sullivan Mountain only about 35° W. The dips in the phyllite above the quartzite and in the schistose Monk formation below the quartzite are erratic. In general they nearly parallel the quartzite, but local reversals are common, and much of the Monk formation southeast of Salmo Mountain dips eastward. Crenulations and small folds are abundant in both the phyllite and the Monk.

The rather simple monoclinal structure that persists from the north boundary of the quadrangle to Sullivan Mountain is cut farther south by a series of fractures of the Pass Creek fault zone and the Johns Creek fault. The Pass Creek fault zone is about 1 mile wide and cuts across all other structural features. The fault surfaces are rarely exposed, but the evidence indicates a steep north dip. The Johns Creek fault cuts off the Hall Mountain anticline and the Harvey fault, but it is not exposed, and its attitude is unknown. It is inferred from the much brecciated rocks along the valley, from the omission of much of the Gypsy quartzite and Monk formation, and from the offset in the Shedroof conglomerate to the east.

Hall Mountain is apparently the nose of an anticline that pitches southwestward. The pitch of linear structures and subsidiary folds is between 15° and 45° SW. The axial plane of the major fold coincides approximately with the fault that trends N. 55° E. across the saddle northwest of the Hall Mountain fire lookout. The attitude of the bedding in the phyllite south and west of Hall Mountain suggests that the fold is slightly overturned to the east. The Hall Mountain anticline resembles the anticline west of Lost Lake in that the quartzite is thoroughly shattered and brecciated, so that the bedding, although locally recognizable, cannot be followed. Also, the pattern of the quartzite in each fold is hook-shaped, with the short east limb abutting against a fault. In neither fold is it entirely clear whether the anticlinal structure is genetically related to the fault or, like the Hooknose anticline, essentially a product of regional folding. The uniform homoclinal structure east of the Gypsy quartzite north of the Pass Creek fault zone indicates that the Hall Mountain anticlinal axis did not continue northward beyond the fault zone and implies that the quartzite must have continued southward from its termination east of Hall Mountain. This continuation of the quartzite south of Hall Mountain is presumably cut out by the Harvey fault.

The Hall Mountain anticline is reflected also in the outcrop pattern of the Maitlen phyllite, although not suggested clearly by the records of foliation and bedding shown on plate 1. This is not surprising, however, as the phyllites are distorted and recrystallized. Bedding can be recognized only locally; it is commonly obscured by shear banding (see pl. 6, *D*) with which it can be easily confused. In addition, the evidence seems to indicate two epochs of deformation, each relieved by movement on a set of shear planes. Figure 4 is a sketch of folded and sheared foliation. In places where the late deformation is weak, bedding can be recognized; elsewhere the younger shear planes shown in figure 4 are spaced so closely as to obscure all earlier structure. The strike of the younger shear planes is nearly parallel to that of the Pass Creek fault zone, and their average dip is 55° NE. The offsets of bedding and foliation on these shear planes are generally in the same direction as the offset of the top of the Gypsy quartzite by the Pass Creek fault zone at the north end of Sullivan Lake.

The Harvey fault is one of the major structural breaks in the district. It is exposed on the west slope of Molybdenite Mountain, south of Harvey Creek, where the dip is 44° W. At this point the fault is marked by a zone of schist and elliptical fragments about 300 feet wide. Throughout the length of the fault the dip is westward, as shown by differences in altitude along the strike. The west side is down relative to the east side, but the exact amount of offset is difficult to estimate; it is probably a maximum of about 15,000 feet. The Harvey fault crosses the strike of the formations at small angles and for much of its known extent brings Maitlen phyllite against greenstone of the Leola volcanics. On Hall Mountain the greenstone was not found, and the phyllite rests directly against the Shedroof conglomerate. Northward the Harvey fault is apparently cut off by the Johns Creek fault, and it has not been recognized with certainty north of the Johns Creek fault or the Pass Creek fault zone. Northeast of the Pass Creek zone, however, both the greenstone and the Monk formation thin abruptly. This thinning may be explained by a fault concealed beneath the alluvium in the Sullivan Creek Valley and as the valley is approximately parallel to the Harvey fault, the two faults may be related.

The Pass Creek fault zone cannot be traced westward much beyond the upper contact of the Gypsy quartzite. The movement along the zone was apparently taken up by folding and slipping along foliation planes in the phyllite.

EASTERN BLOCK

The eastern block, consisting of the rocks stratigraphically below the base of the Monk formation, has been only superficially studied, and its structure is not known. The rocks are phyllitic and schistose with the exception of a few massive layers, and in many places are intricately folded. The structure is also complicated by the igneous intrusion and its resultant wide hornfels zone.

East of Hall Mountain near the junction of Pass Creek and Sullivan Creek the outcrop pattern of the rocks to the east indicates a broad anticline, which is well shown by the Shedroof conglomerate. The bedding in the conglomerate is indistinct, but foliation planes are conspicuous. In the southeastern part of the fold the foliation planes and the bedding in the underlying limestone are nearly horizontal, but the foliation steepens toward the west. To the east, in secs. 18 and 19, T. 38 N., R. 44 E., the Shedroof conglomerate is cut off by an obscure fault that trends N. 45° E. The fold is further complicated by the Pass Creek fault zone, which trends a little south of east and may approximately follow the outcrop of the axial plane of the fold. From Round Top Lookout greenstone and conglomerate can be followed northeastward until they merge into the main Shedroof conglomerate. It is likely that the exposures northeast of Round Top Mountain are part of the main conglomerate brought up by folding, although this is not definitely known.

The Pass Creek fault zone can be traced eastward to a point within about 2 miles of the intrusive contact and it probably continues farther. One prominent fault in this zone crosses Round Top Mountain just southwest of the peak. The fault surface is not exposed but is marked by a shallow trench more than 50 feet wide. The rocks on opposite sides of this trench do not coincide, and the amount and direction of offset on the fault are unknown.

The Johns Creek fault cannot be traced southeastward beyond the crest of the Hall Mountain ridge, where an intrusive mass is found along its strike. Farther to the southeast, however, the fault probably continues, as shown by an apparent offset in stratigraphic units such as the band of quartzite in sec. 26, T. 38 N., R. 44 E.

About a mile south of Salmo Mountain a northwestward-trending structural feature may be present. Other than an apparent offset in the contacts of the formations and the flattening of the dips, nothing of the nature of the deformation was learned. The fold is shown on section *D–D′* of plate 1 as a shallow syncline similar to some mapped by Walker in the Salmo area, to the north.[70]

Daly [71] and Walker [72] each show a major northwestward-trending fault which if projected should cross the international boundary about 1¾ miles west of the eastern border of the Metaline quadrangle, but care-

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[70] Walker, J. F., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, geologic map No. 2337, 1934.

[71] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, map between longitude 117° and 117°30, 1912.

[72] Walker, J. F., op. cit., p. 20.

ful mapping in the difficultly accessible northeast corner of the quadrangle failed to reveal any evidence of a northwestward-trending fault. Kirkham and Ellis,[73] however, show a fault of similar trend that passes just outside the northeast corner of the Metaline quadrangle.

RELATION OF THE STRUCTURE TO THAT OF SURROUNDING REGIONS

Steeply dipping normal faults have been described from many nearby areas to the north and east, and in the same areas low-angle thrust faults are few.[74] Sampson,[75] in the Pend Oreille district, Idaho, recognized two types of steeply dipping normal faults—(1) post-intrusion faults, and (2) faulting caused by intrusive forces. This distinction is of particular interest, as the Pend Oreille district is on the eastern border of the Bayview granodiorite, which is thought to be the same continuously exposed intrusive mass as the Kaniksu batholith. Anderson,[76] in the Clark Fork district, Idaho, confirmed Sampson's observations, although in this area the great east-west Hope fault has somewhat confused the study.

In the Nelson map area of Canada, where the formations are correlated with those of Metaline, Rice [77] has recently shown steeply dipping normal and reverse faults. In the Cranbrook map area, Rice [78] distinguished two types of deformation—(1) by compressional forces that produced thrust faults and close folds and (2) by tensional forces that produced normal faults of great throw. Walker [79] describes numerous folds in the Salmo map area but found clearly defined faults at only a few places.

Practically no published structural studies have been made in the region west of Metaline. The few reconnaissance surveys indicate mainly that the structure is complex and that both folding and faulting are involved.[80]

[73] Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, pl. 3 and p. 28, 1926.

[74] Schofield, S. J., Geology of Cranbrook map area, B. C.: Canada Geol. Survey Mem. 76, pp. 92–97, 1915. Sampson, Edward, Geology and silver ore deposits of the Pend Oreille districts, Idaho: Idaho Bur. Mines and Geology Pamph. 31, pp. 12–16, 1928. Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, pp. 40–47, 1930. Rice, H. M. A., Preliminary report, Nelson map area, B. C.: Canada Geol. Survey Paper 37–27, 1937. Allan, J. A., Geology of Field map area, B. C. and Alberta: Canada Geol. Survey Mem. 55, pp. 201–203, 1914. Rice, H. M. A., Cranbrook map area, B. C.: Canada Geol. Survey Mem. 207, pp. 27–32, 1937.

[75] Sampson, Edward, op. cit., pp. 12–16.

[76] Anderson, A. L., op. cit., pp. 40–47.

[77] Rice, H. M. A., Preliminary report, Nelson map area, B. C.: Canada Geol. Survey Paper 37–27, 1937.

[78] Rice, H. M. A., Cranbrook map area, B. C.: Canada Geol. Survey Mem. 207, p. 30, 1937.

[79] Walker, J. F., Geology and mineral deposits of Salmo map area, B. C.: Canada Geol. Survey Mem. 172, pp. 18–21, 1934.

[80] Pardee, J. T., Geology and mineral resources of the Colville Indian Reservation, Wash.: U. S. Geol. Survey Bull. 677, pp. 23–24, 1918. Weaver, C. E. The mineral resources of Stevens County, Wash.: Washington Geol. Survey Bull. 20, pp. 52–53, 1920; Geology and ore deposits of the Covada mining district, Wash.: Washington Geol. Survey Bull. 16, pp. 29–31, 1913.

The summation of the structural studies in areas near Metaline emphasizes the need for more detailed work. The papers discussed show an almost uniform agreement as to the presence of folds and steeply dipping faults, but in general no attempts have been made to interpret structural details or to record a comprehensive structural history.

RELATION OF DEFORMATION TO BATHOLITH INTRUSION

Schofield,[81] in the Cranbrook map area, interpreted the faulting to be a direct result of igneous intrusion, but Rice,[82] in a more recent study of the same area, considered the intrusive masses to be later than the faulting. Drysdale [83] thought that the Nelson batholith was emplaced by a combination "of active intrusion and magmatic stoping." His field observations indicated that most instances of the granitic intrusives conform to the structure of the overlying formations but a few are crosscutting.

Sampson,[84] in the Pend Oreille district, Idaho, thought that the grouping of the faults around the intrusive mass indicated that the faults were caused by intrusive forces. Sampson also shows the Bayview granodiorite to be involved in post-intrusion faulting.

Anderson,[85] in the Clark Fork district, Idaho, and Kirkham and Ellis,[86] in Boundary County, Idaho, attributed part of the faulting in these districts to intrusive forces.

A necessary corollary to the theory that the deformation was caused by forces set up by intrusion seems to be that, in general, although not in detail, the intrusive contacts should be concordant with the dominant structure planes in the intruded rock.[87] In the Metaline quadrangle the intrusive contact is only locally concordant, and where the contact crosses the regional northeastward trend the foliation planes abut sharply into the intrusive mass. (See fig. 5.) The folding and the foliation of the metamorphic rocks antedate the intrusion—a conclusion in which most workers in nearby areas concur.

No conclusive evidence of major faulting of the Kaniksu batholith is known near Metaline, although several thin sections show that the intrusive rocks, par-

[81] Schofield, S. J., op. cit.

[82] Rice, H. M. A., Cranbrook map area, B. C.: Canada Geol. Survey Mem. 207, p. 31, 1937.

[83] Drysdale, C. W., Ymir mining camp, B. C.: Canada Geol. Survey Mem. 94, p. 36, 1917.

[84] Sampson, Edward, op. cit., pp. 14–16.

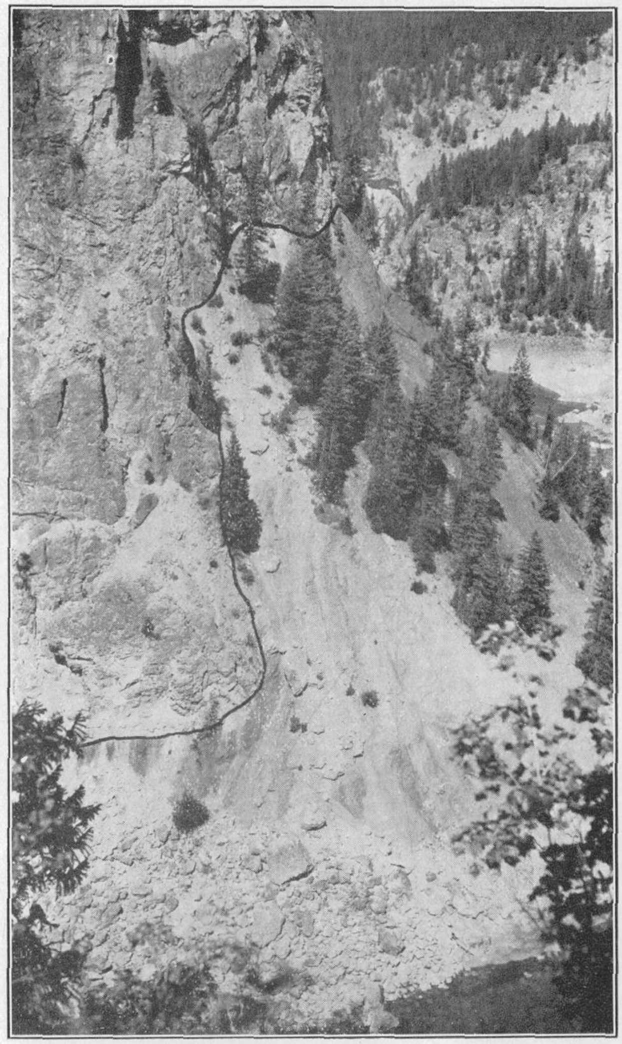
[85] Anderson, A. L., op. cit., pp. 39, 41–42.

[86] Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, p. 29, 1926.

[87] Balk, Robert, Structural behavior of igneous rocks: Geol. Soc. America Mem. 5, pp. 45–95, 1937. Lovering, T. S., and Goddard, E. N., Laramide igneous sequence and differentiation in the Front Range, Colo.: Geol. Soc. America Bull., vol. 49, pp. 38–39, 1938. Cloos, Ernst, The application of recent structural methods in the interpretation of the crystalline rocks of Maryland: Maryland Geol. Survey, vol. 13, pp. 44–47, 79, 1937. Hersey, H. G., Structure and age of the Port Deposit granodiorite complex: Maryland Geol. Survey, vol. 13, pp. 129–130, 1937.

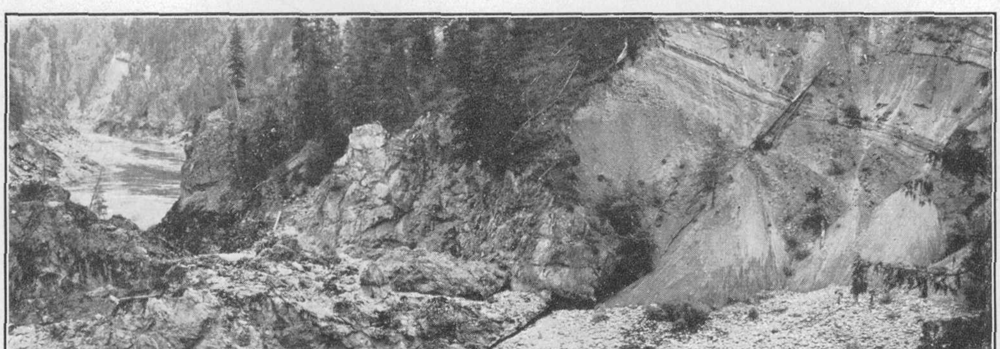
A. TIGHTLY FOLDED METALINE LIMESTONE NEXT TO RUSSIAN CREEK FAULT.

Note thickening of the layers at the crests of the folds.



B. METALINE LIMESTONE THRUST OVER LEDBETTER SLATE.

Line of thrust is shown in black. View west across the Pend Oreille River from the Riverside mine.



C. METALINE LIMESTONE THRUST OVER LEDBETTER SLATE.

Line of thrust is shown in black. River gorge north of Metaline Falls at low water. Terrace deposit at upper right.

ticularly in the muscovite-rich areas, are considerably shattered. Along the Flume Creek fault west of Lost Valley and along the Johns Creek fault southeast of Hall Mountain the batholith may either be faulted or intruded along preexisting or contemporaneous faults. At several places the contact between the intrusive mass and the metamorphic rocks is nearly a straight line. Such a contact is exposed in the hills west of the Pend Oreille River but appears to be without appreciable post-intrusion faulting. Several shorter but similar straight contacts are exposed in the Granite Creek drainage area.

The distribution of the faults, with the possible exception of the Harvey fault, is difficult to attribute to stresses set up by the known masses of intrusive rock. However the distribution of the batholith in surrounding areas is poorly known, and its distribution in depth is largely conjectural. For this reason, any generalizations concerning stresses exerted by the magma are at present little better than opinions. The meager evidence obtained in the Metaline quadrangle indicates, however, that the Kaniksu batholith followed and did not cause the folding.

Another approach to the solution of this problem is the study of linear structure, although in many places the characteristics have been destroyed by igneous metamorphism and the development of hornfels. No comprehensive study of these structural features was made, however, and far too few readings were taken to permit structural conclusions based on them.

DEVELOPMENT OF THE TOPOGRAPHY

The field work for this report was concerned largely with the bedrock geology, although some observations on physiography and glacial geology were recorded. This section is an attempt to present these observations in approximate chronologic order. It should be emphasized, however, that the observations were less numerous and less complete than would be needed for a comprehensive discussion of these subjects.

Land forms in the Metaline quadrangle are largely determined by the resistance to weathering and, to a lesser extent, by the structure of the underlying rocks. The topography has been somewhat modified by activity of the Cordilleran ice cap. In the north it is abrupt, and the mountains are steep and rugged. In the south, on the other hand, the mountains, where underlain by the Kaniksu batholith, are more gently sloping and rounded. No evidence of mature dissected upland surface has been recognized.

The region is drained principally through the Pend Oreille River (Clark Fork), which flows from south to north across the quadrangle.

That the Cordilleran ice sheet covered the entire region except the highest peaks is evident from the widely distributed glacial features. A lobe of the Cordilleran ice advanced southward up the Pend Oreille Valley at two and probably more different stages. According to Alden [88] the earlier ice extended southward beyond Spokane, and the latest ice advanced as far southward as Newport. Daly [89] states that the top of the ice cap was about 6,800 feet above sea level west of the summit of the Nelson (Quartzite) Range and decreased to about 6,500 feet at the Columbia River. This figure appears to be essentially correct, as the highest evidence of glaciation found was a granitic erratic seen on Crowell Ridge at an altitude of about 6,500 feet. The ice sheet, therefore, had a maximum thickness of at least 4,000 feet. Glacial striae were seen on Hall Mountain at 6,100 feet, on Shedroof Mountain at 5,900 feet, and on the spur west of Abercrombie Mountain at 5,900 feet. The altitude of the top of the ice at the south is less definite, but many of the mountains and ridges were probably buried. Flint [90] indicates that at its maximum in the southern part of the Metaline quadrangle the upper surface of the ice was about 4,000 feet above sea level. This figure is low, as erratics are found on Timber Mountain, in the southwest corner of the quadrangle, at an altitude of 4,700 feet. The overriding of the region by southward-moving ice tended to scour the northward- and southward-sloping valleys and to fill in the transverse valleys.

Where the road from Newport enters the broad valley of the Pend Oreille River two well-defined terrace levels are recognized. The altitude of one is 2,100 feet, and that of the other ranges from about 2,500 feet in the south to 2,600 feet in the north. Several other terrace levels were recognized but in general are poorly formed and discontinuous. The two principal levels, at 2,100 feet and 2,500 to 2,600 feet, are shown in plate 15, *A*. Flint [91] describes the 2,100-foot level at Newport as the upper limit of silt deposited in a lake dammed by an ice lobe to the north and by another to the east, and controlled by an outlet at Newport, by way of the Little Spokane River, to the Spokane River. Large [92] earlier had recognized the channel at Newport as the outlet of "glacial Lake Clark" to the north. The 2,100-foot level has not been recognized north of Metaline Falls. So far as the writers know, only casual reference has been made to the high terrace (2,500 to 2,600 feet). This terrace extends along the river valley across the entire quadrangle, although it is poorly defined and indistinct south of Ione. The material in this terrace can be seen at several places in

[88] Alden, W. C., personal communication, 1939.

[89] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, p. 588, 1912.

[90] Flint, R. F., Pleistocene drift border in eastern Washington: Geol. Soc. America Bull., vol. 48, pp. 226–230, 1937.

[91] Flint, R. F., Stratified drift and deglaciation of eastern Washington: Geol. Soc. America Bull., vol. 47, p. 1880, 1936.

[92] Large, T., Drainage changes in northeastern Washington and northern Idaho since extravasation of Columbia basalts: Pan-Am. Geologist, vol. 41, pp. 259–270, 1924.

road cuts south of Metaline and near Metaline Falls. It is generally silt and fine sand except along tributary streams such as Sullivan Creek, Slate Creek, and Flume Creek, where coarse sand, gravel, and cobbles are found. The material is difficult to account for except as a deposit in ponded water. No descriptions of the region to the south nor the available topographic maps indicate a dam high enough to pond water above 2,500 feet.[93]

That glacial Lake Clark drained southward seems likely from the work of Large and Flint and from the flat gradient of the Pend Oreille River south of Ione. Northward between Newport and Ione the river drops 50 feet in 50 miles, or a gradient of only 1 foot to the mile.[94] Many of the tributary streams drain southward, and the topography indicates that the streams were adjusted over a long period to a southward-flowing preglacial drainage. Only in the recently excavated mouths is there a tendency toward a northward swing. The reason for the change in direction of the Pend Oreille drainage is obscure; it may be preglacial stream capture. Large [95] points out the complex history of the large rivers in northeastern Washington, and his caution is timely. On the terrace east of the Grandview mine and next to the highway north from Metaline Falls, the Metaline Mining & Leasing Co. put down a drill hole 434 feet without striking bedrock. This, combined with additional drillholes nearby, indicates a buried channel comparable in depth to the present river channel. A somewhat similar channel is inconclusively indicated along the Flume Creek fault west of the Bella May mine, and several old watercourses filled to an unknown depth can be seen in the limestone east of Z Canyon. It is likely that additional channels, not now known, are buried under the lake deposits. These abandoned channels are probably stream courses carved during preglacial and interglacial time and subsequently filled by debris from overriding ice or lake silts.

Between Ione and Metaline the Pend Oreille River flows through Box Canyon, the first constriction in the channel north of Newport. North of Box Canyon the stream again occupies a wide flat bed for 6 miles to Metaline Falls. At Metaline Falls the river plunges into a series of steep, narrow gorges, that in places are 500 feet or more deep. The wild, turbulent river continues northward across the border into Canada, where it swings abruptly westward and eventually flows into the Columbia. The best known of the gorges is probably that of Z Canyon, where an average discharge of 26,570 second-feet over a period of 24 years (1912–36) [96] flows through a channel reported to be only 18 feet wide. It is inconceivable that such a gorge as that shown in plate 7 ever carried the large volume of water and quantity of debris characteristic of glacial streams. The gorges are certainly later than the terrace, as the banks are commonly capped by the silt of the 2,600-foot level. From the mouth of Sullivan Creek to the Canadian border, a distance of 11 miles, the river drops 225 feet.[97] No evidence of glacial erosion has been seen in this 11 miles of canyon, and it is therefore thought to be largely postglacial.

Although the inner gorge of the river is postglacial, the main valley dates from preglacial time, as indicated by the southward-flowing tributory streams. The remnants of the Tiger formation, of Tertiary age are, so far as known, limited to the valley, and no indication has been found that these remnants were down-faulted in postglacial time. The valley was therefore essentially at its present depth near Ione before deposition of the Tiger formation. Excavation of the valley during Pleistocene time was undoubtedly vigorous in places, but the tremendous amount of debris that has been moved from the valley indicates that huge quantities of actively eroding ice must have been necessary. Large amounts of ice were present, but, as the glaciers were beginning to wane in the Metaline quadrangle, most of the glacial features to the south are depositional rather than erosional. Even in the Metaline area the deposits of silt, some of which may be interglacial, and the preservation of the Tiger formation indicate that ice erosion was insufficient to clean out the valley thoroughly.

Throughout its course north of Ione the Pend Oreille River parallels the Flume Creek fault to the Canadian boundary, where it swings abruptly west more or less parallel to the Russian Creek fault. This parallelism suggests that the course of the river valley is dependent upon the underlying structure, and the valley either follows a narrow down-faulted block or has formed along the Metaline limestone and Ledbetter slate, which are more easily eroded than the other formations.

Terraces that rise gradually upstream are well defined along the sides of most streams tributary to the Pend Oreille Valley. (See pl. 15, *B*.) The number and distribution of these terraces indicate a long, complex physiographic history, the details of which are not known.

The drainage into the river from the east is carried through a few master tributaries, Slate Creek, Sullivan Creek, and LeClerc Creek. These streams, except near the headwaters, flow in V-shaped valleys bordered

[93] Flint, R. F., Stratified drift and deglaciation of eastern Washington: Geol. Soc. America Bull., vol. 47, pp. 1849, 1884, 1936; Pleistocene drift border in eastern Washington: Geol. Soc. America Bull., vol. 48, pp. 203–232, 1937. Alden, W. C., Personal communication, 1937.

[94] Profile surveys in the basin of Clark Fork of Columbia River: U. S. Geol. Survey Water-Supply Paper 346, 1914.

[95] Large, T., Drainage changes in northeastern Washington and northern Idaho since extravasation of Columbia basalts: Pan Am. Geologist, vol. 41, pp. 260–261, 1924.

[96] Grover, N. C., and others, Surface water supply of the United States, 1936, pt. 12: U. S. Geol. Survey Water-Supply Paper 812, p. 95, 1937.

[97] Profile surveys in the basin of Clark Fork of Columbia River: U. S. Geol. Survey Water-Supply Paper 346, 1914.

by terrace deposits. They do not have the round U shape of typical glacial valleys, probably because the southward-moving ice did not appreciably modify the small transverse valleys. In the lower courses of Slate Creek and Sullivan Creek the streams have cut deep, narrow gorges in an attempt to adjust their drainage to the present level of the Pend Oreille River.

The streams tributary to the Pend Oreille from the west are similar to those from the east, although in general they are shorter. The lower parts of the northern tributaries are precipitous; Pewee Falls on Pewee Creek and Corkscrew Falls in the Flume Creek gorge are well-known examples. These falls result from the weak streams failing to cut their channels as rapidly as the Pend Oreille channel was lowered.

In the southern part of the quadrangle the Pend Oreille River has not excavated its channel greatly since Pleistocene time. The result is that the tributary streams such as LeClerc Creek and Ruby Creek have lowered their channels at nearly the same rate as the river and the lower courses of the streams are therefore not precipitous, in marked contrast to the tributaries farther north.

The spurs west of the Pend Oreille River rise steeply at first and then more gently toward the ridge, which, north of Ione, is 4 to 5 miles west of the valley. The ridge culminates in Abercrombie Mountain, at an altitude of 7,308 feet above sea level. South of Ione the slopes westward from the river are more gentle and the drainage divide is about 10 miles or more to the west.

East of the Pend Oreille Valley the slopes rise at moderate angles to a group of hills and mountains, the highest of which is Gypsy Peak, at 7,318 feet above sea level, or about 5,400 feet above the river 8 miles to the west. From the steep, rugged peaks in the north the hills decrease southward in altitude and pass into the rounded, less abrupt topography of the area underlain by the Kaniksu batholith.

The divide that separates the Pend Oreille drainage from that of the Priest River system to the east or from that of the Salmo River system to the north contains many of the highest peaks in the region. In the north it is considerably cut up by amphitheaters and erosion by local glaciers. (See pl. 16, *A*.)

East of the divide the drainage channels into the Priest River-Priest Lake system resemble those of the Pend Oreille tributaries, although only the headwaters of the streams were traversed. The terraces along the eastward-draining streams are extensive and better developed than those along the streams to the west. No attempt has been made to study or correlate these terraces.

The northeast corner of the quadrangle is drained by the headwaters of the South Fork of the Salmo (Salmon) River. The present small stream is entirely inadequate to carve the wide, deep valley through which it flows. This valley cuts directly across the structure, but an adequate account of its history has not been attempted.

Near the center of sec. 24, T. 37 N., R. 42 E., there is an unusual kettle topography. The kettles are 50 to 300 feet in diameter and as much as 40 feet deep. They are closely spaced and separated by knife-edge ridges. The surface material at this place is mainly silt and gravel, with a few cobbles as much as 8 inches in diameter.

Dry Canyon exhibits some interesting glacial features. The head of the canyon is cut off by Maitlen Creek about 4 miles east of Ione; the abandoned channel is about 175 feet above the bed of Maitlen Creek. The Dry Canyon Valley is nearly level at its head and increases its gradient toward the south. It is about 11 miles long from Maitlen Creek south to its junction with the west fork of LeClerc Creek and in this distance drops nearly 500 feet, or an average of about 45 feet to the mile. The canyon floor is covered with an unknown thickness of unsorted debris, probably dropped by the ice during its retreat. Many kettles and small lakes such as Caldwell Lake and Scotchman's Lake are distributed through the valley, particularly in the southern part. These depressions are thought to have been formed by the melting of remnant blocks of stagnant ice. Except in the spring or during periods of heavy rainfall the drainage is mainly subsurface through the coarse porous debris. Scotchman's Lake is reported to have fluctuated as much as 80 feet in a year.

Much of the bedrock, particularly in the southern part of the quadrangle, is covered by a blanket of glacial debris. This debris is both coarse and fine, is unsorted, and contains many types of rock. Small ponds and swamps are widely distributed in the debris-choked valleys and in silted depressions in glacial debris. The ponds are illustrated by Lake Leo, Lost Lake, Ledbetter Lake, Yokum Lake, and a host of others, many unnamed. These lakes may have formed by the melting of stagnant ice in the glacial drift and the gradual silting of the resulting depressions. Hughes Meadow is an example of a wide flat marsh formed by filling an older valley to an unknown depth. Such marshes are rather common, and in this region the larger ones are known as meadows.

Contrasting with the ponds and swamps of the choked valleys and drift areas are the rock-carved basins, formed where glacial scour has been particularly active. Sullivan Lake is the largest lake in the area. It occupies a depression between two ice-scoured walls and is dammed at each end by low, flat blockades. These blockades are similar to the blockades at Liberty

Lake and Newman Lake, recently described by Flint.[98] The blockade at the north end of Sullivan Lake is shown in plate 16, *B*.

Glacial striae are seen at few places but are well preserved on a limestone knob south of the Grandview open cut. At other places striae have been found, but they are mostly on the sides of tributary valleys and their orientations tend to converge toward the valleys. They were evidently formed by local glaciers or perhaps by movement toward the valleys during continental glaciation.

At several places in the region nearly level benches, in places 50 feet or more wide, have been developed, apparently by ice scour. Such a bench can be seen on Hall Mountain (see pl. 16, *B*), to the east (left) of Sullivan Lake. This bench is particularly conspicuous, as it cuts across the trend of the quartzite in Hall Mountain. Other benches have been recognized along the west side of Sullivan Mountain and Crowell Ridge.

Daly[99] has recently discussed the subject of elastic recoil of the earth's crust after removal of a large ice cap. Flint,[1] however, was unable to reach any conclusions as to the amount of such rebound in eastern Washington. In the Metaline quadrangle the effects of such rebound are not discernible on the silts of the 2,100-foot terrace. This surface seems to be essentially horizontal from Newport to Metaline Falls. The apparent difference in altitude of the high terrace, 2,600 feet at the Canadian border and about 2,500 feet near the southern part of the quadrangle, may or may not have been caused by elastic recoil.

Local glaciers were present on the higher peaks long after the Cordilleran ice cap vanished. On Snowy Top Mountain, just northeast of the Metaline quadrangle, a small stagnant ice pocket still persists. In one of the amphitheaters on the east side of Gypsy Peak (see pl. 16, *A*), a little snow remained in September 1936. Many of the amphitheaters contain lakes and other features characteristic of recently glaciated regions. Evidence of local glaciers is difficult to recognize in the southern part of the quadrangle, owing in part to the rapidity with which the intrusive rock disintegrates.

CAVES

In many places in the Pend Oreille Valley caves are found in carbonate rocks, generally along fractures or breccia zones. Probably the best known of these caves is the Gardner Cave, which is a State park in the east-central part of sec. 4, T. 40 N., R. 43 E. All known caves in the carbonate rocks are above the river level and were probably formed by downward-percolating meteoric waters.

Several filled caves were cut in the long adit driven by the Metaline Mining & Leasing Co. at the Bella May mine. These caves are filled with apparently structureless masses of clay and stratified silts and coarse sands. They have yielded no fossils but are at the base of the 2,600-foot terrace and for this reason were probably present before the last ice invasion. It is possible that these caves are as old as Tertiary. Caves similar to those in the Bella May adit are found in Washington Rock, west of Metaline Falls, and at a few other places in the river valley. One such cave in Washington Rock was filled with brown clayey iron oxide that was mined by the Lehigh Portland Cement Co. for use in the manufacture of cement. The iron oxide showed crude banding roughly parallel to the walls of the chamber but was otherwise structureless.

Jenkins[2] mentions caves found in the Grandview workings. He says: "In one natural cave it was noticed that breccia was much in evidence. Broken-off pieces of brecciated rock containing galena partly filled the cave."

A group of unusual caves was found during the development of the Pend Oreille mine, and some of them are labeled on the mine map. (See pl. 33.) Many of these caves contained sphalerite and galena in fragments on the floors and in crystals lining parts of the walls, and for this reason they were quickly mined out. The best cave seen was above the 500-foot level; it was about 8 feet wide, 4 feet high, and more than 20 feet long. Other caves, both above the 500-foot level and above the 300-foot level, are reported to have been considerably larger. The country rock is brecciated Metaline limestone, generally silicified. In all the caves examined one side of the cavity is bounded by a smooth slickensided wall. (See pl. 17, *A*.) The caves are most common above the 500-foot level (altitude 2,124 feet) and decrease in size and numbers in depth. On the 700-foot level (altitude 1,900 feet) the openings are little more than enlarged vugs, and all seen were less than 3 feet in greatest dimension. The caves continue upward and were found in the zero adit of the mine (altitude about 2,550 feet).

Many of the caves were well below ground-water level before mining began, although all known are above the river level and are situated where the hydraulic gradient is steep and the circulation, even in the zone of saturation, is probably considerable.

One of the most peculiar features of these caves is the lining of paligorskite (pl. 17, *B*), a hydrous magnesium-aluminum silicate, which hangs from the roofs and sides in soft dangling masses that resemble

[98] Flint, R. F., Stratified drift and deglaciation of eastern Washington: Geol. Soc. America Bull., vol. 47, pp. 1859–1862, 1936.

[99] Daly, R. A., The changing world of the ice age, pp. 120–150, Yale Univ. Press, 1934.

[1] Flint, R. F., Pleistocene drift in eastern Washington: Geol. Soc. America Bull., vol. 48, p. 230, 1937.

[2] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Conservation and Development, Div. Geology, Bull. 31, p. 60, 1924.

soiled and frayed rags. Paligorskite, "mountain leather," or "asbestos," as it is known locally, is thought to have been formed by the reaction of dolomitic limestone, or in places calcite, with a solution bearing the elements needed to form the mineral. As pointed out in the section on mineralogy (p. 59), paligorskite is unstable near the surface. In the caves on the zero level of the Pend Oreille mine a few remnants of paligorskite in cracks are brittle and apparently are being slowly dissolved. The mineral is most abundant in the caves near the 500-foot level and is rare or absent in the deeper openings.

Under the layer of paligorskite is commonly a surface of crystalline quartz and sphalerite that grades into jasperoid and ore. That the paligorskite was deposited after the quartz and ore is indicated by their relative positions in the caves, by the fact that veinlets of paligorskite cut the jasperoid and ore, and by the motley arrangement of included fragments suspended in the paligorskite. (See pl. 18.) Fragments of ore are also abundant on and in the paligorskite, and the dirty-gray appearance of part of the mineral is caused by finely crystalline sphalerite. Some of the quartz is in small doubly terminated crystals, and some is in thin rounded and pitted sheets as if partly dissolved. A little anglesite (lead sulfate) was found on paligorskite from the 300-foot level.

Four possible modes of origin of the mineralized caves suggest themselves. (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[8]; (3) they are related to a possible erosion surface at the top of the Metaline limestone and below the Ledbetter slate; and (4) they resulted from solution by hydrothermal fluids that deposited jasperoid and ore.

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.

ALTERATION OF THE SEDIMENTARY ROCKS

REGIONAL METAMORPHISM

The sedimentary and volcanic rocks of the region were already indurated, foliated, and recrystallized by regional metamorphism before intrusion of the Kaniksu batholith. As a result of the regional metamorphism sandstones were converted to quartzites, carbonate rocks were recrystallized, volcanics were converted to green-

[8] Davis, W. M., Origin of limestone caverns: Geol. Soc. America Bull., vol. 41, p. 480, 1930.

stones, and argillaceous rocks were converted to slates, phyllites, and schists. The metamorphism in the older rocks is, in general, although not uniformly, of higher grade and is more nearly complete than in the younger rocks. The higher-grade rocks merge into those of lower grade without a recognized hiatus. This gradation may be explained as resulting from the greater depth of burial of the older rocks and the greater load on them at the time of deformation.

IGNEOUS METAMORPHISM

GENERAL FEATURES

The sedimentary rocks within a mile, or exceptionally more, of the border of the Kaniksu batholith are altered as a direct result of the intrusion. This alteration, in contrast to that in many igneous-metamorphic zones, has consisted of recrystallization and the formation of new minerals by rearrangement of the constituents already present. It is thought that little new material, except locally silica and ore minerals, has been added from the batholith, although large quantities of hot water and other mineralizers probably facilitated the transfer and rearrangement of the pre-intrusion minerals. The resulting metamorphic products are strikingly similar to those in the Pend Oreille district of Idaho described by Gillson.[4] The igneous metamorphosed rocks are, however, a bit unusual in that the lack of iron-bearing minerals is particularly noticeable.

Igneous metamorphism was superimposed on the sedimentary and volcanic rocks after the main period of regional deformation. (See pl. 19, *A*.) For this reason bedding, foliation, and other structural features are obscured in the metamorphic zone. In some places, however, particularly in banded calcareous phyllites, the banding is preserved, although the mineral suite is changed. The retention of the banding indicates the extent to which the original composition of the rock influenced the result; probably no large-scale replacement by introduced magmatic products has occurred.

The quantity of material added to the older rock from the magma can be determined only by careful sampling, which was not done. The impression obtained is that silica was the principal material added, and in places large quantities may have been introduced. At the Coffin property sulfides—pyrrhotite, galena, sphalerite, pyrite, and molybdenite—and probably other minerals were added. A little molybdenite in the marble on the Dry Canyon road and a part of the small amount of almandite garnet in the sedimentary beds were probably introduced also.

For purposes of description the igneous metamorphism is here treated under two headings—(1) simple recrystallization and (2) alteration to silicate minerals, including the formation of hornfels.

RECRYSTALLIZATION

The term "recrystallization" is used here to mean a change in the physical state of a rock, essentially without the introduction of additional materials. As thus defined recrystallization has been the most widely distributed type of metamorphism in the zone of igneous influence and extended far beyond the inner zone of intense alteration to silicate minerals.

The carbonate rocks and the quartzites show most clearly the effects of recrystallization. The results in the carbonate rocks are similar to those described by Nolan[5]—a general increase in grain size accompanied by bleaching. The white marble thus formed is dense and massive; individual grains are generally one-sixteenth inch or less in diameter but in a few places exceed a quarter of an inch. Faulting and other structural features are difficult to recognize in the marbles, as they were generally obscured during recrystallization.

The recrystallization of the quartzites has in some places resulted in an increase of grain size; in other places the individual grains seem to have been broken up into many smaller particles. Strain shadows, so common in the normal quartzites, were destroyed during recrystallization.

ALTERATION TO SILICATE MINERALS

The type of silicate minerals formed during igneous metamorphism depends largely upon the original composition of the rocks affected. Limy beds are altered principally to diopside and tremolite and in minor degree to other minerals. The rocks that were originally composed mainly of clay minerals are altered to mica schists and hornfels, which grade into each other.

Diopside and tremolite in very few places make up the entire rock, but they are generally scattered through white marble. Diopside commonly occurs in cores in the tremolite (see pl. 19, *B*, *C*) and seems to alter readily to tremolite; although in some of the rock tremolite is absent. A little pale-green actinolite in place of tremolite is found in the schistose rocks. The concentration of diopside and the amphiboles is such that they may well have resulted from rearrangement of the constituents of siliceous dolomite or from the addition of silica to dolomite. The formation of diopside and calcite from dolomite (dedolomitization) in a locality in western Massachusetts has been ably described by Eskola.[6] Pale yellowish-green serpentine

[4] Gillson, J. L., Contact metamorphism of the rocks in the Pend Oreille district, northern Idaho: U. S. Geol. Survey Prof. Paper 158-F, pp. 111-121, 1930.

[5] Nolan, T. B., The Gold Hill mining district, Utah: U. S. Geol. Survey Prof. Paper 177, p. 91, 1935.

[6] Eskola, Pentti, On contact phenomena between gneiss and limestone in western Massachusetts: Jour. Geology, vol. 30, p. 287, 1922.

is found in the marble in Dry Canyon, at the O. K. property, and at the Coffin property. Many marbles, particularly the argillaceous ones, contain muscovite or phlogopite, or both. Where the carbonates decrease in quantity the micas increase, and the marble grades through calcareous schist to phyllite.

A calcareous schist is exposed on the ridge between Harvey Creek and Noisy Creek, where the rock has a felted silky appearance and has obscure layers of pale-brown, light-greenish, and white minerals. The darker layers contain muscovite and pale yellowish-brown phlogopite; the lighter layers are made up of calcite and tremolite. Small radiating clusters of thomsonite were noted in thin sections, and a few small grains of pale-yellowish tourmaline and rutile were identified. A few grains of quartz are also present.

Many of the fine-grained rocks, including some that are calcareous, form dense compact porcelaneous hornfels near the intrusive mass. Crystalline schists are arranged around the intrusive borders and in general are coarser-grained nearer the intrusive. In places the schists are converted to hornfels near the contact but elsewhere they lie immediately next to the igneous rocks.

The hornfels is banded or vaguely mottled, dominantly in shades of gray, green, and brown. A somewhat unusual type is found south of Sand Creek in the Ledbetter slate, where the rock appears to be simply indurated; no crystallization was noted, and the black color is retained. In many places in the hornfels no minerals can be distinguished without microscopic aid. Quartz, feldspars, either orthoclase or albite, and micas are the dominant minerals, but a wide variety is recognized. The micas are commonly muscovite or phlogopite, but biotite is present in the darker layers. Fine needles of tremolite, actinolite, or dark-green hornblende are widely distributed, and epidote is locally abundant in the greenish rocks. Clinozoisite and allanite accompany the epidote, generally in small amounts, and zoisite was noted in one thin section.

Start

Sillimanite is a widely distributed constituent of the hornfels and in places makes up much of the rock. The best development of the mineral seen is near the Little Muddy Creek road west of Ione. Here the sillimanite needles can be readily recognized and form as much as 50 percent or more of the rock. Plate 20, *B*, is a photomicrograph of rock from this locality, in which the needles are haphazardly oriented. In addition to sillimanite the rock contains mainly quartz, greenish tourmaline, reddish-brown biotite, and colorless chlorite. In most places sillimanite forms a fine feltlike mass that can be recognized only under the microscope.

Andalusite is another common mineral in the hornfels. It is present customarily in microscopic grains, but on Hall Mountain it occurs as needles as much as three-quarters of an inch long (see pl. 20, *C*) and in the Maitlen phyllite near Cedar Creek northwest of Ione it forms even larger crystals. Much of the andalusite is altered, and its character is obscured by a mat of sericite. The crystals from Hall Mountain were obtained on the ridge trail just east of the intrusive mass; they are comparatively fresh and easy to study.

Stop

Cordierite was recognized by Charles Milton, of the United States Geological Survey, while examining a specimen of knotty hornfels (see pl. 20, *D*) from the peak at the head of Wolf Creek. Pale-yellow pleochroic halos are found around some of the many inclusions in the mineral. The cordierite forms nodules about one-eighth of an inch across. It is difficult to recognize in thin sections and has not been identified with certainty elsewhere in the region. In several places, however, its presence has been suspected, and with more careful study it may be recognized. It is associated with andalusite in hornfels from the line between secs. 4 and 9, T. 35 N., R. 43 E. The Wolf Creek material (pl. 20, *D*) illustrates particularly well the porphyroblastic character of the biotite.

In addition to the minerals mentioned, greenish to black tourmaline, chlorite, zeolite (commonly thomsonite), iron oxides, zircon, apatite, rutile, and sulfides, particularly pyrrhotite, are widely distributed in different proportions. At the Coffin property jefferisite, a little chondrodite, serpentine asbestos (chrysotile), and an unusual pink manganiferous diopside were found associated with sulfides in metamorphosed carbonate rock.

Away from the intrusive border the hornfels generally become coarser-grained and grade into mica schists. Feldspars and the micas, phlogopite and biotite, decrease in quantity, and quartz and muscovite become dominant, but small amounts of other minerals are also present. The muscovite flakes rarely exceed a quarter of an inch across and are generally arranged haphazardly. Chloritoid (see pl. 20, *A*) occurs in the Maitlen phyllite as much as 4 miles from the known intrusive border but probably resulted from intrusion activity. The flakes of chloritoid are flat and transverse to the dominant foliation.

HYDROTHERMAL ALTERATION NOT DIRECTLY RELATED TO IGNEOUS MASSES

DOLOMITIZATION

Some carbonate rocks of the Metaline quadrangle are nearly pure limestone, others are nearly pure dolomite, and many are intermediate and are called dolomitic limestones. Two types of deposits are considered—bedded deposits and crystalline dolomite not bedded. In places the two types cannot be separated, but in general they are sufficiently distinct to permit a rough classification. The detailed study of magnesium in carbonate rocks has been limited to the Pend Oreille Valley and especially to the beds 600 feet and less below the Ledbetter slate. Unless stated otherwise the following discussion applies only to beds in the Metaline limestone.

BEDDED DEPOSITS

The magnesium content of certain beds—for example, in the upper Lehigh quarry—is nearly constant for at least 1,000 feet along the strike, and layers of different magnesium content are separated by bedding planes. The contacts between rocks of different magnesium content, although sharp, do not everywhere conform to bedding surfaces and in places crosscut the bedding at high angles. Such a relation is indicated in the middle Lehigh quarry, where a wedge of limestone was mined. This wedge was surrounded by dolomitic limestone, and so far as could be determined, no faulting was involved. In many places dolomites appear to grade into dolomitic limestone, and the contacts are not sharp surfaces.

The origin of the dolomite in the rocks immediately below the Ledbetter is difficult to study because individual layers are hard to recognize and trace. The problem is further complicated by the fact that the limestone just below the slate was peculiarly favorable for the circulation of ascending solutions and for ore deposition. To offset these difficulties is the fact that many thousands of feet of diamond-drill cores are available for study, and many of the mine workings penetrate the strata. The data obtained at the Pend Oreille mine establish no relation between the slate-carbonate rock contact and the magnesium content. Layers of dolomite cannot be correlated and appear to crosscut the bedding, generally at low angles. At Z Canyon and in the Slate Creek district the rock below the slate is a dense fine-grained dolomite that contains almost no calcite. Core drilling at the Bella May, Grandview, Lead King, and several other properties furnishes additional data as to the irregular distribution of magnesium in the carbonate rocks immediately below the slate. The irregular distribution of the magnesium is clearly shown in plates 21 and 22. These graphs were compiled from the analytical data given in the table on pages 43–44.

The meager data obtained on the magnesium content of carbonate rocks in the Metaline limestone other than the beds directly below the Ledbetter slate support the impression that the magnesium carbonate is irregularly distributed and is not confined to certain beds. These data are entirely observational and are not supported by analyses. The beds near the base of the Metaline limestone east of the upper Lehigh quarry are a series of limestones, shales, and dolomitic limestones. A similar sequence is exposed on Threemile Creek, but near Ione and near the Canadian border on Boundary Mountain what is though to be the same stratigraphic sequence apparently contains more dolomitic layers.

Many of the dolomites and dolomitic limestones are so fine-grained that crystal cleavages cannot be seen without a microscope. Other beds are recrystallized and cleavage surfaces an eighth to a quarter of an inch across are common. The colors range from light creamy gray to dark gray and black. During the recrystallization organic coloring matter was largely expelled but in a few places it accumulated as small buttons that have the composition of anthracite.[7] (See pl. 23, *A*.) Alternating black and white dolomite beds and patches of rock of one color in the other are described on page 18 and illustrated in plate 9, *A*. Samples of these black and white rocks were taken about 1 foot apart in the same layer. Analyses of the samples are given in the table below. The two rocks are nearly identical in composition, but the dark one contains a small amount of organic material. Practically all dolomites contain small crystal-lined vugs, generally less than a quarter of an inch in longest dimension, although exceptionally they are larger.

Analyses of dolomite from north side of Crescent Lake, sec. 12, T. 40 N., R. 44 E.

[Analyst, R. C. Wells]

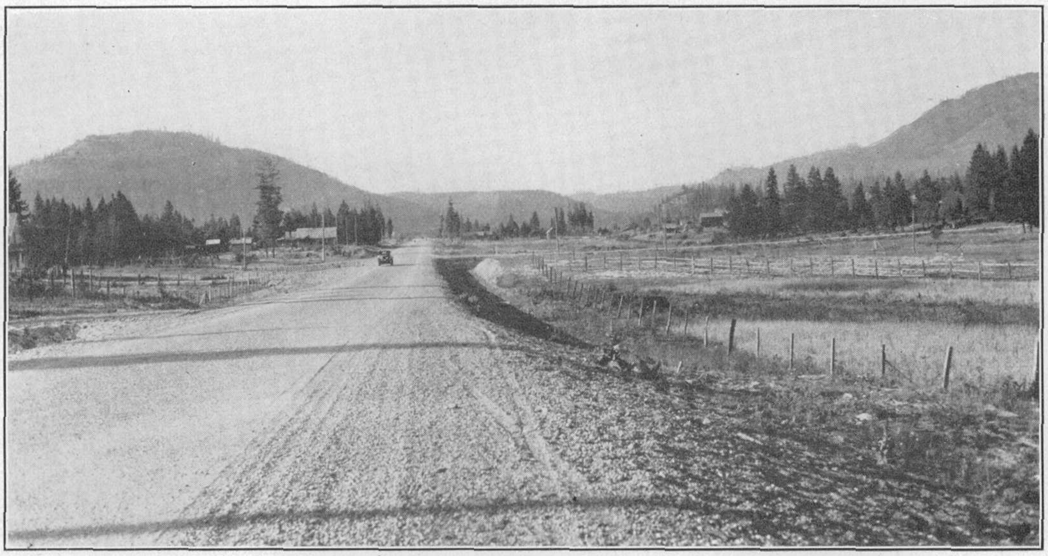
	Dark		Light	
Organic matter	------	A little	------	Trace
SiO_2 and insoluble	------	0.16	------	0.24
$(Al, Fe)_2O_3$	------	.22	------	.29
CaO	30.45	------	30.35	------
CO_2 (calculated)	23.89	------	23.81	------
$CaCO_3$	------	54.34	------	54.16
MgO	21.68	------	21.69	------
CO_2 (calculated)	23.66	------	23.67	------
$MgCO_3$	------	45.34	------	45.36
		100.06		100.05

The black and white bands in many places form narrow alternating layers (generally less than 0.5 inch wide and commonly 0.2 inch or less) that are appropriately termed by the miners "zebra" rock.[8] (See pl. 23, *E*.) This term, although commonly used for striped carbonate rocks, has also been used for other banded types.[9] In the carbonate rock both the black and the white layers are dolomite; they differ only in

[7] Hendricks, T. A., Recently adopted standards of classification of coals by rank and grade: Econ. Geology, vol. 33, pp. 136–142, 1938. Fixed carbon determined by Taisia Stadnichenko.

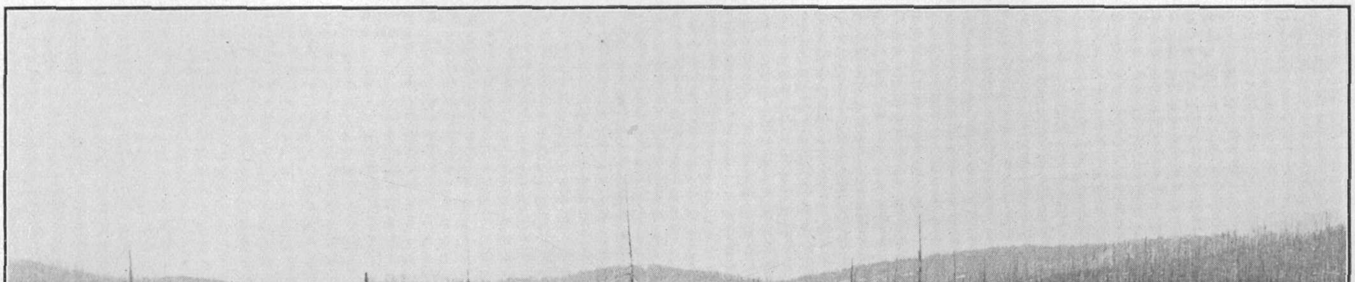
[8] Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff district, Colo.: Colorado Geol. Survey Bull. 30, p. 36, 1925.

[9] Hobson, R. A., "Zebra rock" from the east Kimberly: Royal Soc. Western Australia Jour., vol. 16, pp. 57–70, 1930.

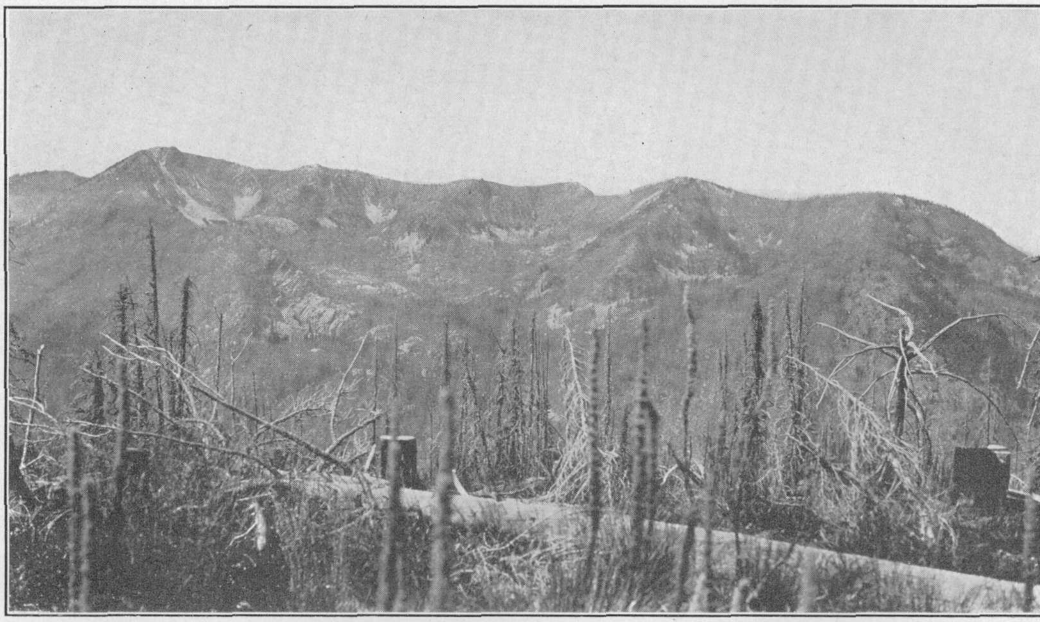


A. TERRACES ALONG PEND OREILLE RIVER.

View north from a point about 1 mile south of Ione. The road is on the 2,100 foot level, and the 2,500- to 2,600-foot level is in the central background.

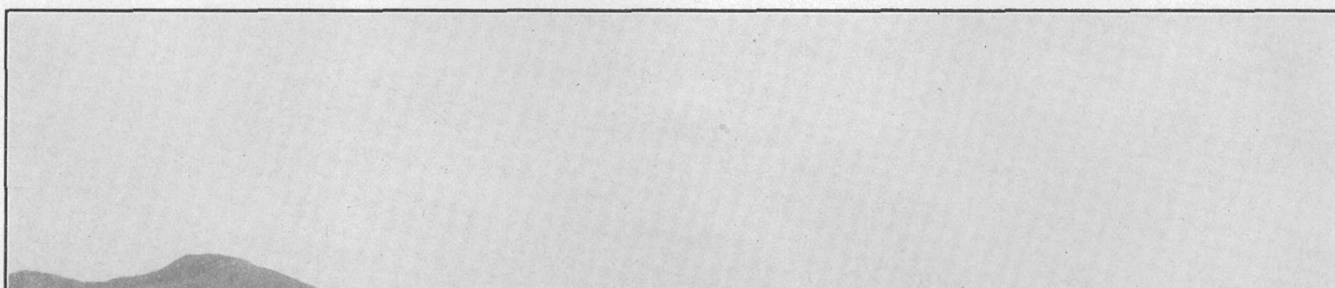


B. STREAM TERRACES ON UPPER RUBY CREEK.



A. AMPHITHEATERS ON EAST SIDE OF GYPSY RIDGE.

View from Salmo Mountain.



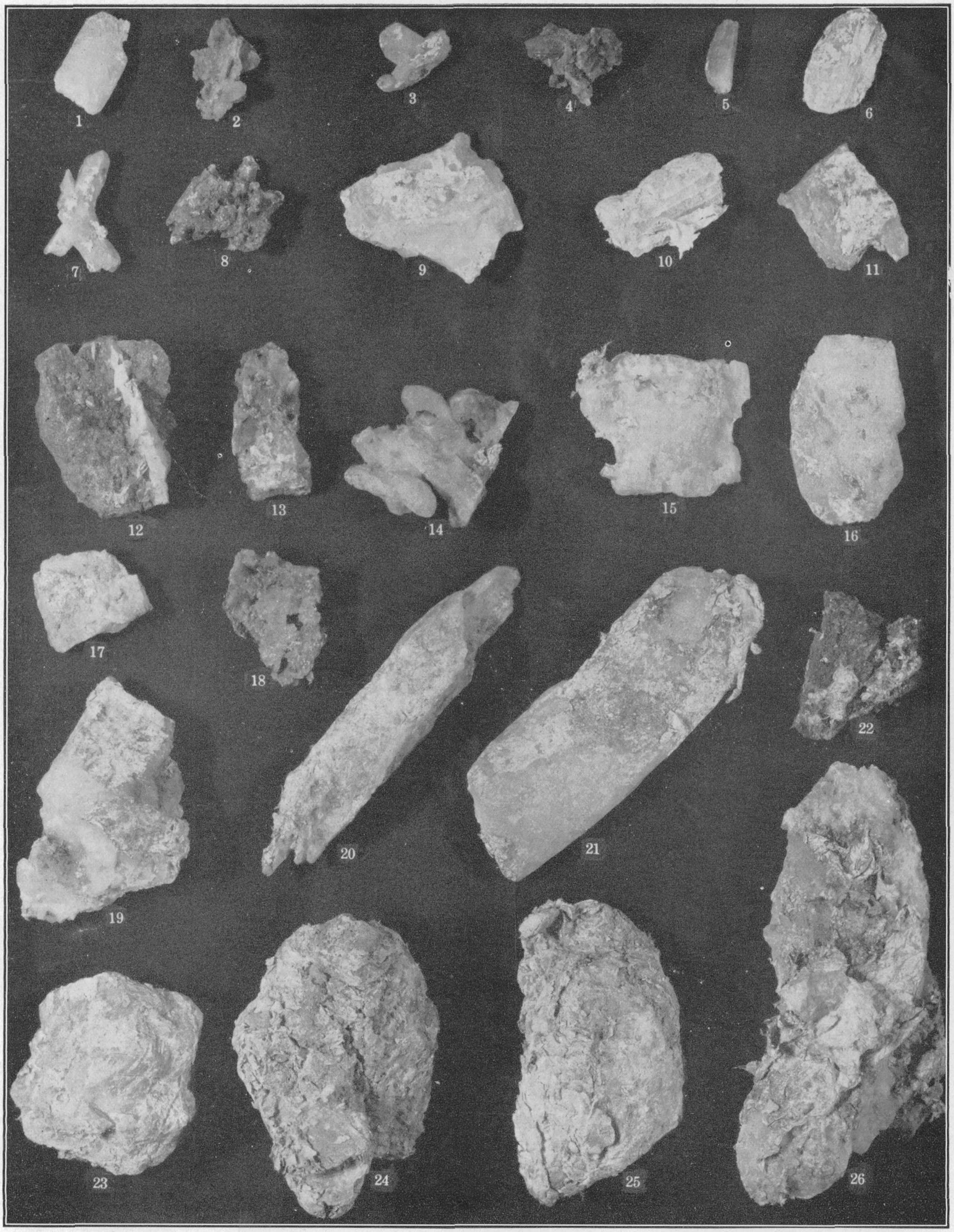
B. GLACIAL BLOCKADE AT NORTH END OF SULLIVAN LAKE.

View from slope of Sullivan Mountain.

A. PALIGORSKITE IN CAVE, 500-FOOT LEVEL, PEND OREILLE MINE.

Height of cave about 4 feet. Note slickensided wall on right.

B. PALIGORSKITE FROM 500-FOOT LEVEL, PEND OREILLE MINE.

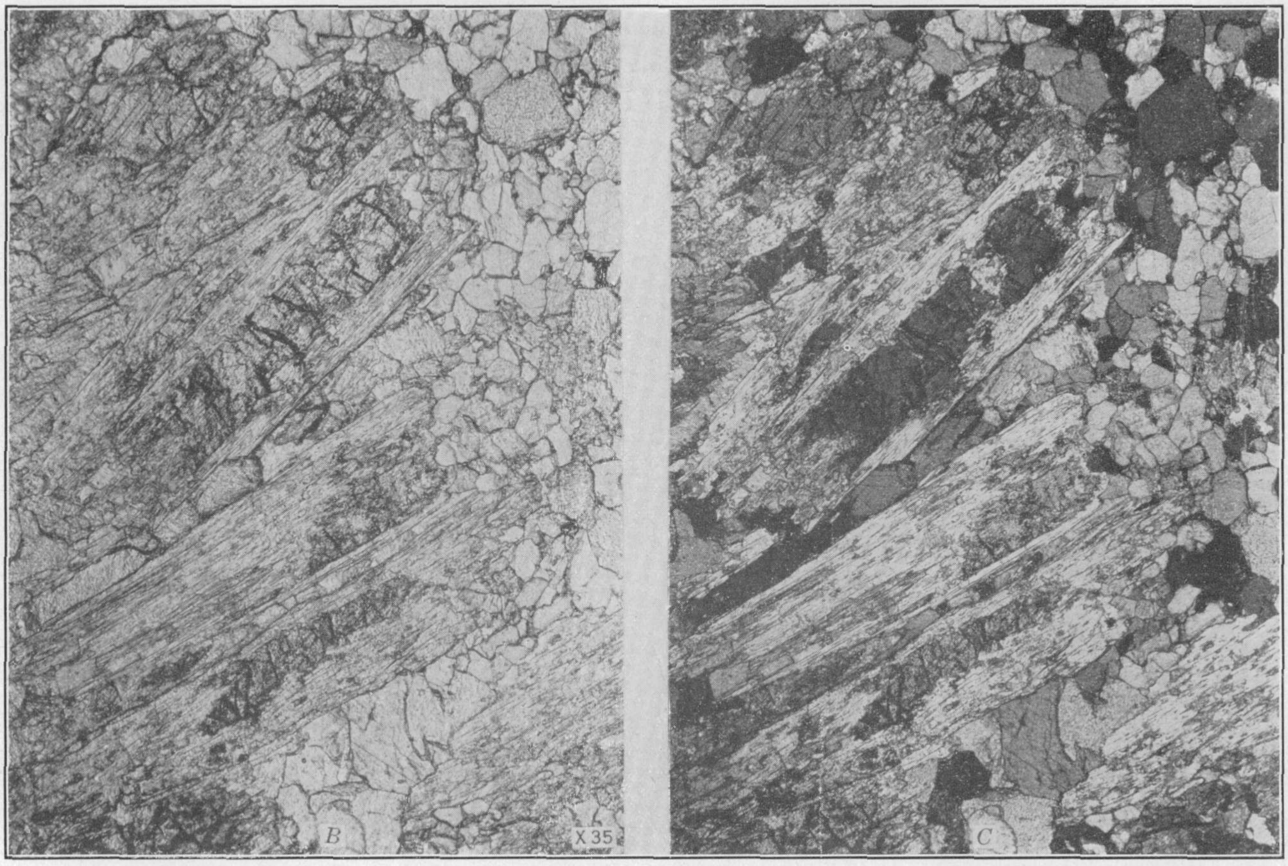


FRAGMENTS OF CALCITE, JASPEROID, ORE, AND CRYSTALLINE QUARTZ TAKEN FROM INSIDE A PIECE OF PALIGORSKITE FROM 300-FOO LEVEL, PEND OREILLE MINE.

Calcite, 6, 9, 10, 23. Jasperoid, 12, 13, 24–26. Ore, 4, 8, 22. Crystalline quartz, 1–3, 5, 7, 11, 14–21. Natural size.

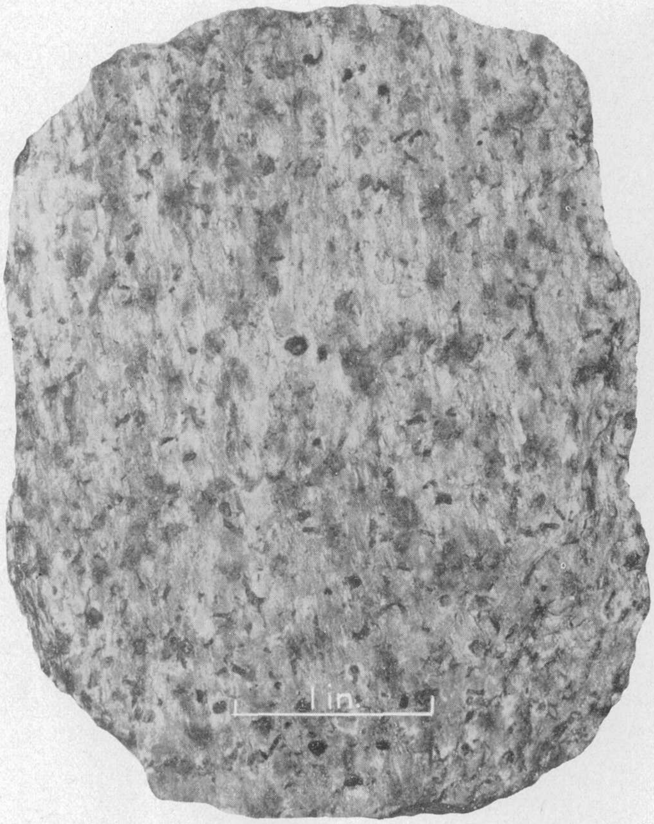
A. HORNFELS DEVELOPED IN PREVIOUSLY FOLDED PHYLLITE.

Half a mile west of Stagger Inn Camp. Altitude, 4,400 feet.



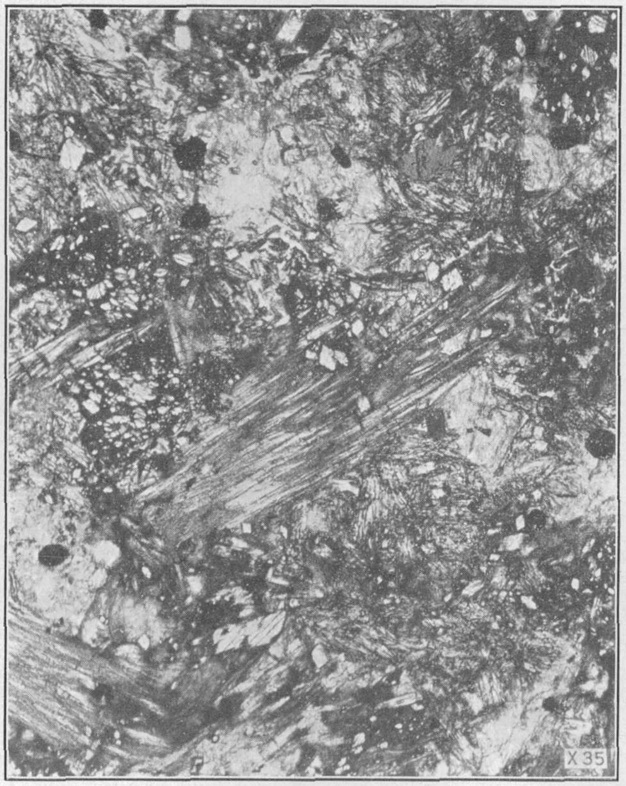
B, *C*. PHOTOMICROGRAPHS OF ALTERED CARBONATE ROCK.

Cores of tremolite laths are white diopside. *C* same as *B*; crossed nicols.



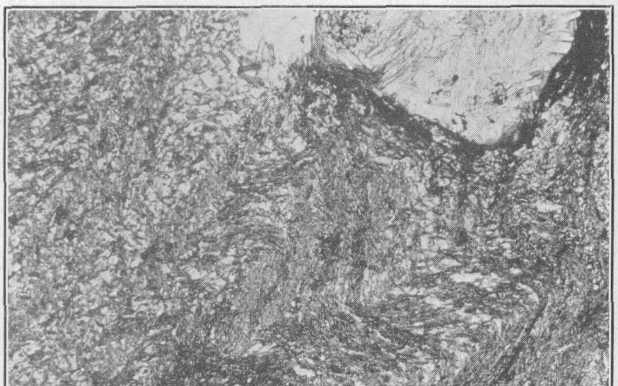
A. CHLORITOID SCHIST FACIES OF MAITLEN PHYLLITE.

About 150 feet above Gypsy quartzite, on hill between Sweet Creek and the South Fork of Flume Creek.



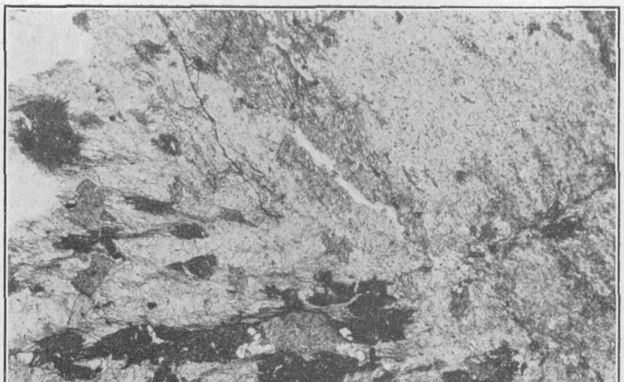
B. PHOTOMICROGRAPH OF SILLIMANITE SCHIST.

Little Muddy Creek road west of Ione. Diamond-shaped crystals and fibers are sillimanite.



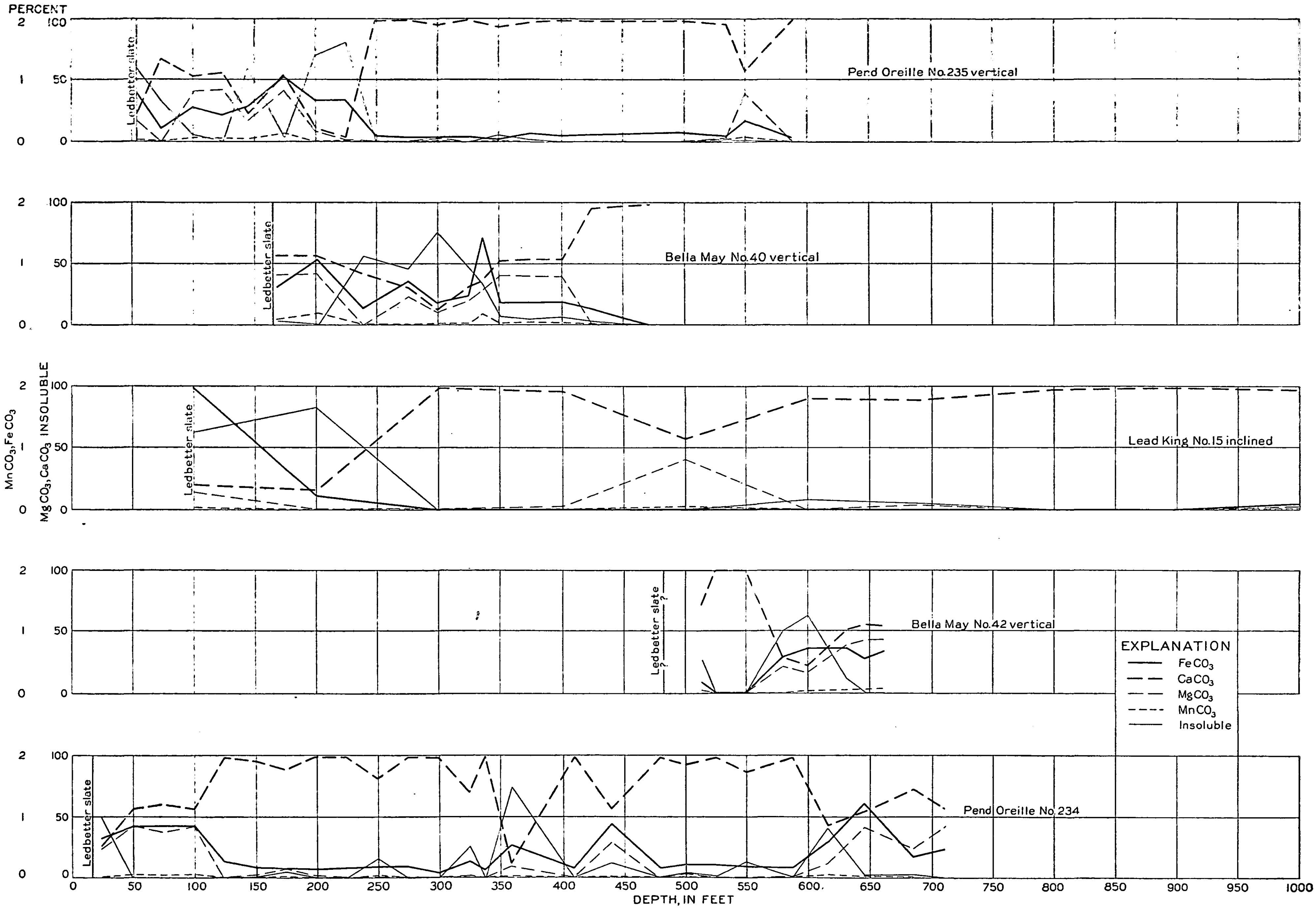
C. PHOTOMICROGRAPH OF ANDALUSITE GRAINS IN MICA SCHIST.

Hall Mountain ridge, northeast corner of sec. 15, T. 38 N., R. 44 E.



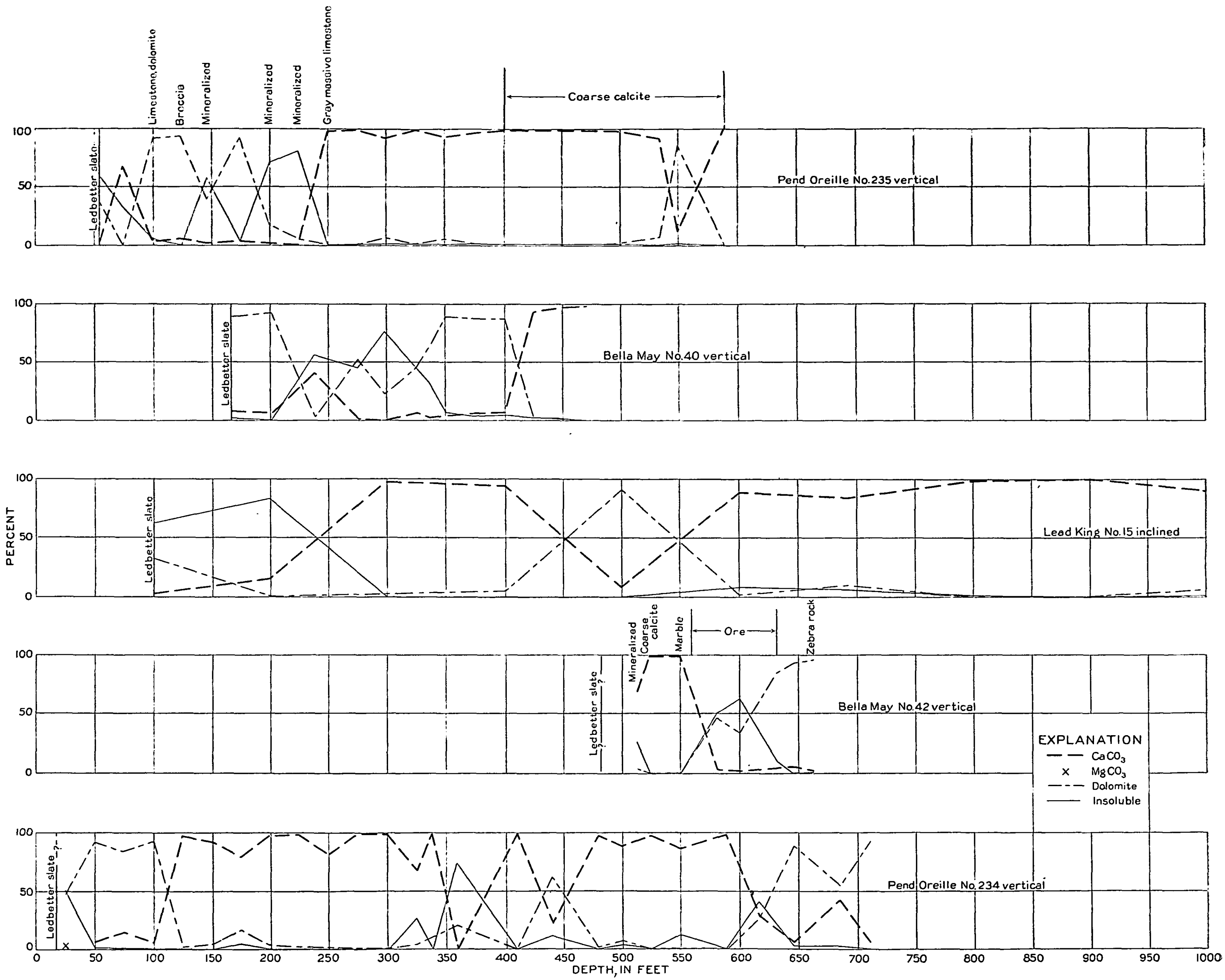
D. PHOTOMICROGRAPH OF METAMORPHOSED PHYLLITE.

From peak at head of Wolf Creek. Black biotite porphyroblasts developed after the foliation. The large grain in the upper right-hand corner is cordierite.



GRAPHS OF ANALYSES OF DIAMOND-DRILL CORES.

Minerals computed as carbonates and insoluble. CO_2 calculated in all analyses.



GRAPHS OF ANALYSES OF DIAMOND-DRILL CORES.

Minerals computed as dolomite, calcite, and insoluble. CO_2 calculated in all analyses.

the presence of a little organic matter in the black layers and the fact that the light layers are slightly coarse-grained and somewhat vuggy. The suggestion is here offered that the "zebra" banding in the dolomite was caused by a partial or complete recrystallization of gray or black dolomite along closely spaced surfaces, the trends of which were determined by shear planes and possibly bedding or other planar structures. Figure 8 is a sketch of the wall of the new Bella May adit 400 feet from the portal. It was one of the most clear-cut examples seen of "zebra" banding related to shear planes.

The graphs in plate 21 show a close agreement in distribution of magnesium, iron, and manganese, although the last two elements commonly total less than 2 percent of the rock. This agreement is too widespread to be fortuitous and seems to indicate rather uniform conditions during the formation of dolomite. The addition of iron and manganese to limestone during dolomitization was pointed out by Hewett.[10]

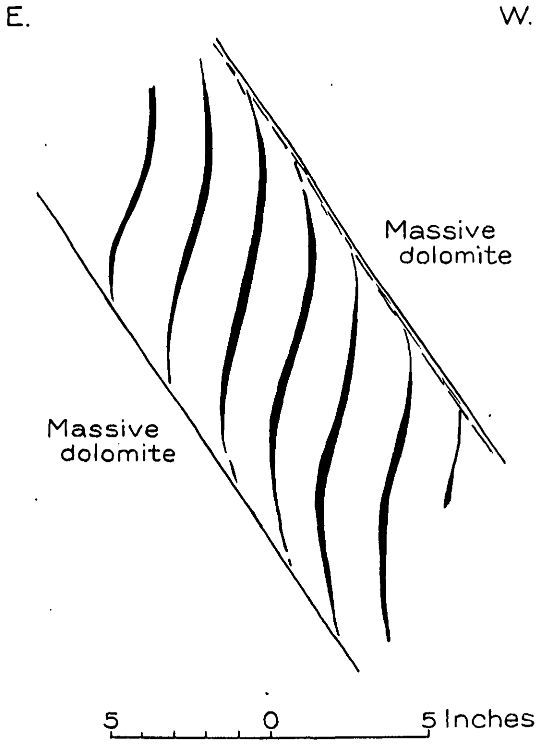


FIGURE 8.—Sketch of "zebra" banding 400 feet from portal of the new Bella May adit. Banding is limited by shear planes, and its character suggests that it is related to torsional movement. Vertical plane.

In the following table analyses of 79 samples of dolomitic limestone are given. No distinction was made in the analyses or graphs (pls. 21 and 22) between the two types of dolomite, bedded or nonbedded. In general nonbedded dolomites are more abundant near mineralized bodies and rocks of high silica content.

Analyses of dolomite and dolomitic limestone from Metaline quadrangle

Pend Oreille mine, between secs. 15 and 16, south half T. 39 N., R. 43 E. Hole 235.

[Analyst, R. E. Stevens]

Depth (feet)	Acid insoluble (110° C.)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
55 [1]	59. 19	0. 79	23. 09	16. 89	0. 02	99. 98
75	32. 81	. 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

[1] Ledbetter slate.

Bella May mine, SW¼, sec. 29, T. 39 N., R. 43 E. Hole 42.

[Analyst, J. G. Fairchild]

Depth (feet)	Acid insoluble (100° C.)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
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

Pend Oreille mine, line between secs. 15 and 16, south half, T. 39 N., R. 43 E. Hole 234.

[Analyst, E. Theodore Erickson]

Depth (feet)	Acid insoluble (110° C.)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
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

[10] Hewett, D. F., Dolomitization and ore deposition: Econ. Geology, vol. 23, pp. 849–50, 1928.

Analyses of dolomite and dolomitic limestone from Metaline quadrangle—Continued

Bella May mine, SW¼ sec. 29, T. 39 N., R. 43 E. Hole 40

[Analyst, J. G. Fairchild]

Depth (feet)	Acid insoluble (110° C.)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
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

Lead King mine, SE¼ sec. 27, T. 40 N., R. 43 E. Hole 15, inclined 60° E.

[Analyst, Jos. J. Fahey]

Depth (feet)	Acid insoluble (110° C.)	$FeCO_3$	$CaCO_3$	$MgCO_3$	$MnCO_3$	Total
100 [1]	62.15	1.97	20.99	14.69	0.02	99.82
200	82.94	.23	15.15	.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

[1] Ledbetter slate.

CRYSTALLINE DOLOMITE NOT BEDDED

The crystalline dolomite is found near and in ore deposits and along faults and in breccia zones. It is particularly abundant in the beds just below the Ledbetter slate. It is independent of bedding and in places obliterates bedding and other sedimentary and structural features. The contacts between this dolomite and other rocks are generally sharp, but in some places the crystalline dolomite appears to grade into and cannot be separated from bedded dolomites. It is small in amount compared to the bedded deposits.

The crystalline dolomite is so coarse that grain boundaries can generally be recognized. The individual grains average about 0.1 to 0.2 inch across, although exceptional ones are coarser or finer. The color ranges in tints of cream and gray but is rarely uniform. Irregular spots and bands, probably caused by slight differences in organic content, are commonly seen and appear, at least in places, to be due to the preservation of corroded and partly recrystallized remnants of bedded dolomite.

An unusual type of concentrically banded dolomite, silica, calcite, and sulphides is shown in plate 26. This concentric arrangement is discussed under the heading "Ore deposits" (p. 50). In a somewhat similar category is the crustified dolomite shown in plate 23, *D*.

The composition of the crystalline dolomite agrees approximately with that of pure domolite. Small amounts of iron and manganese, similar to those in the bedded deposits, can be detected, although systematic anaylsis of this dolomite was not attempted.

SILICIFICATION

In the Metaline quadrangle jasperoid or silicified limestone is widespread. It is particularly abundant at Lead Hill and in the Pend Oreille mine but is noticeable near or in most mineralized bodies. To date it seems to be true that the zinc ores of the Metaline area are most abundant and richest in the silicified carbonate rocks. Jasperoid is a common associate of zinc ores in many mining districts, but the sphalerite is more abundant in the carbonate rock than in the jasperoid.[11]

The jasperoid is a fine-grained, dense gray or black material that generally preserves the texture and structure of the replaced rock. Plate 23, *B*, illustrates a polished slab of silicified and mineralized breccia from the Pend Oreille mine in which the pre-jasperoid structure is clearly seen.

Irving [12] recognized two types of silicification of carbonate rocks connected with the formation of ore deposits. In one there is a gradual increase in silica content from the carbonate rock to the jasperoid, and in the other the silification advanced in waves and the contacts are sharp. Silification in the Metaline district is of the first type; the limits are vague and silica extends through the carbonates in minute veinlets. (See pl. 24, *B*.) A few doubly terminated quartz crystals are isolated in the carbonates and in the sulphides. Small vugs that contain quartz crystals which seem to merge with the jasperoid are common and are particularly well exposed in the Pend Oreille mine.

The close association of the jasperoid and ore are interpreted to mean that the two products originated from the same solutions, which were probably hydrothermal. The presence of a few quartz crystals on sphalerite and veinlets of silica crosscutting ore show that some silica followed ore deposition. Most sulfides are, however, probably postjasperoid, but it is likely that a little silica was deposited at the same time as the ore and some after the ore.

A small part of the jasperoid consists of aggregates of spheroids and resembles material from Tintic and

[11] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U. S. Geol. Survey Prof. Paper 148, pp. 217–219, 1927.

Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 97–101, 1932.

Loughlin, G. F., and Behre, C. H., Jr., Classification of ore deposits: Ore deposits of the Western States (Lindgren volume), pp. 39–40, Am. Inst. Min. Met. Eng., 1933.

McKnight, E. T., Zinc and lead deposits of northern Arkansas: U. S. Geol. Survey Bull. 853, pp. 111–112, 133–136, 1935.

[12] Irving, J. D., Some features of replacement ore bodies and the criteria by means of which they may be recognized: Canadian Min. Inst. Jour., vol. 14, p. 422, 1911; Econ. Geology, vol. 6, pp. 556, 558, 1911.

Mercur that has been interpreted by Lindgren[13] and Gilluly[14] to indicate an introduction of silica in the colloidal state. It is difficult to understand why colloidal or other solutions should form spheroids while replacing a massive carbonate rock in a breccia and yet preserve the outline of the replaced fragments, unless spheroids were present in the original rock. Spheroids of this type were seen only in the jasperoid.

Spheroids, where of known colloidal origin, are usually thought of as forming in a gel. One of the criticisms of the theory of formation of silica as a gel that is voiced by many geologists is the absence of dehydration or shrinkage cracks in the resulting quartz. The criticism may be voided if the Wiegner effect is active. This effect is defined by Liesegang[15] as follows: "When a polydispersoid sol coagulates, submicrons will act as coagulation nuclei for amicrons. Flowing water can then bring highly dispersed minerals into contact with larger mineral particles and form shell-like layers." This means that when a colloidal solution which contains several sizes of suspended particles coagulates, the larger particles (submicrons) act as coagulation nuclei for small particles (amicrons). So far as known, this effect is active in small spaces and does not require more than very thin layers of gel at any one time. It may help to explain the origin of such spheroids as those found in the jasperoid.

In the new Bella May adit and at Lead Hill light-gray fine-grained silica has been extensively introduced into the dolomitic limestone. This silica resembles the darker jasperoid except in color, and the relations between the two types of silica are unknown. The two may grade into each other, or the light-gray silica may possibly have been deposited by water descending from the surface.

COARSE-GRAINED CALCITE

Translucent white or light-gray calcite, with cleavage surfaces 6 inches or more accross, is commonly found near and in ore deposits, along faults, and in irregular areas away from known ore or faults. Good exposures of the calcite can be seen in the cliffs where the road to the Pend Oreille mine crosses the Flume Creek gorge.

Analyses of the calcite show it to be practically pure calcium carbonate. Both preore and postore calcite are recognized, but physically and chemically they seem to be alike, and no criteria for separating them have been recognized. Plate 23, *C*, represents a polished fragment of ore from the Pend Oreille mine in which galena replaces calcite along cleavage cracks. This seems to be the most common relation in the Pend Oreille mine, but in other places, as shown in plate 26, calcite cuts across the sulfides. This inconsistency may be interpreted to indicate two ages of calcite, two ages of sulfides, or one period of overlapping deposition.

FORMATION OF THE ALTERATION PRODUCTS

The erratic distribution of magnesium in the bedded deposits indicates the formation of dolomite in limestone beds by the action of underground solutions and makes improbable an origin from sea water. Unfortunately the stability relations among the carbonates are practically unknown, and conclusions regarding the proportions of the elements that are stable under certain conditions are conjectural. If the so-called bedded dolomites were formed by underground solutions, the alteration should be more complete near paths of easy circulation, which means, in general, that a relation exists between dolomitization and structure. The controlling structures were probably none too conspicuous at any time and probably have been greatly obscured by postdolomitization deformation. It cannot be said that dolomitization and brecciation everywhere have occurred together. Some of the mineralized breccias in the Pend Oreille mine contain limestone fragments. On the other hand, the gently tilted but otherwise little-deformed beds south and east of Z Canyon are almost uniformly dolomites and dolomitic limestones.

No relation has been established between dolomitizing solutions and the Kaniksu batholith. That the magnesium was introduced before the intrusion is suggested by the common dedolomitization in the zone of igneous metamorphism. This dedolomitization is, however, limited to formations in which dolomitization has been little studied, and it is questionable how far to apply the above-stated conclusion to the Metaline limestone.

Bedded dolomites and dolomitic limestones have been faulted and brecciated in many places. Some of the breccias are uncemented, and others are cemented by silica and calcite. Dolomite beds are dragged along faults, and fragments of dolomite and limestone are mixed in the gouge. Regional dolomitization was probably accomplished before the introduction of the ore-bearing solutions, and it may have taken place early in the structural history.

Hewett,[16] in a discussion of the origin of dolomite, points out that magnesium is freed during the silicification of dolomite. This magnesium could accomplish alteration to dolomite of any limestone through which the solution later passed.

[13] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 154–158, 1919.

[14] Gilluly, James, Geology and ore deposits of the Stockton and Fairfield quadrangle, Utah: U. S. Geol. Survey Prof. Paper 173, pp. 97–101, 1932.

[15] Liesegang, R. E., Colloid chemistry and geology: Colloid Chemistry, vol. 3, edited by Jerome Alexander, p. 253, 1931.

[16] Hewett, D. F., Dolomitization and ore deposition: Econ. Geology, vol. 23, p. 859, 1928.

According to Knopf,[17] coarse white calcite at Pioche, Nev., is found around the peripheries of many replacement deposits in limestone. This calcite has cleavage surfaces 6 to 8 inches long and from Knopf's description is similar to the calcite at Metaline. He considers the calcite to have resulted from the recrystallization of fine-grained limestone and suggests 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." He also offers the alternative explanation that the calcite was "the most advanced member of the vanguard in front of the growing ore body."

A combination of the theories offered by Hewett and Knopf is thought to explain the origin of the nonbedded dolomite and the coarse calcite in the Metaline quadrangle.

Crystalline nonbedded dolomite is commonly found near irregular-shaped bodies of coarse-grained calcite. At Lead Hill and the Grandview mine the intimate association of these minerals is well shown. The agreement in distribution is not fortuitous but is consistent. Plate 24, *A*, shows the detailed relation between crystalline dolomite and calcite that appear to have formed from bedded dolomitic limestone.

Jasperoid is another common constituent that has been introduced into the bedded dolomite near crystalline nonbedded dolomite. All stages of the change are seen, from bedded dolomite with small fractures filled with silica (see pl. 24, *B*) to the complete replacement of carbonate. In plate 25, *A*, crystalline dolomite is crustified and appears to be formed in cracks through jasperoid, an analysis of which is given below.

Analysis of cherty dolomitic limestone from Grandview adit, Metaline Falls, Wash.

[Analyst, R. C. Wells]

Insoluble	87.92	SiO_2	86.96
		R_2O_3	.61
		CaO	.05
		MgO	.04
			87.66
R_2O_3	0.47		
$CaCO_3$	6.81		
$MgCO_3$	4.83		
	100.03		

The centers of many of the dolomite areas are calcite and the crustified dolomite is not connected by clean-cut fractures but by hazy ill-defined zones. In some specimens crystalline dolomite surrounds fragments of jasperoid and in other places seems to be replaced by jasperoid.

The paragenesis of the jasperoid, ore, calcite, and nonbedded dolomite is complicated, and an explanation of the origin of one must consider the origin of the others. The large bodies of jasperoid and ore are thought to have been deposited by hot solutions from below. Large quantities of magnesium and calcium carbonates were liberated during the replacement of dolomitic limestones and bedded dolomites by the jasperiod and ore. In general, in the solutions obtained by dissolving dolomitic limestones, calcium carbonate was in excess of that required to form dolomite with the available magnesium. The liberated carbonates were moved along solution channels away from the sphere of silicification and were redeposited nearby in more favorable places. Where dolomite was deposited in limestone or dolomitic limestone more calcite was added to the solution and was redeposited elsewhere. The result has been crosscutting dolomite and coarse-grained calcite irregularly distributed around jasperoid and ore bodies. The quantity and distribution of the nonbedded dolomite and the coarse calcite seem to be adequately accounted for by the process outlined, which also explains the complicated paragenesis of the silica, sulfides, dolomite, and calcite. That some recrystallization with a minimum of transportation has taken place is indicated by the local gradation of the crosscutting crystalline dolomite into fine-grained bedded dolomite.

ECONOMIC FACTORS

In recent years many mining districts have been described in which dolomite, at least in part, is ascribed to the addition of magnesium from magmatic sources to limestone beds.[18] The subject is of considerable interest, as it may, in certain districts, act as a guide in hunting ore. At Aspen, Colo., Spurr[19] thought that dolomitization and sulfide mineralization were intimately related, but Vanderwilt[20] has recently questioned the validity of this conclusion. Hayward and Triplett,[21] in an interesting paper on mineralized dolomite in seven deposits of northern Mexico, concluded that the dolomite was the result of regional metamorphism and is both near to and remote from ores. Sam-

[17] Westgate, L. G., and Knopf, Adolph, Geology and ore deposits of the Pioche district, Nev.: U. S. Geol. Survey Prof. Paper 171, pp. 49–50, 52, 1932.

[18] Hewett, D. F., Dolomitization and ore deposition: Econ. Geology, vol. 23, pp. 821–863, 1928. Rastall, R. H., Physico-chemical geology, p. 196, London, 1927. Nolan, T. B., The Gold Hill mining district, Utah: U. S. Geol. Survey Prof. Paper 177, p. 109, 1935.

[19] Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, pp. 206–216, 1898.

[20] Vanderwilt, J. W., Revision of the structure and stratigraphy of the Aspen district, Colo., and its bearing on the ore deposits: Econ. Geology, vol. 30, p. 239, 1935.

[21] Hayward, M. W., and Triplett, W. H., Occurrence of lead-zinc ores in dolomitic limestones in northern Mexico: Am. Inst. Min. and Met. Eng. Tech. Pub. 442, 1931.

pling (nearly 1,000 samples) indicated no addition of magnesia during the period of mineralization, but the ore showed a decided preference for dolomites rather than limestones. This was explained on the basis of four points: (1) Dolomite beds are more crystalline and break more readily than limestone; (2) dolomites are more porous; (3) difference in chemical composition; (4) damming influence of dense thin-bedded dolomites. (Dolomite as used by Hayward and Triplett contains plus 5 percent of MgO.)

Field observations at Metaline check those of Vanderwilt and Hayward and Triplett in that regional dolomitization preceded ore deposition. The evidence is interpreted to indicate that no dolomite was added by the ore-bearing solutions although magnesium in the rocks was moved and concentrated by the solutions.

The dolomitized limestones appear to be more porous and vuggy than the unaltered beds, although precise data are not available. To change a cubic decimeter (0.035 cubic foot) of limestone into dolomite with no change in volume requires an addition of 628 grams of MgO and 178 grams of CO_2 and the loss of 646 grams of CaO. As pointed out by Hewett,[22] however, if the dolomite has any porosity, the quantities of MgO and CO_2 added are diminished proportionally. Huge quantities of CaO are liberated and apparently removed during dolomitization.

If a given volume of calcite is changed to dolomite and the excess calcium removed, an increase in porosity of about 12.46 percent takes place. The process of dolomitization is generally incomplete, and part of the pore spaces are filled with calcite and silica. Nevertheless, the increase in voids during the change from calcite to dolomite is a factor large enough to have an appreciable influence on permeability and possibly on ore deposition.

ORE DEPOSITS

HISTORY OF MINING

The earliest recorded exploration of the region was made by David Thompson in 1811. Thompson's excellent geographic observations [23] are well known, although he did not mention the mineral possibilities of the Pend Oreille Valley. According to Browne [24] the first mineral discovery (gold) in eastern Washington was about 1855 in the vicinity of Fort Colville on several tributaries of the Columbia. Bauerman [25] recorded gold placers on the lower Pend Oreille River being worked in 1858, and Bethune [26] gives a few details of the early discoveries.

According to Mineral Resources,[27] lead deposits were known in the Metaline district as early as 1869. A mineral map of the Territory of Montana,[28] published in 1865, includes the Metaline region but gives no indication of mineral in the area, and the geography is largely hypothetical. A topographic map of the Colville region,[29] published in 1882, shows a small part of the Pend Oreille River near what is now Metaline Falls. The country was accessible by trail from Colville, but no settlement was indicated in the Pend Oreille Valley. and the geography was imperfectly known. Bethune [30] states that the rich lead-silver deposits of the Colville area were discovered in 1883 and that the region was brought into prominence by the development of the Old Dominion mine in 1885. Bethune also states that the Metaline district was one of the largest and oldest mineral divisions of Stevens County (which at that time included the present Pend Oreille County). The name Metaline was applied because of the immense amount of metal in sight.[31] Apparently some attempt at mining was made about 1886,[32] and Bethune [33] mentions the Bonnie Blue Belle claim being patented in 1891. Abercrombie [34] explored the Pend Oreille Valley from Pend Oreille Lake to the international boundary in 1885 and was impressed by the mineral possibilities of the region. Taylor [35] surveyed the river valley in 1897 and recommended methods of improving navigation as far north at Metaline.

Prior to 1906 the district was difficultly accessible by boat from Newport down the Pend Oreille River to a landing below Ione and thence by wagon road, or else by a poor wagon road over the mountain from Colville, a distance of about 50 miles. In 1906 the Federal Government deepened the channel of the Pend Oreille at Box Canyon, thus permitting through boat service between Newport and Metaline, a trip of about 60 miles. The Idaho & Washington Northern Rail-

[22] Hewett, D. F., op. cit., p. 850.

[23] Thompson, David, Narrative of explorations in western America, 1784–1812; edited by J. B. Tyrrell, Toronto, Champlain Society, 1916. New light on the early history of the Greater Northwest (manuscript journals of Alexander Henry and David Thompson), edited by Elliot Coues, New York, Francis P. Harper, 1897.

[24] Browne, J. R., Resources of the Pacific slope, p. 182, New York, Appleton, 1869.

[25] Bauerman, H., Report on the geology of the country near the 49th parallel of latitude west of the Rocky Mountains, based on observations made in 1859–61, pp. 35B–37B, Montreal, 1884.

[26] Bethune, G. A., Mines and minerals of Washington: State Geologist, 1st annual Rept., pp. 5–10, 1891.

[27] Mineral Resources U. S., 1906, p. 451, information furnished by L. P. Larsen and Mr. and Mrs. D. D. Birks.

[28] DeLacy, W. W., Mineral map, Territory of Montana, in personal files of J. T. Pardee, published 1865.

[29] Gannett, Henry, Map of Colville region, Washington Territory, Northern Transcontinental Survey, 1882.

[30] Bethune, G. A., op. cit., p. 12.

[31] Idem, pp. 82–83.

[32] Mineral Resources, U. S., 1906, p. 451.

[33] Bethune, G. A., op. cit., p. 83.

[34] Abercrombie, W. R., Report on the Pend d'Oreille River: Mining, 1896, pp. 245–250.

[35] Taylor, Harry, Survey of Pend Oreille River, from its source at Lake Pend Oreille, Idaho, to the town of Metalline, Wash.: Chief Eng. Rept., 1898, pt. 4, pp. 3124–3131.

road, now a branch of the Milwaukee System, was completed to Metaline Falls in 1910. With the advent of the railroad the region entered a new era of development, as its timber and mineral resources were rapidly exploited.

The presence of limestone and shale suitable for cement manufacture was known before completion of the railroad.[36] After the railroad was installed an attempt was made to manufacture cement just north of Ione but proved a failure. Another plant at Metaline Falls was successful and is now operated by the Lehigh Portland Cement Co.

The development of the metal resources of the region has been slow because of the inaccessibility, the low grade of the lead-zinc ores near the surface, and the general absence of gold and silver. The successful growth of the district is due largely to the persistence and tenacity of Lewis P. Larsen, who first became materially interested in the district in 1906, when he obtained control of what was then known as the Clark property. Mr. Larsen and his financial backers tried repeatedly to develop ore on a commercial scale and to construct plants capable of handling the low-grade lead-zinc bodies profitably. It was not until 1928–29 that, as a result of diamond core drilling, a considerable body of minable zinc-lead ore was found on the property of the Pend Oreille Mines & Metals Co. Since that time, development has been rapid and the limits of the known ore have been greatly extended. In 1936–37 the Metaline Mining & Leasing Co., a subsidiary of the American Zinc, Lead & Smelting Co., began operations in the old Bella May mine on ore previously determined by diamond drilling.

The district has not been without its periods of inflation and promotion bubbles, the most flagrant of which was in 1928–29 in connection with the development of the Grandview property.[37]

PRODUCTION

The earliest known production of ore from the Metaline district was in 1906, when a small shipment containing 73.1 percent of lead, 2 percent of zinc, and 1.1 ounces of silver was made.[38] Prior to 1915, however, production was negligible, but in that year 3,111 tons of an average value of $9.76 was shipped from the Pend Oreille mine (Clark property). Some production has been made yearly since 1915 except in 1920, 1921, 1928, and 1935. With the improved modern milling facilities now available it is expected that production will be greater in the future, depending of course on economic conditions and an adequate ore supply.

The value of metals recovered from ores of the Metaline district is shown in the following table compiled by C. N. Gerry, of the United States Bureau of Mines.

During the early period of mining the principal product was of lead, but in recent years zinc has become the most valuable metal. The silver and copper are byproducts of the zinc-lead mining, but the gold was obtained from placers and from the Oriole ores.

Most of the production has come from the Pend Oreille mine, but considerable yield is credited to the Bella May and Grandview. Smaller shipments have been made from the Oriole, Z Canyon, Lead Hill, Lead King, Lucky Strike, Cliff, Diamond R, Lead Queen, and a few other claims.

In addition to the production from the Pend Oreille Valley two other properties, the United Treasure and the Frisco Standard, are known to have produced some metal. These two mines, in the northwestern part of the quadrangle, in Stevens County, have yielded lead, silver, copper, and a little gold. The total value of their production is not known but is probably several thousand dollars.

Prospecting from 1927 to 1937 was so encouraging that large tonnages of ore were developed and are being mined. Development has been slow and expensive, but, in view of the results, it is felt that the future of the district is assured for several years.

ORE BODIES

The ore deposits in the Metaline quadrangle are of several types. By far the most productive type comprises the replacement deposits accompanied by some cavity filling in the carbonate rocks outside of the zone of marked igneous metamorphism. A closely related type which has been little explored consists of the replacement deposits in altered carbonate rocks adjacent to the Kaniksu batholith. Lodes are worked at several places, and a few have been productive. Molybdenite is reported from a pegmatite dike on Molybdenite Mountain,[39] but the prospect could not be found during this investigation. The Mule Deer deposit is unique in the region, but sufficient development work has not been done on it to permit classification. It appears to contain sphalerite and galena disseminated through highly altered quartz monzonite of the Kaniksu batholith. A little placer gold has been recovered in the gravels of the Pend Oreille River and its tributaries.

[36] Adair, J. B., The Metaline district: Northwest Min. Jour., vol. 7, p. 56, 1909.

[37] Haggen, E. A., Geology of the Pend Oreille formations (Metaline district): Min. and Indust. Record (Vancouver, B. C.), vol. 31, pp. 82–83, April 1928; Mines Mag., vol. 38, no. 6, pp. 384–385, June 1928.

[38] Mineral Resources U. S., 1906, p. 451.

[39] Bancroft, Howland, Ore deposits of northeastern Washington: U. S. Geol. Survey Bull. 550, p. 45, 1914.

Gold, silver, copper, lead, and zinc produced in the Metaline district, Pend Oreille County, Wash., 1901–40, in terms of recovered metals (prior to 1911, Stevens County)

[Compiled by C. N. Gerry, statistician U. S. Bur. Mines]

Year	Mines		Ore (short tons)	Gold		Silver		Copper		Lead		Zinc		Total Value
	Lode	Placer		Fine ounces	Value	Fine ounces	Value	Pounds	Value	Pounds	Value	Pounds	Value	
1906	1		26			45	$30			34, 100	$1, 943			$1, 973
1909		1		13. 98	$289	2	1							290
1901–10			26	13. 98	289	47	31			34, 100	1, 943			2, 263
1911	1	1	51	30. 62	633	1, 605	851	411	$51	11, 982	539	20, 590	$1, 174	3, 248
1915	1		3, 111									244, 906	30, 368	30, 368
1916	1		15, 145			85	56			37, 695	2, 601	861, 322	115, 417	118, 074
1917	6		15, 093	8. 22	170	1, 504	1, 239	490	134	129, 639	11, 149	1, 176, 715	120, 025	132, 717
1918	4		245			264	264			184, 734	13, 116	38, 873	3, 537	16, 917
1911–20			33, 645	38. 84	803	3, 458	2, 410	901	185	364, 050	27, 405	2, 342, 406	270, 521	301, 324
1923	2		34			46	38			31, 233	2, 186			2, 224
1924	2		966			1, 291	865			868, 920	69, 513			70, 378
1925	8	1	914	1. 69	35	1, 043	724			757, 652	65, 916			66, 675
1926	12		813	4. 60	95	1, 818	1, 135	117	16	326, 931	26, 155	65, 485	4, 912	32, 313
1927	4		35, 348	11. 03	228	2, 913	1, 651	1, 075	141	290, 861	18, 324	936, 576	59, 941	80, 285
1929	2		50, 920	8. 03	166	2, 250	1, 199	4, 762	838	655, 958	41, 325	2, 061, 574	136, 064	179, 592
1930	2	2	7, 200	9. 53	197	1, 023	394	315	41	534, 370	26, 718	703, 782	33, 782	61, 132
1921–30			96, 195	34. 88	721	10, 384	6, 006	6, 269	1, 036	3, 465, 925	250, 137	3, 767, 417	234, 699	492, 599
1931	1	3	80, 968	15. 67	324	4, 595	1, 333	2, 670	243	2, 514, 977	93, 054	9, 947, 495	378, 005	472, 959
1932	2	4	33, 443	28. 59	591	2, 606	735	3, 396	214	1, 364, 066	40, 922	4, 489, 334	134, 680	177, 142
1933	1	3	48, 479	18. 62	[1] 476	3, 263	1, 142	5, 062	324	1, 443, 783	53, 420	6, 738, 169	283, 003	338, 365
1934	1	5	28, 322	12. 53	438	1, 151	744	2, 575	206	473, 649	17, 525	3, 852, 419	165, 654	184, 567
1935		3		6. 00	210									210
1936	1	2	76, 060	3. 20	112	3, 317	2, 569	6, 011	553	1, 540, 847	70, 879	8, 777, 220	438, 861	512, 974
1937	4	4	106, 028	10. 00	350	12, 525	9, 688			5, 287, 797	311, 980	8, 190, 600	532, 389	854, 407
1938	2	3	249, 184	7. 00	245	14, 584	9, 428			8, 018, 500	368, 851	22, 804, 000	1, 094, 592	1, 473, 116
1939	2	2	259, 320	8. 00	280	11, 603	7, 876			7, 018, 404	329, 865	20, 260, 558	1, 053, 549	1, 391, 570
1940	4	0	273, 233			8, 609	6, 122			4, 989, 500	249, 475	23, 120, 000	1, 456, 560	1, 712, 157
1931–40			1, 155, 037	109. 61	3, 026	62, 253	39, 637	19, 714	1, 540	32, 651, 523	1, 535, 971	108, 179, 795	5, 537, 293	7, 117, 467
1906–40			1, 284, 903	197. 31	4, 839	76, 142	48, 084	26, 884	2, 761	36, 515, 598	1, 815, 456	114, 289, 618	6, 042, 513	7, 913, 653

[1] Gold calculated at $25.56 an ounce.

REPLACEMENT DEPOSITS

GENERAL FEATURES

The principal replacement deposits occur in the Metaline limestone, although some are found in other carbonate beds. Production from the Metaline limestone has been almost entirely from the upper 500 feet, just below the Ledbetter slate.

The mineral composition of the replacement ores is simple. Sphalerite is at present the most valuable constituent, but it is usually accompanied by galena. Small quantities of silver and copper are recovered in parts of the ore.

Sphalerite is found in a wide variety of colors, pale yellow or resin, brown, and red, all of which may be present in a single ore shoot. Small amounts of galena are distributed through the ores, but galena appears to be concentrated near the peripheries of the ore bodies. In a few places more galena is present than sphalerite. Pyrite occurs in large quantities at many of the mines, particularly the Lucky Strike, Riverside, and other properties in the river gorge. Pyrite is scarce or absent in the ores at the Pend Oreille, Bella May, and Lead Hill mines, although it is found in the nearby country rock. A little marcasite is widely dispersed in much of the ore.

The gangue is customarily dark-gray or black jasperoid which in places grades into milky quartz. (See pl. 25, *B*.) Crystalline dolomite and coarse calcite are abundant, and in some places sphalerite and galena are disseminated through bedded dolomites and dolomitic limestones. In a few places, as at the Pend Oreille mine, unaltered limestone has been locally mineralized. Barite is one of the common minerals at Lead Hill but is scarce or absent in other deposits.

The replacement ores are generally massive but in some places are porous and vuggy, the vugs being lined with crystals of sphalerite and quartz. Unquestionably some open-cavity deposition of ore has taken place, but the amount is thought to be subordinate to that of replacement origin. The textures of the zinc ores vary widely; many are fine-grained and dense, others are coarse-grained and massive and contain crystals of sphalerite half an inch or more across. Galena crystals probably average larger than sphalerite crystals, but in a few places fine-grained or "steel" galena is found.

A mottled appearance or a crude banding (see pl. 24, *C*) that resembles the so-called "zebra" dolomite is found in many places, particularly in the coarser-grained and lower-grade ores.

An unusual type of concentrically banded mineralized dolomite is present at several properties, particularly those near Z Canyon. (See pl. 26.) The rock resembles some of the zinc ores from the southern Appalachian deposits [40] and from Upper Silesia.[41] Currier believes that the concentric structure has resulted partly from cavity filling and partly from replacement of a breccia in which the sharp corners and edges were more rapidly attacked than the rest of the breccia fragments. Krusch [42] thinks that the Upper Silesian ores were introduced in the colloidal state and attributes the banding to rhythmic precipitation. It would appear that concentric banding might result from either or both of these processes. No conclusive evidence in support of either idea was found at Metaline.

FORM AND STRUCTURE

The mineralized replacement bodies are irregular in size and shape. They range from a few scattered sulfide grains to the ore bodies shown on the map of the Pend Oreille mine (pl. 33). In a general way the ores follow bedding, but in detail they are crosscutting. Most of the ore bodies are 10 to 20 feet thick, but one mass of ore about 50 feet in its shortest dimension was mined in the Pend Oreille.

Most of the ores occur in breccia zones in the carbonate rocks. The jasperoid and ore have cemented and replaced breccia fragments and obscure preexisting structures. In several stopes in the Pend Oreille mine well-defined fractures in the country rock can be followed to the ore, and the sulfides and jasperoid spread out from the fractures. All the ore bodies studied in detail are related to breccia zones or fractures which have acted as feeders and from which the ore-bearing solutions have replaced the more favorable carbonate beds.

Many ore bodies are cut or bounded by smooth slickensided surfaces that brecciate and polish the ores. (See pl. 25, *C*, *D*.) The postmineral movement was generally small, offsets of more than 10 feet being uncommon, although along a few faults the displacement may be 100 feet or more. Many postmineral faults seem to merge into the premineral faults and are lost in cemented and mineralized breccia and in coarse calcite. For this reason most of the postmineral faults are thought to have been formed by minor readjustments along older fractures.

Caves are of rather common occurrence along fractures and in breccia zones. A few caves in the Pend Oreille mine were mineralized and yielded good ore.

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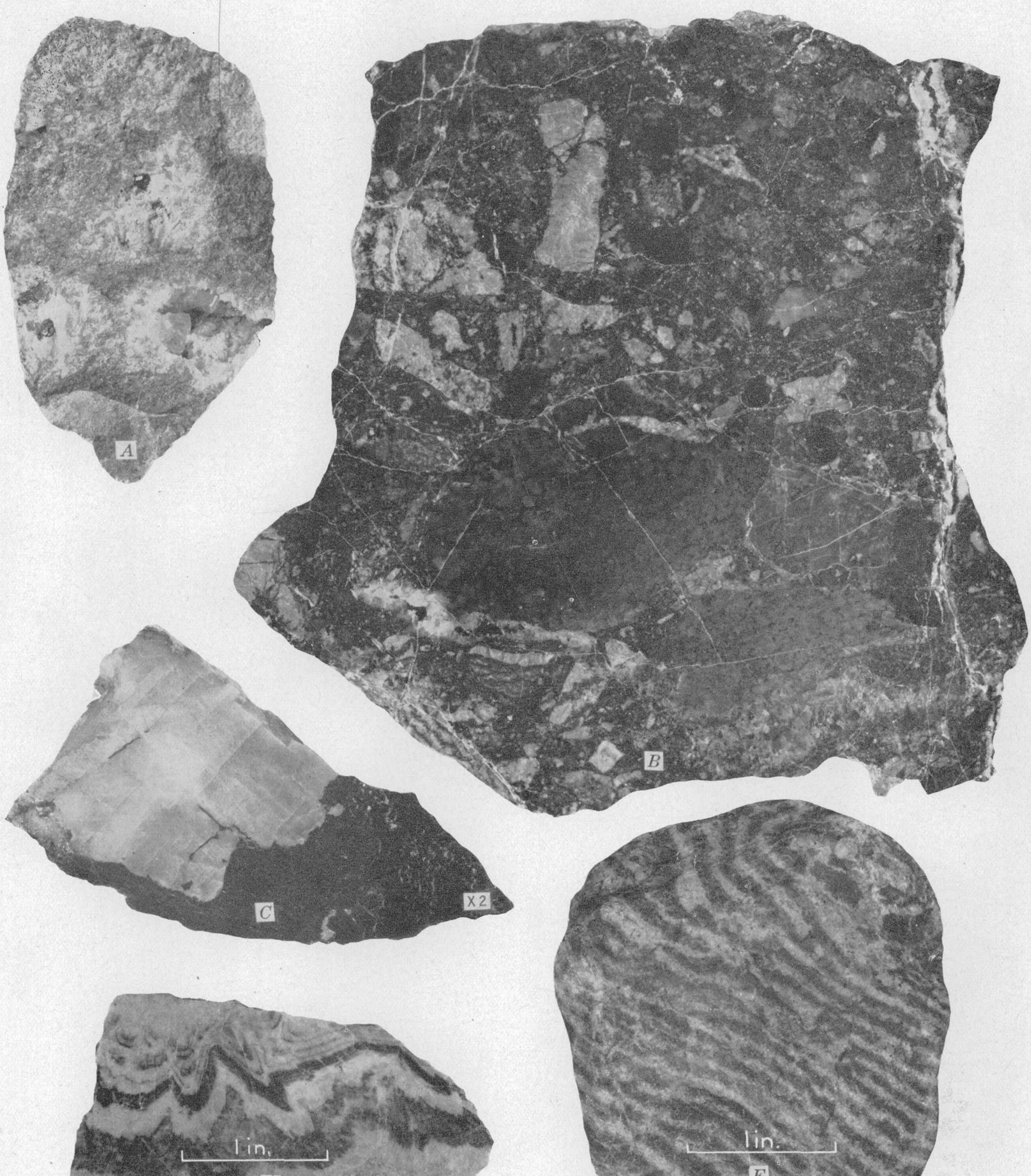
[40] Currier, L. W., personal communication, March 1938; Zinc and lead region of southwestern Virginia: Virginia Geol. Survey Bull. 43, pls. 24, 25, and 26, 1935.

[41] Stappenbeck, R., Ausbildung und Ursprung der oberschlesischen Bleizinkerzlagerstätten: Archiv für Lagerstättenforschung, Heft 41, pp. 79–85, Preuss. geol. Landesanstalt, 1928.

[42] Krusch, P., Über kolloidal Vorgange bei der Entstehung der oberschlesischen Zink-Bleierzlagerstätten: Deutsche geol. Gesell. Zeitschr., Band 81, pp. 169–170, 1929.



A. BUTTONS OF ANTHRACITE COMPOSITION IN RECRYSTALLIZED DOLOMITIC LIMESTONE, WOLF CREEK PROSPECT.

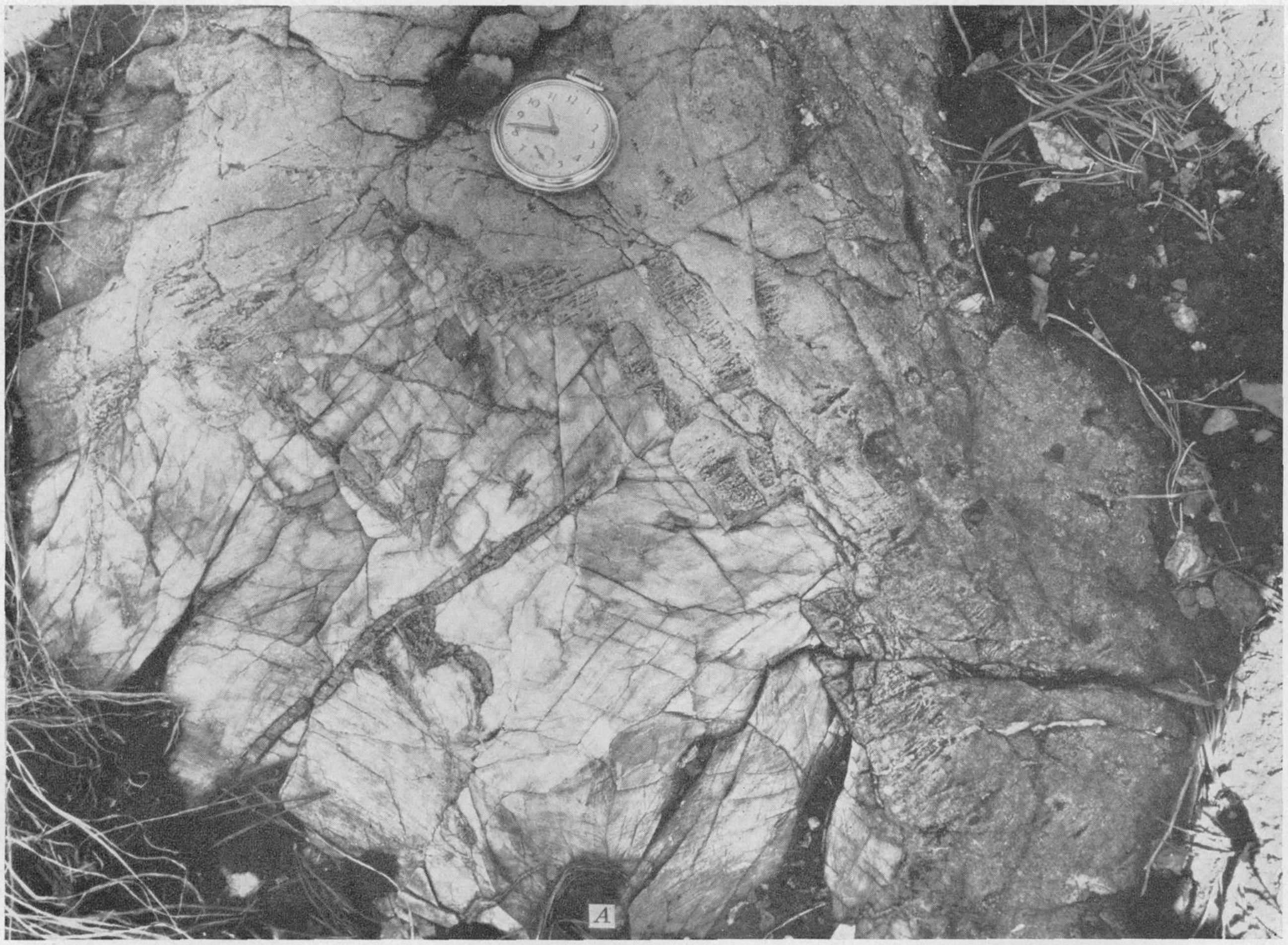
B. SILICIFIED AND MINERALIZED BRECCIA, PEND OREILLE MINE.

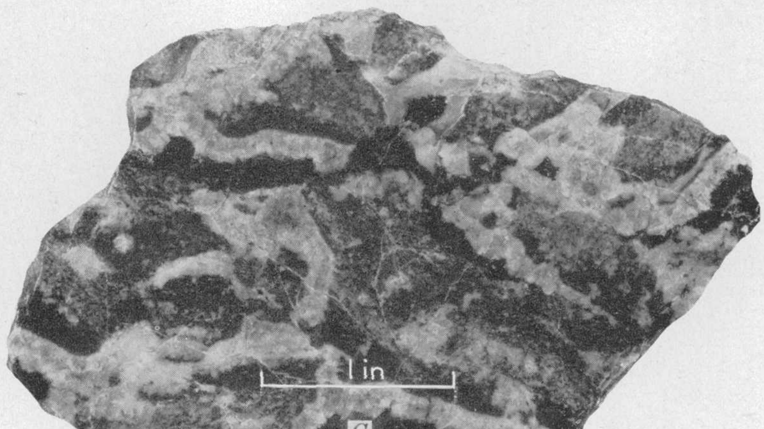
Light gray is mostly dolomite with a little translucent quartz. Dark gray is jasperoid and ore minerals. Veinlet along lower edge of specimen contains sphalerite in carbonates.

C. POLISHED FRAGMENT OF ORE IN WHICH GALENA (BLACK) REPLACES CALCITE ALONG CLEAVAGE PLANES, PEND OREILLE MINE.

D. CRUSTIFIED BANDING IN DOLOMITE, LAKEVIEW PROSPECT.

E. "ZEBRA" ROCK, COBBLE FROM STREAM IN EAST CENTER OF SEC. 14, T. 40 N., R. 42 E.





A. CALCITE AND DOLOMITE, LEAD HILL MINE.

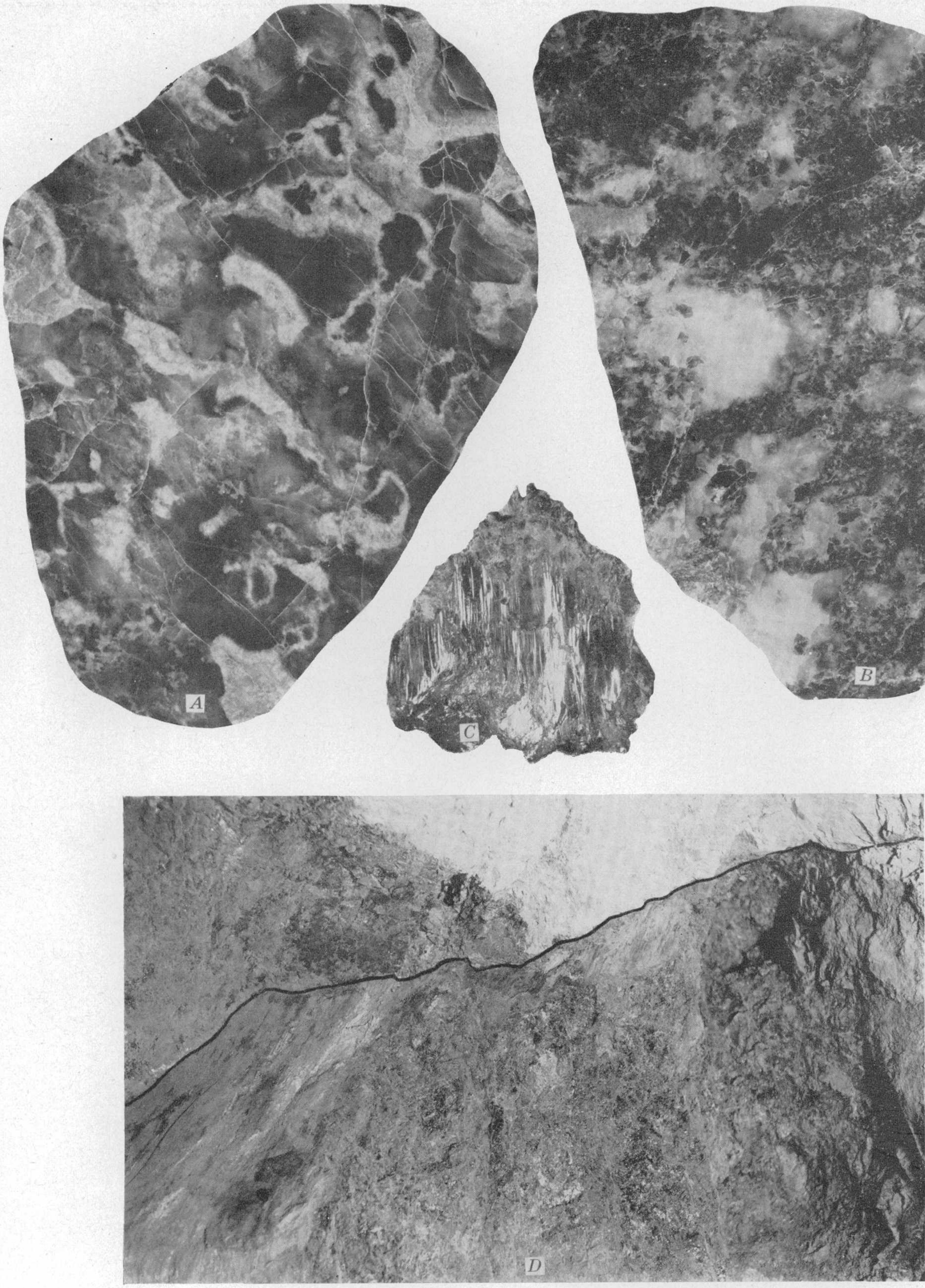
The calcite shows large rhombohedral cleavage surfaces and in general is lighter than the dolomite.

B. PARTLY SILICIFIED DOLOMITE, PEND OREILLE MINE.

Natural size. Note the seams of dark-gray quartz through the dolomite.

C. CRUDELY BANDED MINERALIZED ROCK, LAKEVIEW PROSPECT.

Black is sphalerite, light gray is dolomite, and dark gray is silicified dolomite.



A. POLISHED SLAB FROM GRANDVIEW ADIT.
Crustified dolomite (light) in jasperoid (dark). The centers of many of the dolomite areas are calcite. Natural size.

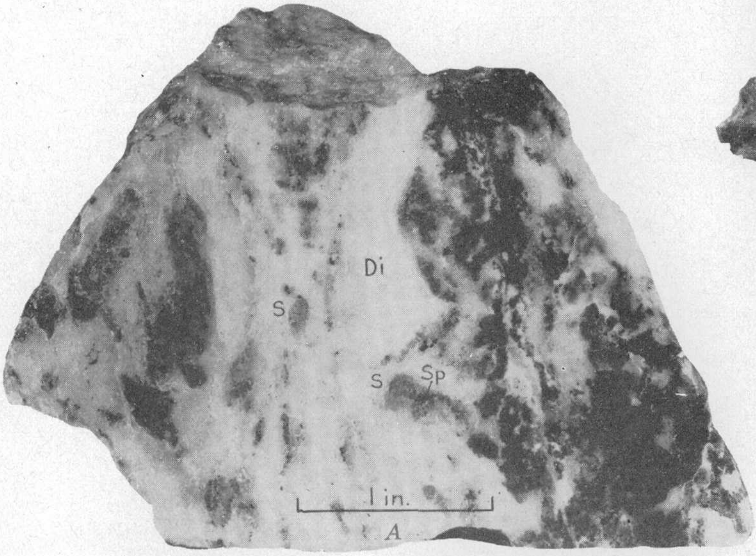
B. ZINC ORE FROM 500-FOOT LEVEL, PEND OREILLE MINE.
Dark gray and black are sphalerite and jasperoid. This specimen contains more milky quartz (white) than most ore. Natural size.

C. SLICKENSIDED GALENA, PEND OREILLE MINE.
From 700-foot level. Natural size.

D. POST-MINERAL FAULT, CALCITE FAULTED AGAINST ORE, PEND OREILLE MINE.
In stope, 500-foot level. Height of face approximately 6 feet.

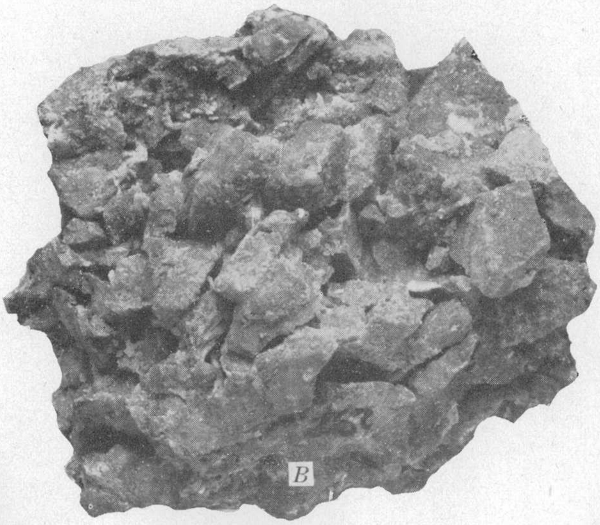
CONCENTRICALLY BANDED DOLOMITE AND SULFIDES, Z CANYON MINE.

Black is sphalerite with galena near outer edges, gray is dolomite, white is calcite, and a little pyrite is in the centers of the nodules. Natural size.



A. POLISHED SURFACE OF SPECIMEN OF MINERALIZED ROCK FROM THE COFFIN PROPERTY.

Serpentine (S), sphalerite (Sp), diopside (Di). Other minerals not labeled. Most serpentine contains cores of sphalerite.



B. CAVE BRECCIA, PEND OREILLE MINE.

700-foot level. Natural size.

C. WASHER AND GRAVEL BAR, SCHERDING PLACER, LOOKING NORTH.

The subject is discussed in some detail on pages 38–39.

In many underground workings a concentration of sphalerite is noticed at contacts between jasperoid and coarse calcite. The sphalerite is generally in layers of almost pure zinc sulfide a few inches to 2 feet thick. The contacts between sphalerite and calcite are sharp, and the sphalerite is commonly crystalline, as if deposited in cavities that were later filled with calcite. Sphalerite grades into lower-grade ore or jasperoid away from the calcite.

REPLACEMENT DEPOSITS IN THE IGNEOUS-METAMORPHIC ZONE

The replacement deposits in the igneous-metamorphic zone are of particular interest in a study of the genesis of the ores, although little effort has been made to develop them commercially. At several places along the contact of the Kaniksu batholith small amounts of sulfides are associated with diopside, garnet, serpentine, and other metamorphic minerals. The best-exposed body of this type is at the Coffin property, at the western edge of the quadrangle, in sec. 16, T. 38 N., R. 42 E. The workings at this property are in an altered carbonate layer in the Maitlen phyllite at the contact of the Kaniksu batholith.

A polished surface of typical ore is illustrated in plate 27, *A*. This photograph shows particularly well the clear, pale yellowish-green serpentine (light gray in the figure) in the white diopside. The cores of most of the serpentine areas are clear resinous sphalerite. Galena and sphalerite are associated with diopside, serpentine, and other metamorphic minerals in the right-hand one-third of the specimen but are not labeled in the figure. The sulfides, in addition to sphalerite and galena, include pyrrhotite, molybdenite, and pyrite. The gangue is principally diopside and carbonate with lesser amounts of serpentine, phlogopite, tremolite, chrysotile, and other metamorphic minerals.

Not enough work has been done to delimit the mineralized ground at the Coffin property, but the sulfides are distributed through the rock similarly to the distribution in the better-known replacement bodies in the carbonate beds. The similarity of the two types of deposits is further brought out by mineralized bodies such as that at the O. K. property, which appear to be transitional from one type to the other.

The O. K. deposit is in the Monk formation west of the Flume Creek fault and is about 2 miles from the closest known contact with the batholith, although a few pegmatite dikes and small, poorly exposed granitic rock outcrops are nearby. This deposit consists of a small proportion of sulfides (sphalerite, galena, tetrahedrite, pyrite, pyrrhotite, and very little chalcopyrite) in a dominant gangue of white crystalline limestone that contains diopside, tremolite, yellowish-green serpentine, and a few other metamorphic minerals. Molybdenite has been found only near the batholith contact at three places—the Coffin property, a road cut in marble in Dry Canyon, and the Noisy Creek prospect. Wulfenite, however, has been found in the oxidized ores at the Bella May and Diamond R properties, and it is possible that molybdenite is present in small amounts in the unoxidized ores.

LODE DEPOSITS

Lode deposits are known in many places in the quadrangle. Probably the most productive are those in the Ledbetter slate at the Frisco Standard, United Treasure, and nearby properties and in the Monk formation at the Oriole. Well-defined fissure veins are rather common but are generally less than 1 to 2 feet thick in the greenstone and associated rocks at the Gypsy copper camp. At the Noisy Creek prospect an irregular quartz body lies along the contact between a small granitic intrusive mass and the Maitlen phyllite.

The lodes at the Frisco Standard, United Treasure, and other prospects nearby have many features in common. The ore minerals are silver-bearing tetrahedrite, galena, sphalerite, and pyrite, and their oxidation products. The gangue is made up of a vitreous milky-white quartz and a little white carbonate. The lodes consist of numerous stringers and small veins, which in places coalesce and form quartz bodies up to 7 feet thick. Ribbons and fragments of carbonaceous country rock are abundant in the quartz, most of which has a layered structure formed by preservation of part of the carbonaceous material. So-called shadows or skeletons of the slate in the quartz are interpreted to mean that the quartz replaced the country rock. The quartz bodies are much contorted and irregular but are not appreciably faulted or shattered. Much black graphitic gouge is found along the borders of the quartz bodies. Bedding planes cannot everywhere be recognized, but as a rule the quartz bodies appear to follow the crenulations of the deformed bedding, although in detail quartz cuts the beds. It is thought that the quartz was introduced along minor zones of faulting that nearly conformed to the bedding. A little post-mineral movement can be recognized, but in general it appears to be negligible. At the United Treasure and My Era properties the ore bodies in places are parallel to basic sills. The sulfides are not distributed uniformly through the quartz but are concentrated in shoots, the sizes and shapes of which are unknown.

The ore deposit at the Oriole mine has been described by Jenkins [43] and by Patty.[44] Most of the workings

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[43] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Cons. and Devel., Div. Geology, Bull. 31, pp. 67–69, 1924.

[44] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, pp. 87–88, 1921.

at this mine were inaccessible except for the adits in the oxidized zone and a part of one stope in the sulfides. The ore on the dump contains silver-bearing tetrahedrite, sphalerite, galena, and pyrite. The gangue in the more massive sulfides is vitreous white quartz that is commonly in spheroidal grains about half an inch in diameter. The leaner sulfides are scattered through white quartz or a granular silicified rock that is derived through the alteration of sandy dolomite in the Monk formation. In the upper workings the lode is a gouge-filled fissure a few inches wide that locally widens to 2 or 3 feet. These wider parts were mined out and apparently yielded the ore from the upper levels. In depth the shoots are reported to be up to 4 feet thick but they pinch and swell abruptly on the strike. Patty describes the ore shoots as replacement lenses in breccia. The Oriole is best described as a narrow, steeply dipping shear zone in silicified dolomite. Along this zone there are several small lenses or pipes. The deposit could as well be classified as of a replacement type, although the distribution of the ores in a narrow zone along a fissure distinguishes it from the more irregular-shaped bodies at the Bella May and Pend Oreille mines.

Bancroft [45] describes the deposit at the Riverside property as a fissure vein in which the country rock is partly replaced on each side, and parallel fissures extend 15 to 20 feet from the main vein. The Riverside was inaccessible when visited by the writers, and no additional information about the mineralization was obtained. In many nearby mineralized areas what appear to be similar fissures are exposed. The deposits probably should be classified as replacement bodies rather than veins, as the mineralized ground is irregular and extends laterally from the fissure zone into carbonate beds.

RELATIONS OF ORE DEPOSITS TO REGIONAL STRUCTURE

The localization of the ore deposits is closely dependent upon the regional structure. Two features particularly stand out—the relation between the ore deposits and major faulting and the relation of the ore deposits to the Ledbetter slate.

Most of the ore deposits are within a mile of one of the major faults, particularly the Flume Creek fault, Russian Creek fault, and Slate Creek fault. The ores are not in the major faults but are associated with lesser breaks and breccia zones, particularly in the hanging-wall blocks of the major faults. A few deposits, such as that at the Oriole, are in the footwall blocks. Other deposits, such as those at Z Canyon and at the mouth of Slate Creek, are near faults of comparatively minor structural significance.

[45] Bancroft, Howland, Ore deposits of northeastern Washington: U. S. Geol. Survey Bull. 550, pp. 50–51, 1914.

The principal known replacement ore bodies, in addition to being near faults or in breccia zones, are in the Metaline limestone within less than 500 feet below the Ledbetter slate. It is reasonable to suppose that the ore deposition was aided by the damming action of the relatively impervious slate. The ores are generally in dolomite or dolomitic limestone, but some are in limestone. The localization in dolomite may be explained by the fact that most carbonate beds below the slate are dolomitic rather than that replacement was partial to magnesian beds.

A few deposits, such as that at the Coffin property, are localized in a carbonate bed, at the contact with the Kaniksu batholith. Other deposits, such as the veins at the Gypsy copper camp, have not been studied in detail, and their relations to the regional structure are unknown.

The relations of regional folding to ore deposition, if any, are not known.

BRECCIATION

Many of the rocks in the Metaline quadrangle, particularly the brittle carbonate rocks and quartzites, are brecciated. The breccias in the carbonate rocks are of particular interest because of their close association with the ores. Three types are recognized—crush breccia (crackle type), rubble breccia, and cave breccia.

Crush breccia.—Crush breccia is by far the most abundant type in the Metaline limestone. It is defined as a breccia in which the individual fragments are generally 2 inches or less in greatest dimension, show little or no rounding, and relatively little displacement or rotation.[46] All the breccia bodies examined in detail show slickensided surfaces and other evidences of minor fault movement. The breccia is strikingly similar to that associated with the zinc-lead deposits of southwestern Virginia and Tennessee, where Newman [47] and Currier [48] attribute the crushing to tectonic forces. Newman ascribes the breccia to movement, although faults of any magnitude were not recognized in the mines. Vanderwilt [49] points out that the amount of brecciation in limestone is no criterion of the amount of offset along a shatter zone. The crush-breccia bodies at Metaline are vaguely defined and fade into the unbroken carbonate rock. In places, such as the Pend Oreille mine and the Lead Hill mine, practically the entire country rock is brecciated. Superficially at least, the brecciation appears to be more intense in the dolo-

[46] Norton, W. H., A classification of breccias: Jour. Geology, vol. 25, pp. 161, 188–189, 1925.

[47] Newman, M. H., The Mascot-Jefferson City zinc district of Tennessee: 16th Internat. Geol. Congress Guidebook 2, pp. 161–162, 1933.

[48] Currier, L. W., Zinc and lead region of southwestern Virginia: Virginia Geol. Survey Bull. 43, pp. 83–86, 1935; Structural relations of southern Appalachian zinc deposits: Econ. Geology, vol. 30, pp. 260–286, 1935.

[49] Vanderwilt, J. W., Revision of structure and stratigraphy of the Aspen district, Colo., and its bearing on the ore deposits: Econ. Geology, vol. 30, pp. 234–235, 1935.

mite than in the limestone, although not confined to the dolomite.

The abundant stylolites in the upper parts of the Metaline limestone (see pl. 8, *A*) indicate that appreciable removal through solution has taken place. Slumping of overlying beds, caused by this solution, may account for part of the brecciation, and it is possible that the brecciation has been accentuated by the dissolving action of mineralizing solutions.[50] Crush breccia, however, is too widespread to be attributed entirely to slumping. This type of breccia, obviously connected with faulting and folding, is also found in the Gypsy quartzite in at least three places—Hall Mountain near the junction of the Russian Creek and Flume Creek faults, and west of Lost Lake. Crush breccia in the Metaline quadrangle is attributed almost entirely to tectonic forces. The brecciation was not, however, the result of a single period of activity but probably occurred at several stages in the long structural history.

Rubble breccia.—Where crush breccia approaches fault zones the fragments have been increasingly displaced and rotated, forming what is known as rubble breccia. The fragments are smaller than those in the crush breccia and average about half an inch in diameter. They are generally subrounded to subangular. In the faults the breccia becomes in places a limy gouge in which are embedded rounded particles varying widely in number and variety. Rubble breccia is everywhere associated with faults and was caused by faulting.

Cave breccia.—Fractures and breccia zones offer favorable paths for circulation of solutions. In places the solutions enlarge their channels and form caves and vugs in which the less soluble parts of the rock and slumped fragments accumulate. Such a breccia is illustrated in plate 27, *B*. In this specimen the individual fragments are cemented by calcite dripstone and chalcedony.

ORIGIN OF THE ORES

The zinc-lead deposits of the Metaline quadrangle are thought to have been deposited mainly by hot solutions, the source of which was the magma that is now represented in part by the Kaniksu batholith. The pale-yellow sphalerite may be, at least in part, of supergene origin, as it is found in caves on paligorskite and is commonly near and in fractures where groundwater circulation is now vigorous.

The similarities between the replacement ores in the Metaline limestone and the replacement bodies in the igneous-metamorphic zone suggests that the two types were deposited during one period of mineralization. The replacement ores in the metamorphic rocks were possibly formed after diopside and other high-temperature silicate minerals, as the paragenesis indicates that the sulfides are late, although the relations are somewhat vague. Igneous metamorphism in the Metaline area was directly related to the Kaniksu batholith, and the metallization in such deposits as that at the Coffin property was an essential part of the igneous metamorphism. It is concluded, therefore, that the ore deposits are directly related to the Kaniksu batholith and were emplaced late in the igneous history, probably after partial or complete solidification of the intrusive mass.

If the assumption is admitted that the lead-zinc metallization took place during only one period, then the sphalerite and galena in the altered intrusive rock at the Mule Deer prospect afford further evidence that the metals were introduced after solidification of the batholith.

Localization of the ores near the major faults is interpreted to mean that a source of the mineralizing fluids in depth was tapped by the larger fractures. It is likely that intrusive rock is within a few thousand feet of the surface at the Oriole and O. K. properties, as indicated by the pegmatitic and small granitic bodies and by the igneous-metamorphic effects shown in the phyllites along the Flume Creek fault. It is also likely that the mineralizing solutions originated in or beneath this buried intrusive mass and worked toward the surface through the fractured zone associated with the Flume Creek fault. It is reasonable to assume that the batholith, lamprophyres, and ores had the same ultimate source and that they were emplaced in that order.

OXIDIZED ORES

Oxidation of the ores in the Metaline district in general has been slight. Galena commonly is unaltered at the surface, and at a few places fresh sphalerite is found. The sphalerite is commonly leached, however, and vugs that may or may not contain iron oxide mark its former presence. At the Oriole mine oxidation has been rather thorough to a depth of 50 feet. Below this level a little iron oxide is found in fractures and channels where circulation is particularly rapid.

The explanation of the shallow oxidation zone is probably found in the scouring action of the Pleistocene ice sheets, which removed most of the loose, weathered material.

The mineral composition of the oxidized ores is simple. The gangue consists principally of quartz and soft powdered carbonates. Iron-oxide stains are abundant, particularly in the pyrite-rich areas. Smithsonite and cerussite are present in most outcrops, and there are a few small patches of other minerals such as greenockite and malachite.

[50] Locke, A., The formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, pp. 431–453, 1926.

FUTURE OF THE DISTRICT

Development of the Metaline district has been slow, and only in the last 10 or 12 years have large, commercially valuable ore deposits been found. Evidence of mineralization near the surface is generally scattered, and the ore is developed only through expensive and persistent exploration. The ore bodies are too imperfectly known to permit generalizations as to size and grade of new bodies likely to be found. It should be emphasized here that most of the Metaline ores are not of high grade; perhaps 5 to 15 percent of combined lead-zinc is a fair average of mine run. The hope of the district in the future lies in efficient handling of large tonnages.

The largest ore bodies known to date are in the Metaline limestone less than 500 feet below the Ledbetter slate. They occur generally in jasperoid that has replaced breccia, and they are commonly bordered by an irregular shell of nonbedded crystalline dolomite and coarse-grained white or gray calcite. Bodies of mineralized jasperoid associated with crystalline dolomite and coarse-grained calcite are found at several places in the upper part of the Metaline limestone. These places are worthy of study and possibly of exploration. Additional ore may also be found below the Ledbetter slate in carbonate beds not now exposed. In general exploration below the slate should probably be limited to known mineralized areas until the detailed structure in the valley is better understood. Such unexplored mineralized areas near slate are numerous—for example, Wolf Creek, Morning and Mammoth, Grandview, Lead King, Giant, and Lead Hill, to mention a few of the claims.

Many carbonate beds, similar so far as known to those near the top of the Metaline limestone, are found throughout the region. The beds near the base of the Metaline limestone are interlayered with phyllites, and the structural conditions are similar to those below the Ledbetter slate. Most of these lower beds in the known mineralized areas are buried under 1,000 feet or more of other rocks and are difficult to explore. It is possible, however, that ore will be developed at some of these other horizons. Such a deposit is known at the Reeves-McDonald mine, in Canada just north of the Pend Oreille River at the mouth of Russian Creek.

The structural geology of the region has been given little study heretofore, and the present report leaves much to be desired. The geologic conditions, however, indicate that the chances of finding additional ore appear to be good.

Limestone and the other constituents used in the manufacture of cement are the only nonmetallic mineral resources mined at present. The available quantities of these materials seem to be adequate to supply normal needs for many years.

Andalusite and sillimanite, which are used in the ceramic industries, are of wide distribution in the metamorphic rocks near igneous contacts. Some of the occurrences are easily accessible, but whether or not the quantity and grade of the material will justify commercial development is not known.

MINERALS OF THE ORE DEPOSITS AND METAMORPHIC ROCKS

In the following paragraphs the minerals are listed according to Dana's classification.

NATIVE ELEMENTS

Graphite (C).—A few small flakes of metallic-appearing graphite were found in a fault zone at the Bella May mine. Soft black clay gouge that probably contains finely divided graphite is abundant along fault zones, particularly those in and near the Ledbetter slate.

Sulfur (S).—A little sulfur was found in an oxidized iron sulfide body at the Riverside mine. The mineral burned with a pale-blue flame and gave off fumes of SO_2.

Gold (Au).—Most of the gold recovered in the region is obtained from stream gravel, where it occurs in small, well-worn flakes that appear to have traveled long distances from their sources. This gold has probably been concentrated by the reworking of low-grade glacial drift. A little gold is reported in the ores at the Oriole and in even smaller amounts at the Frisco Standard and United Treasure properties. A little gold is possibly present in some of the quartz veins and stringers at the Gypsy copper camp.

SULFIDES

Molybdenite (MoS_2).—Small flakes of molybdenite are scattered through the altered limestone at the Coffin property and on the Dry Canyon road. The mineral is present also in small veinlets in the intrusive body at the Noisy Creek prospect and has been reported from a pegmatite dike on Molybdenite Mountain.

Galena (PbS).—Galena is the principal ore mineral of lead and is found in all the mines and prospects. Most of the galena was deposited after sphalerite, and in replacement bodies lead ores are commonly of higher grade near the borders of shoots. Most of the galena is so coarse that cleavage surfaces are readily seen, and a few octahedral crystals were found at the Wolf Creek property. A small part of the galena is the fine-grained variety known as steel galena.

Chalcocite (Cu_2S).—A very little chalcocite was found coating pyrite in the partly oxidized ores at the Oriole mine and in a small cut on the Dumont group of claims in Uncas Gulch.

Sphalerite (ZnS).—Sphalerite is the principal ore mineral of zinc and at present is of greater economic value than other ore minerals recovered in the region.

Several varieties of sphalerite are found; that in the veins is commonly "blackjack," but that in the replacement bodies is nearly free from iron. Four types of sphalerite are recognized in the replacement bodies. (1) A clear, pale-yellow or resin-colored variety (resin jack) of possible supergene origin is generally associated with and in places grades into (2) a bright-reddish type (ruby jack). The centers of individual grains are commonly reddish, and the borders are resin-colored, although the reverse relations are known. A third type, of brownish color, is found in the same deposits and appears to grade into the resin-colored and reddish varieties. The fourth type is somewhat unusual in that it is so fine-grained that individual cleavage surfaces are difficultly visible. A specimen from the Bella May dump contains light-brownish sphalerite mixed with barite. Material on the Lucky Strike dump is pale waxy or dirty white. The Lucky Strike ore is peculiar in that the specimens are about 50 percent pyrite, with the rest of the rock practically iron-free sphalerite and dolomite.

Sphalerite is generally associated with galena. Good crystals are found in calcite and more rarely in dolomite, projecting in vugs, and on quartz and paligorskite.

Greenockite (CdS).—The bright-yellow sulfide of cadmium was identified by W. T. Schaller in several specimens picked up on the dump at the Josephine shaft of the Pend Oreille mine. Greenockite was also recognized in the oxidized ores at the Z Canyon mine.

Pyrrhotite (FeS_{1+}).—Pyrrhotite is an uncommon mineral but has been recognized in the altered limestone at the Coffin and O. K. properties. A little pyrrhotite is found in a prospect pit with garnet, quartz, pyrite, and chalcopyrite in the west center of sec. 31, T. 35 N., R. 44 E., and also in the metamorphic rocks on Timber Mountain.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite is a rare mineral in the district. It has been identified microscopically in the ores from the United Treasure and Frisco Standard and from the O. K. and Oriole properties, where it occurs in small blebs scattered through tetrahedrite. Chalcopyrite is also present in the veins at the Gypsy copper camp and has been found with pyrrhotite, pyrite, garnet, and quartz near the intrusive contact in the west center of sec. 31, T. 35 N., R. 44 E.

Pyrite (FeS_2).—Pyrite is one of the most widespread and abundant ore minerals. It forms large bodies in the carbonate rocks of the Pend Oreille Gorge and in such places as the Flusey, Riverside, and Lucky Strike mines is abundant in and near the ore. Pyrite is present in small quantities in most of the ore deposits but is rare in the better replacement ores. Specimens from the Lucky Strike dump contain radiating clusters of fibrous iron sulfide that resemble marcasite. These radiating fibers are, however, isotropic and for this reason are called pyrite.

Marcasite (FeS_2).—A little marcasite is found in the ore deposits in cracks and vugs. Where identified it is probably supergene. It is possible that part of the iron sulfide bodies exposed in the Pend Oreille Gorge are marcasite, although the radiating fibrous mineral from the Lucky Strike is pyrite.

SULFOSALTS

Pyrargyrite (Ag_3SbS_3).—A small spot of a dark ruby-red mineral was found in a piece of ore from the Frisco Standard mine. Unfortunately this mineral was lost while a polished section was being prepared for study. It is thought that the material was a dark ruby silver, pyrargyrite or possibly pearceite (Ag_9SbS_6).

Tetrahedrite ($Cu_8Sb_2S_7$).—Tetrahedrite is the ore mineral sought at the Frisco Standard, United Treasure, and Oriole mines, where it is reported to contain considerable silver. A few spots of tetrahedrite or tennantite ($Cu_8As_2S_7$) were seen in the Pend Oreille ore and in the marble at the O. K. property.

HALOIDS

Cerargyrite (AgCl) and bromyrite (AgBr) have been reported by Patty[51] from the Frisco Standard mine, but these minerals have not been identified during this investigation.

OXIDES

Quartz (SiO_2).—Quartz is one of the most widespread and abundant minerals in the ore deposits and in the metamorphic rocks near igneous contacts. Fine-grained dark-gray jasperoid is developed in the replacement bodies. Locally light-gray chert masses are abundant, and light-gray chert nodules are common in the upper part of the Metaline limestone. Transparent crystalline quartz is found in vugs in the jasperoid ore, and gray chert and doubly terminated quartz crystals were seen in both the ore and the carbonate gangue. Skeleton quartz crystals are enclosed in the paligorskite.

A few small specimens of an unusually fine fibrous quartz were obtained from an old stope in the Grandview mine. The material was analyzed with the following results:

Analysis of fibrous quartz from Grandview mine

[Analyst, Charles Milton]

Ignition	1.0
SiO_2	95.7
Al_2O_3	1.3
CaO	.5
MgO	3.2
	101.7

[51] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 113, 1921.

Under the miscroscope the fibrous mineral has the optical properties of quartz except for the tips of the fibers, which appear to be chrysotile asbestos. The quartz seems to have replaced and inherited the structure of the chrysotile, although this relation is not as clear as might be desired. Fibrous quartz, although uncommon, has been known for years. The subject has recently been reviewed by Thiesmeyer.[52]

Chalcedony (SiO_2).—A little chalcedony is found in fractures in some of the shallow ores and rocks. It is probably supergene wherever identified.

Cuprite (Cu_2O).—A few grains of cuprite were identified in a specimen of partly oxidized calcite and white quartz rock from the Dumont Brothers' claims on Uncas Gulch. The cuprite is associated with black copper oxide, malachite, and azurite.

Hematite (Fe_2O_3).—The specularite variety of hematite is rather common in quartzite beds but has not been identified with certainty elsewhere. No effort has been made to separate brown earthy hematite from goethite ($Fe_2O_3.H_2O$), and the two are described as iron oxides throughout this report.

Ilmenite ($FeTiO_3$).—Typical ilmenite plates are found in a quartz vein on the Fairview claim west of the Oriole mine.

Magnetite (Fe_3O_4).—Magnetite is a common accessory mineral in all the igneous rocks and is abundant in the lamprophyre dikes. It is unusual in the metamorphosed carbonate rocks and has been identified only at the Coffin property, where a few tiny crystals were found.

Rutile (TiO_2).—Small rutile crystals were seen in the altered carbonate rocks in the Priest River group north of Harvey Creek, and tiny needles are common in chlorite resulting from the alteration of ferromagnesian minerals, particularly biotite.

CARBONATES

Calcite ($CaCO_3$).—Calcite is one of the most widespread minerals in the region. It is abundant in the marbles and limestones, and the coarse-grained white variety is common near the ore deposits and along faults. Calcite is generally found in the quartz veins and occurs in veinlets and as crystals in vugs throughout the region.

Dolomite ($CaMg(CO_3)_2$).—Dolomite is one of the abundant gangue minerals in the replacement ore bodies. It is widely distributed through the bedded carbonate rocks, and crystalline dolomite is habitually found in and near the ore bodies.

Smithsonite ($ZnCO_3$).—The near-surface parts of most replacement ore bodies contain small quantities of zinc carbonate. Unusual specimens of botryoidal gray smithsonite were picked up on the dump of the Diamond R but are also found at the Pend Oreille and Bella May mines. Most of the smithsonite, however, is typical "dry bone" and in places is mixed with iron oxides. A little smithsonite was reported to have been mined at the Josephine workings of the Pend Oreille mine during the first World War.

Cerussite ($PbCO_3$).—Cerussite is widely distributed in the outcrops of most of the ore bodies. Beautiful "nests" with crystals as much as three-quarters of an inch long were found in galena on the old Bella May ore pile, and smaller crystals were found in the mine workings. In most regions cerussite is separated from galena by a layer of anglesite ($PbSO_4$), but anglesite has been identified in only one place in the Metaline area, in small crystals on paligorskite from the 300-foot level of the Pend Oreille mine. Two common types of cerussite crystals are developed. One is dark gray, greasy, and tabular; the other is in needles and is white. A few vugs in the Bella May ore are lined with white crystals that are separated from galena by the darker crystals.

Malachite ($CuCO_3.Cu(OH)_2$).—Green copper carbonate is a minor but conspicuous constituent in much of the white quartz in the oxidized zone at the Frisco Standard and other nearby lodes. A small amount was found at the Oriole mine and in an outcrop of white quartz and carbonate on the Dumont group, on Uncas Gulch.

Azurite ($2CuCO_3.Cu(OH)_2$).—Blue copper carbonate is generally present with malachite but in smaller quantities.

SILICATES

Orthoclase ($KAlSi_3O_8$).—Potash feldspar is found in hornfels, is generally microscopic, and seems to be largely confined to fine-grained rocks. The orthoclase in the igneous-metamorphic zone is usually fresh but in places is perthitic and partly altered to muscovite. Orthoclase is apparently one of the last silicate minerals to be deposited.

Microcline ($KAlSi_3O_8$).—The potash feldspar microcline is conspicuously developed in places in the igneous-metamorphic rocks and is locally abundant in the intrusive bodies, where it forms crystals as much as 3 inches long. Clear colorless crystals of microcline with epidote and sphene line vugs in a coarse-grained rock from Timber Mountain.

Some specimens of the so-called microcline are optically positive. A sample from the Kaniksu batholith near the contact on the ridge south of Cedar Creek in sec. 10, T. 38 N., R. 42 E., was checked optically by Miss J. J. Glass and showed $\alpha=1.521$, $\beta=1.526$, $\gamma=1.527$, optical character + and −; 2V ranges from 45° to greater than 90°, disp. $r<v$, quadrille twinning excellent. The mineral may be either anorthoclase or isomicrocline.

Albite ($NaAlSi_3O_8$).—The soda feldspar is abundant in the ground mass of hornfels, in the greenstone

[52] Thiesmeyer, L. R., Vein-quartz pseudomorphs of cross-fiber asbestos in Virginia: Am. Mineralogist, vol. 22, pp. 701–719, 1937.

facies of the Leola volcanics, and in lamprophyre dikes. It is rather common in perthitic inclusions in orthoclase and microcline.

Oligoclase (sodic plagioclase with 10 to 30 percent of $CaAl_2Si_2O_8$) *and andesine* (sodic plagioclase with 30 to 50 percent of $CaAl_2Si_2O_8$).—Feldspars of oligoclase and andesine types are recognized at many places in the igneous-metamorphic rocks and pegmatite bodies. Near the top of Timber Mountain crystals of andesine as much as 1 inch across are associated with light-brown garnet, green amphibole, sphene, and epidote.

Diopside ($CaMg(SiO_3)_2$).—Diopside is an abundant mineral in the altered carbonate rocks, where it was probably formed by dedolomitization of dolomitic limestones. The mineral is generally white or rarely pale greenish. At the Coffin property a bright-pink manganoan diopside is intimately associated with white diopside. The indices of the pink mineral were determined by Miss J. J. Glass as $\alpha=1.675$, $\beta=1.683$, $\gamma=1.701$.

Tremolite ($Ca_2Mg_5(OH)_2(Si_4O_{11})_2$).—Tremolite is one of the most abundant minerals in the altered carbonate rocks. It occurs in radiating clusters and in isolated long laths. Tremolite commonly contains cores of white diopside and appears to have been formed from the diopside. The optical properties of a sample from Dry Canyon were determined by Miss J. J. Glass as $\alpha=1.603$, $\beta=1.617$, $\gamma=1.629$, biaxial negative, extinction $Z \wedge C=16°$, $r<v$, axial angle $2V=\pm 80°$.

Actinolite ($Ca_2(Mg,Fe)_5(OH_2(Si_4O_{11})_2)$ *and hornblende* (similar to actinolite but containing alumina, ferric oxide, and alkalies).—Monoclinic amphiboles are abundant in the altered sedimentary rocks, particularly hornfels, in the minor intrusives, and in the border facies of the Kaniksu batholith. Schiller structure is well developed in the green hornblende in the border facies.

Cordierite ($H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$).—Cordierite was identified by Charles Milton in a thin section of knotty phyllite from the head of Wolf Creek. The mineral is packed with inclusions, a few of which have pale-yellow halos. Cordierite, with andalusite, makes up about 75 percent of a specimen of hornfels from the line between secs. 4 and 9, T. 35 N., R. 43 E.

Garnet ($R''_3R'''_2(SiO_4)_3$).—Garnet is an unusual constituent of the altered sedimentary rocks but is common in the muscovite facies of the Kaniksu batholith and is present in pegmatite bodies. A light amber-colored garnet from Timber Mountain has an index of refraction of 1.749. A dark-brown garnet from a prospect pit in the west center of sec. 30, T. 35 N., R. 44 E., gave $n=1.817$. A little brownish garnet was also found in the altered carbonate rocks in Dry Canyon and in Little Muddy Creek Valley. The garnets in the intrusive rocks are generally less than one-eighth of an inch across, but crystals half an inch in diameter have been seen. In hand specimens these garnets are bright red or wine-colored, but under the microscope a specimen from Lost Creek showed reddish-brown cores with a pinkish border zone. The index of refraction $n=1.810$.

Zircon ($ZrSiO_4$).—Microscopic crystals of zircon are found in the igneous-metamorphic zone and are particularly abundant in the fine-grained rocks, although present in the carbonate beds. The best development of zircon seen is on Sand Creek near the contact between the intrusive and phyllite.

Topaz ($[Al(F,OH)_2]AlSiO_4$). — Irregular-shaped grains of colorless topaz were found in a thin section of pegmatite from the O. K. property. Optically the mineral is biaxial positive, with large (estimated 60°) optic angle, negative elongation, and extinction parallel to elongation. The birefringence is low. Samples of the mineral were not available for determining indices in oils.

Andalusite (Al_2SiO_5).—Andalusite has been identified at several places in the hornfels near the Kaniksu batholith. Material collected on Hall Mountain just east of the intrusive in the northeast corner of sec. 15, T. 38 N., R. 44 E., was in well-formed crystals as much as three-quarters of an inch long, but the largest crystals found came from the metamorphic rocks west of Lost Lake, where they form elliptical nodules as much as an inch or more long. Many tiny inclusions in the crystals are crudely arranged, as in the variety Chiastolite. Much andalusite is partly altered to sericite and quartz.

Sillimanite (Al_2SiO_5).—Sillimanite is found in hornfels and schists near the borders of the Kaniksu batholith. Commonly it is in needles less than 1 inch long that fray out at the ends. A photomicrograph of sillimanite from the north bank of Little Muddy Creek in sec. 27, T. 38 N., R. 42 E., is shown in plate 20, *B*. The sillimanite needles are haphazardly oriented.

Zoisite ($HCa_2Al_3Si_3O_{13}$).—The pink manganoan variety thulite has been recognized in three places—near the peak on Timber Mountain, in the west center of sec. 29, T. 36 N., R. 43 E., and in the south center of sec. 32, T. 36 N., R. 43 E. The crystals from Timber Mountain are as much as a quarter of an inch long but are generally smaller. They are distributed through a pegmatitic mass that is made up of andesine feldspar and dark-green chlorite. This thulite was studied optically by Miss J. J. Glass. It is biaxial positive, with 2V moderate but extremely variable; the indices are $\alpha=1.703$, $\beta=1.705$, $\gamma=1.725$. The thulite grades through pink epidote into straw-colored epidote. The other two occurrences of thulite are both in the muscovite phase of the Kaniksu batholith. The mineral is fine-grained and occurs in small spots and knife-edge seams that cut sharply across the rock.

Epidote ($HCa_2(Al,Fe)_3Si_3O_{13}$).—Typical pistachio-green epidote is found in many places in the igneous metamorphic zone. It is present in pegmatite bodies and in the muscovite phase of the Kaniksu batholith. Epidote is commonly associated with the colorless iron-free clinozoisite and in places surrounds nuclei of brownish allanite. Pink and straw-colored epidote are found with thulite.

Allanite ($HR''(R''')_3Si_3O_{13}$).—The brownish rare-earth mineral allanite is widely distributed with epidote. It is present in platy crystals as much as half an inch long in a 4-foot dike in Dry Canyon. The crystals are surrounded by a reddish halo one-eighth to one-fourth inch wide.

Clinohumite ($Mg(F,OH)_2.4Mg_2SiO_4$).—Small orange-colored crystals of clinohumite were found in the metamorphosed carbonate rock at the Coffin property. The optical properties of the mineral were checked by Miss J. J. Glass. The mineral is biaxial positive, has a large optic angle $2V=80°$, indices $\alpha=1.640$, $\beta=1.654$, $\gamma=1.674$, dispersion $r>v$, extinction on a poor cleavage (001?) is a small angle. The indices are well above those of humite and are higher than those of any known chondrodite[53] but agree with those of clinohumite. Similar orange-colored crystals of clinohumite are found in an altered limestone band at the top of Timber Mountain.

Hemimorphite ($H_2Zn_2SiO_5$).—The silicate of zinc, hemimorphite, has not been definitely recognized in the ores, but its presence in the clayey weathered outcrops is suspected.

Tourmaline (a complex borosilicate of aluminum and other metals).—Tourmaline is of widespread occurrence in the igneous-metamorphic rocks, particularly in the hornfels, schists, and quartzites. It is a common constituent in pegmatite bodies and in the muscovite facies of the Kaniksu batholith. Most of the tourmaline is black to the unaided eye and greenish under the microscope, but pale-yellow tourmaline was seen in a thin section of carbonate rock from the Hall Mountain trail north of Harvey Creek. At the O.K. property a fine-grained bluish tourmaline powder occurs in seams cutting quartz veinlets and one specimen of a pegmatite mass contains colorless to deep rich-blue crystals.

Well-rounded detrital tourmaline grains are found in the black quartzite of the Ledbetter slate.

Thomsonite ($(Na_2,Ca)Al_2Si_2O_8 2\frac{1}{2}H_2O$).—Thomsonite is common in the lamprophyre dikes and in small amounts in the hornfels. It is generally in radiating clusters or spherulitic grains. The optical properties of thomsonite from a dike in the east-central part of sec. 8, T. 40 N., R. 44 E., were determined by Miss J. J. Glass. The mineral is biaxial positive, $2V=45°$–$48°$, $\alpha=1.525$–1.530, $\beta=1.527$–1.533, $\gamma=1.535$–1.541. In the lamprophyres thomsonite is formed from the feldspars, which are largely altered.

Muscovite ($H_2KAl_3(SiO_4)_3$).—Well crystallized muscovite and the fine-grained variety sericite are widely distributed throughout the region but are particularly abundant in the less intensely altered rocks of the igneous-metamorphic zone. Muscovite is an essential mineral in much of the Kaniksu batholith and in pegmatitic bodies. It was formed late in the mineral sequence and is thought to have resulted largely from the alteration of feldspars and other micas.

Biotite ($H_2K(Mg,Fe)_3Al(SiO_4)_3$).—Black mica is an abundant constituent in the schists and hornfels. It is widely distributed through the igneous rocks and locally is concentrated in the border zone of the Kaniksu batholith. It is one of the conspicuous minerals in the lamprophyre dikes.

Phlogopite ($H_2KMg_3Al(SiO_4)_3$).—Pale-brownish phlogopite is a conspicuous constituent of the impure carbonate rocks in the igneous-metamorphic zone. Phlogopite occurs in fine-grained aggregates at the Coffin property, and on lower Harvey Creek a pale-brownish schist composed mainly of phlogopite and calcite is one of the common rocks. In general phlogopite and biotite are concentrated in the more intensely metamorphosed rocks and locally are displaced by muscovite in the less altered rocks.

Chloritoid ($H_2(Fe,Mg)Al_2SiO_7$).—Chloritoid is found in black porphyroblasts in the Maitlen phyllite in the schistose aureole that borders the batholith. The chloritoid is so unusual that some of its optical properties are given. The mineral is strongly pleochroic, X=dark gray to indigo, Y=gray blue, Z=colorless, optical character positive, $\alpha=1.723$, $\beta=1.726$, $\gamma=1.732$, $2V=50°$–$60°$ (estimate), moderate to strong dispersion $r>v$. Interference colors are banded purple, blue, and green. Dustlike inclusions are abundant and in some crystals are arranged in hourglass structure. The specific gravity was not accurately determined but is near 3.

Chlorite group ($H_8Mg_5Al_2Si_3O_{18}$).—Dark-greenish chlorite has commonly resulted from the break-down of ferromagnesian minerals. At the O.K. property calcite is in places separated from white diopside by narrow bands (±1 millimeter) of colorless chlorite. Colorless chlorite has also been recognized in a few other slides of altered carbonate rocks.

Jefferisite (complex magnesium-aluminum silicate).—The jefferisite variety of vermiculite was found in altered carbonate rock from the Coffin property. The mineral is in white or pale-greenish flakes, generally one-eighth inch or less across. It is biaxial negative, β=about 1.570. It expands slightly when heated with a blowpipe.

Serpentine ($H_4Mg_3Si_2O_9$).—Two types of serpentine are recognized. One is a yellow or greenish-yellow mineral found in the altered carbonate rocks, and the other is a clear green material that resulted from the

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[53] Larsen, E. S., The optical properties of the humite group: Am. Mineralogist, vol. 13, pp. 354–359, 1928.

alteration of olivine in the lamprophyre dikes. Yellow serpentine was collected from Dry Canyon, the O.K. property, and the Coffin property. Under the microscope it is a colorless fine-grained fibrous mat. The optical properties of the mineral were determined by Miss J. J. Glass. It is biaxial positive, the indices are variable; lowest $\alpha=1.535$, highest $\gamma=1.555$. The optic angle ranges from 25° to 50° or more.

Chrysotile ($H_4Mg_3Si_2O_9$).—Veinlets of serpentine asbestos less than a quarter of an inch wide were found at the Coffin property associated with yellow-green serpentine. These veinlets cut sharply across the enclosing rock, which is mainly diopside and serpentine. A little material thought to be chrysotile almost entirely replaced by quartz was found in the Grandview mine.

Talc ($H_2Mg_3(SiO_3)_4$).—Talc was identified by Miss J. J. Glass in the altered carbonate rock from the Coffin property. The talc occurred with jefferisite in white diopside. It is likely that talc is present at other places in the metamorphic rocks but has not been recognized.

Paligorskite (hydrous magnesium-aluminum silicate).—Paligorskite, an unusual mineral of the sepiolite group, is illustrated in plate 17, *B*, which reproduces a photograph of a specimen from the 500-foot level of the Pend Oreille mine. The mineral is widely distributed in and near the ore deposits in caves and cracks. It has also been found in limestone beds in the Priest River group. The distribution in the Pend Oreille mine is described on pages 38–39. The optical properties determined by Miss Glass show the mineral to be biaxial negative, with the optic plane nearly parallel to the elongation of the fibers, $\alpha=1.506$, $\beta=1.519$, $\gamma=1.531$.

Paligorskite is abundant below the water table but is absent or occurs in thin brittle plates near the surface. This fact indicates that the mineral is leached near the surface—an indication that is given some support by the analyses below.

In order to determine the solubility of the mineral in cool waters samples of 2 grams each were placed in three flasks at room temperature. The first flask contained 1 liter of 0.1 normal HCl, the second contained 1 liter of distilled water, and the third contained 1 liter of 0.1 normal Na_2CO_3. After 21 days, during which the flasks were frequently shaken, the contents of each flask were examined by J. J. Fahey for SiO_2 and Al_2O_3. The results are given below.

	Dissolved (approximate percent of sample)	
	SiO_2	Al_2O_3
0.1 normal HCl	0.3	0.7
Distilled water	Trace	Trace
0.1 normal Na_2CO_3	.6	.4

Mr. Fahey also estimated that the original sample contained not more than 1 percent of calcium.

Dickite ($H_4Al_2Si_2O_9$).—The kaolin mineral dickite, the identification of which was checked by C. S. Ross, was found with barite in an altered carbonate rock in the west center of sec. 23, T. 38 N., R. 45 E.

Montmorillonite ($H_2Al_2Si_4O_{12}H_2O$).—A greasy clay mineral whose optical properties agree with those of montmorillonite is present in an altered pegmatite mass near the O. K. property.

Chyrsocolla ($CuSiO_3.2H_2O$).—A little chrysocolla was found in the oxidized ores at the Frisco Standard mine.

TITANOSILICATES

Sphene (*titanite*) ($CaTiSiO_5$).—Sphene is an unusual mineral in the border facies of the Kaniksu batholith and in the igneous-metamorphic zone. Near the top of Timber Mountain on the east slope beautiful pale waxy brown wedge-shaped crystals as much as half an inch in longest dimensions are conspicuous. Smaller crystals of sphene are found, upon close inspection, to be scattered through the small intrusive bodies and locally in the border facies of the batholith.

SULFATES

Barite ($BaSO_4$).—Barite or heavy spar is abundant at only one place—the Lead Hill mine, where it is a common companion of the lead-zinc ores. This barite is translucent, white, and in typical slightly curved platy aggregates. A few specimens of fine-grained white barite and light-brownish sphalerite were picked up on the dump of the old Bella May mine. Pink barite plates half an inch or less long were found in altered carbonate rock intimately associated with dickite in the west-center of sec. 23, T. 38 N., R. 45 E.

Anglesite ($PbSO_4$).—The sulfate of lead has been identified at only one place—the 300-foot level of the Pend Oreille mine, where it occurs in tiny crystals on paligorskite.

Gypsum ($CaSO_4.2H_2O$).—A little gypsum was identified in the shallow workings on the Wolf Creek property.

MOLYBDATES

Wulfenite ($PbMoO_4$).—Plates of translucent colorless or pale-yellow wulfenite were found in the oxidized ore on the old Bella May dump, in the new Bella May adit, and on the dump at the Diamond R. In one specimen a cluster of small wulfenite crystals is grouped on the surface of a larger crystal of cerussite.

HYDROCARBON COMPOUNDS

Anthracite (C).—Small shiny black globules of the composition of anthracite are found in the ores at the Pend Oreille, Bella May, and Wolf Creek properties. (See pl. 23, *A*.) As determined by Miss Taisia Stadnichenko, the material is about 90 percent fixed carbon and burns clean with no fusing and little residue. The globules are in dolomite, calcite, or quartz. In a few specimens the quartz is molded around the globules, which when removed leave smooth rounded niches.

THE MINES

For convenience of description the mines and prospects are grouped under the following headings: (1) Russian Creek area, (2) Slate Creek district, (3) outlying areas, (4) Metaline district, and (5) placer deposits.

RUSSIAN CREEK AREA

UNITED TREASURE

The United Treasure mine is in Stevens County, in the extreme northwest corner of the Metaline quadrangle. The property consists of three claims near the center of sec. 11, T. 40 N., R. 42 E., but nearly all exploration has been confined to the United Treasure No. 1 claim. In 1937 a low-level adit was being driven by F. G. Stevens, but no ore was being mined.

The property has had a history similar to that of the nearby Frisco Standard. A few small shipments of hand-picked ore have been made through a period of years, and from time to time efforts have been made to develop the prospect.

Most of the prospecting and all the mining were done in shallow adits and cuts along the outcrop of the lode. These aggregate about 1,000 feet of workings. A prospect tunnel has been driven about 800 feet into the hill below the ore, and late in 1937 a raise was started from the end of the drift in the hope of intersecting the lode.

The country rock is black slate, probably of Ordovician(?) age, which is much distorted and faulted. Bedding can, however, be recognized as narrow composition bands, which trend in general in a northwestward direction and dip less than 10° NE. Lamprophyre dikes, generally less than 3 feet thick, are widely distributed through all the workings. They are customarily associated with fault zones of graphitic gouge. The dikes appear to trend in general northwest, parallel to the trend of the bedding, and dip less than 20° NE., although in detail they are extremely crooked.

The faults are rarely sharp, clean breaks; they are generally zones 3 to 10 feet wide in which the slate is much broken and contorted. Seams of graphitic clay are distributed through the disturbed zone. The walls are obscure, as the broken slate grades into less disturbed ground. In one fault in the lower tunnel the drag indicates an overthrust type; the hanging wall has moved up the dip toward the northwest.

The lode is an irregular vein zone of quartz and sulfides that ranges in width from a few inches to a known maximum of about 4 feet. The body is nearly parallel to the bedding of the enclosing slate and is exposed for about 400 feet along its outcrop. In detail the vein crosses and is slightly flatter than the bedding planes. The quartz is in stringers that alternate with slate bands but in places coalesce to form massive quartz bodies with a few partings and shadowy remnants of the carbonaceous slate.

A thin lamprophyre dike accompanies the ore and in most places overlies it but in at least one place is below the ore. Jenkins [54] says: "The ore body * * * in most places lying below the dike, but in some places is found above it, and in some on both sides." In one of the short upper tunnels both the ore and the dike are cut by an irregularly trending fault, and the ore has not been found to the northeast across the fault. The dike is badly altered, but no ore minerals have been found in it. No convincing evidence was found to indicate the relative ages of the ore and dike. Jenkins says: "In one place the igneous sill has been faulted, the rock having been displaced about 20 feet. On the upthrow side the ore lies below the dike and follows down the fault zone, filling and taking a position above the dike on the downthrow side. This shows that ore deposition occurred later than the fault, and therefore later than the dike." Patty [55] agrees that the ore is later than the dike. He points out the presence of ore both above and below the dike. Weaver,[56] however, states: "A completely altered dike * * * apparently cuts the vein or rather has been intruded along the zone of mineralization."

The lower adit was driven to intersect the ore zone on the assumption that the northward dip would be found to continue or possibly steepen. No mineralized ground was found, although several dikes were cut. Late in the summer of 1937 a raise was started from the end of the tunnel in the hope of finding a continuation of the ore zone. To judge from the warped and lenticular nature of the ore bodies, exploration of this type is extremely speculative.

The ore and gangue minerals, in addition to quartz, include a little coarse carbonate, tetrahedrite, galena, and sphalerite. Considerable silver is reported to be present, and most of the returns from mining have been derived from the silver content. Along the outcrop of the lode the quartz is stained by azurite, malachite, and black and waxy yellow minerals not identified with certainty.

Limestone crops out a few hundred feet west of the property and is well exposed along the road to Boundary. This limestone dips northward and is probably

[54] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Conservation and Development, Div. Geology, Bull. 31, p. 105, 1924.

[55] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 115, 1921.

[56] Weaver, C. E., The mineral resources of Stevens County: Washington Geol. Survey Bull. 20, p. 303, 1920.

separated from the Ledbetter slate by a fault parallel to Fish Creek, trending about N. 45° W.

FRISCO STANDARD

The Frisco Standard mine is in Stevens County, in the extreme northwest corner of the Metaline quadrangle. The property consists of nine claims, seven of which are patented. No mining has been done here for several years.

The mine was a desultory producer for many years but has been handicapped by its inaccessibility and the complexity of the ore. The recent completion of a truck road to Metaline Falls should stimulate mining development.

About 1,000 feet of workings were accessible in 1937, and several other adits were caved at the portals. Figure 9 shows the relations of the three open adits and three caved adits of comparable length, as judged from the sizes of the dumps.

The country rock is Ordovician (?) black slate that is much contorted. The regional trend appears to be nearly east-west or slightly north of west, with a flat dip (about 30°) to the south. The crumpling and slipping have changed part of the slate into soft graphitic clay gouge, which appears to be particularly abundant along the lode.

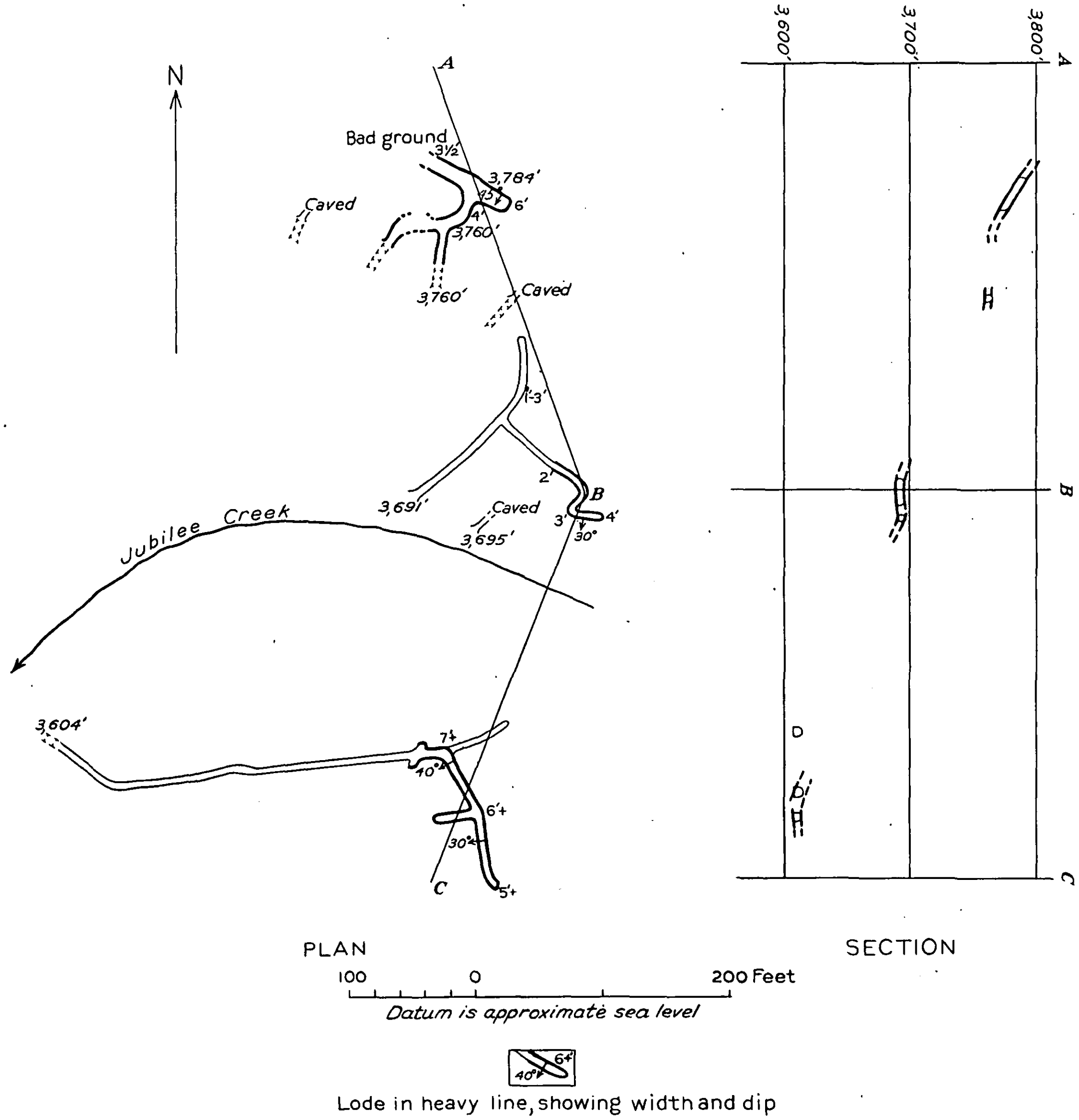


FIGURE 9.—Plan and section of Frisco Standard mine.

The ore is in a quartz lode or zone that has replaced the graphitic slate. The quartz trends about N. 50°–70° W. and dips about 30° S.; it tends to parallel the bedding but in detail is crosscutting. No certainty exists that the three adits are on the same quartz vein, although this is possible. Weaver [57] suggested that the vein may be faulted along Jubilee Creek, and Patty [58] called attention to the possibility of two parallel veins,

[57] Weaver, C. E., The mineral resources of Stevens County, Wash.: Washington Geol. Survey Bull. 20, p. 304, 1920.

[58] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 114, 1921.

one overlying the other. Still a third possibility is that the quartz bodies are lenses in an irregular fissure zone. Some support is given to this idea by the fact that the known fractures in the black shale are extremely irregular.

The quartz bodies vary considerably in thickness; in places they are mere stringers; elsewhere solid quartz masses 7 feet or more thick are found. All gradations between these two extremes exist; where followed toward a solid quartz body the stringers become more numerous and thicker and finally coalesce. Remnants of the carbonaceous wall rock are generally preserved, and even in thick quartz bodies shadows and streaks are retained that parallel the foliation in the country rock. Some of the quartz contains sufficient country rock to give it a ribbon appearance.

The quartz in the ore is generally milky white, massive, and vitreous. The ore minerals are widely distributed but are apparently concentrated in shoots, about which almost nothing is known. The recognized minerals are galena, sphalerite, tetrahedrite, chalcopyrite, and a little pyrargyrite(?). The tetrahedrite is reported to contain considerable silver, and small quantities of gold are also present. Patty [59] gives the following smelter returns on three small shipments of sorted ore from the property:

Smelter returns on ore from Frisco Standard property

Shipment No.	Gold (ounces)	Silver (ounces)	Lead (percent)	Copper (percent)
1	0.01	72.8	9.6	2.7
2	Trace	72.0	16.8	4.6
3	None	49.2	7.0	3.2

The oxidized zone seems to be confined to a depth of 100 feet or less from the surface. In this zone the milky-white quartz is stained brilliant hues of blue, green, yellow, and black. These salts are thought to be mostly those of copper and iron. Patty [60] mentions both cerargyrite and bromyrite, but the presence of these two minerals has not been verified. Malachite and azurite have been recognized.

MY ERA

The My Era property is across the gulch west of the Frisco Standard mine, near the east center of sec. 11, T. 40 N., R. 42 E. Here two shallow adits have been driven into the hill to intersect the mineralized zone. The country rock is distorted black Ordovician (?) slate similar to that in the adjoining Frisco Standard and United Treasure properties. Numerous lamprophyre dikes and sills are shown in the adits and on the slope above the prospect.

The mineralized lode is about 2 feet wide and consists mainly of quartz with bands and remnants of slate. Considerable galena and some tetrahedrite are present and are reported to carry much silver. The ore, where exposed, lies between a dike (sill?) and the country rock. Several other quartz bands were cut in the lower tunnel. These bands are generally next to dikes (sills?) and are barren or weakly mineralized where exposed. The maximum width of quartz is about 4 feet; generally the widths are 2 feet or less.

No work was being done on the property in 1936 or 1937.

JUST TIME

The Just Time (Star) property is in the west center of sec. 15, T. 40 N., R. 42 E., about 1½ miles southwest of the United Treasure. The workings extend from a shaft that was inaccessible when visited, and nothing was learned of them. Meager information was obtained from the dump and the poor exposures of the vicinity.

The country rock is limestone, thought to be of Devonian(?) age. An outcrop near the mine is intraformational conglomerate similar to that found on the road near the United Treasure property and shown on plate 10. The country rock on the dump is a cemented breccia that effervesces weakly with 1:1 HCl. A little crystalline dolomite is present, and coarsely crystalline white calcite is abundant. Milky-white vitreous quartz is also plentiful; part of it is crystalline and vuggy, and numerous veinlets extend through the magnesian limestone.

Small amounts of galena, sphalerite, and pyrite are found in the quartz and, to a less extent, in the coarse calcite and dolomitic limestone.

Some of the coarse calcite is brecciated and cemented by veinlets that contain tiny euhedral quartz crystals.

SLATE CREEK DISTRICT

The Slate Creek district, as the term is used in this report, lies east of the Metaline Falls-Nelson highway and includes all the territory tributary to the Slate Creek road. The district has been known for about 10 years but so far has not become a steady producer. The Lead Hill (Bunker Hill) property was the site of active development in 1931–32 and is the best-known prospect in the district. Galena and sphalerite are widely distributed in the dolomitized limestone. Practically the entire area is held by prospectors and during the recent economic depression was idle, even assessment work being mostly suspended.

The country rock is dolomitized limestone overlain by black slate. The stratigraphic and structural relations are not entirely clear; they have been discussed

[59] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 114, 1921.
[60] Patty, E. N., op. cit., p. 113.

in connection with the Slate Creek fault (pp. 30–31). In general the ore deposits are in the dolomite below the black Ordovician slate, and it is thought that the nearness of the Slate Creek fault has a genetic significance. Some mineralized ground away from the slate and fault appears to be related to subsidiary fractures and minor faults.

LEAD HILL

The Lead Hill (Bunker Hill) property contains 16 claims and fractions, nearly all in sec. 14, T. 40 N., R. 44 E. The workings are on the northwest bank of Slate Creek, about 15 miles from Metaline Falls by a good truck road.

In 1931–32 a development program was undertaken by the Bunker Hill & Sullivan Mining & Concentrating Co., of Kellogg, Idaho. Under the supervision of this company's staff part of the property was diamond-drilled and a 1,400-foot adit was driven into the hill. The many surface cuts and shallow adits are shown on plate 28. During 1937 assessment work was done and a small lot of hand-picked galena was shipped.

The country rock consists of dolomitized limestone and jasperoid overlain by black slate. Near the ore deposits the dolomite is commonly creamy gray and coarse-grained, with patches of "zebra" rock. Stringers of jasperoid and dark-gray dolomite are generally present. Stratigraphically below the coarse-grained dolomite is fine-grained cherty limestone similar to the material below the Ledbetter slate in the unmineralized section. At Lead Hill this limestone is generally high in magnesium or has been converted to jasperoid. Large areas of coarse white calcite are present. Plate 24, *A*, shows these large calcite crystals with dolomite formed around them and in the cleavage cracks. Three types of silica have been recognized; one consists of the cherty nodules common to this horizon, and the others are dark-gray or black jasperoid associated with the ore deposits and a light gray jasperoid that grades into the darker mineral. The black slate in the neighborhood of Lead Hill is poorly exposed, as it is largely under the Slate Creek terrace. However, the black quartzite member can be seen just southwest of the long adit and in Slate Creek below the mine. The slate can also be seen at several places along the road and the old trail northeast from the mine.

The attitude of the dolomites is not very well shown in the workings, but on the hill to the northwest banded black and white dolomitic limestones trend east of north and dip about 30° E. The quartzite layer in the black slate has a similar trend but appears to have a steeper dip. Much of the dolomite is brecciated and recemented by jasperoid. This material is particularly well shown on the good outcrops north and northwest of the mine, on top of the ridge. Faulting at the mine is obscure, but is probably common. A general north to northeast trend prevails, although slips trending nearly east and west are also found. The small amount of diamond drilling done on the flat below the mine indicates a cover of black slate underlain by dolomite, confirming an eastward dip for the contact. The mine workings are probably about a quarter of a mile from the main Slate Creek fault.

The known ore deposits are confined to a shallow zone near the surface. The long adit nearly parallels the strike of the bedding or cuts it at a low angle and, except for mineralized ground about 100 feet from the portal and a few "shines" near the face, appears to be devoid of sulfide mineralization. The rock exposed in the adit includes some jasperoid similar to that usually found with or near ore deposits. If, as appears to be reasonable, this deposit is comparable to the more completely explored bodies near Metaline Falls, the ores approximate bedding deposits. The ores throughout the region are generally in jasperoid and dolomite under a cover of black slate. At Lead Hill the slate-carbonate rock contact dips eastward. All available evidence indicates that the extension of the known ore body, if it exists, is to the east under the Slate Creek terrace below the black slate. If this is true, most of the exploration to date has been below the mineralized beds. This statement, however, is not meant to imply the belief that no mineralized ground will be found at the horizons below the adit.

Galena which locally is rich enough to cob by hand, is the most abundant ore mineral and is generally fresh at the surface. A little sphalerite is also found, although this mineral is generally leached. In contrast with all other deposits in the quadrangle, one of the common minerals at Lead Hill is barite. This barite resembles the coarse white calcite at first glance; it is in cleavage plates as much as about 2 inches long and is white like the calcite.

Much of the ore on the surface is unoxidized. However, along cracks and in porous breccias oxidation has taken place. This can be seen in the adit, where limonite is developed on nearly all fractures and in breccias. Small amounts of smithsonite and cerussite were found.

BAILEY-HANSON

The Bailey-Hanson group of 16 claims is in sec. 1, T. 40 N., R. 44 E. The property is reached by a good dirt road extended northeast about 2½ miles from Lead Hill in 1937.

Numerous cuts and shallow prospects adits have been made here. These diggings are scattered on mineral showings throughout the claims, and no drilling or deep exploration has been attempted.

The country rock consists of dolomite and limestone similar to those at Lead Hill. Near the mineralized zone the dolomite is generally crystalline and creamy or gray. Part of it is fine-grained, dense limestone wtih cherty nodules; stratigraphically below this are banded black and white limestone and dolomite. To the east lies the Ordovician slate, which is exposed in road cuts between the property and Lead Hill. This slate contains many poorly preserved graptolites. At least one lamprophyre dike, about 4 feet thick, trending N. 30° E. with a steep east dip, and one light-colored dike, now altered to a zeolite-rich rock, were noted.

In the canyon of the Salmo River to the north the slate-dolomite contact trends N. 20°–30° E. and dips about 65° E. The dolomite flattens westward from the contact, although toward the east dips as great as 45° are found. It is probable that the section is repeated by strike faulting, thus making the strata appear much thicker than they are.

Both galena and sphalerite are widely but sparingly distributed through the dolomite on the surface. They are commonly localized along fissures and small faults. Some of the sphalerite is leached, and smithsonite is formed in solution channels.

DUMONT PROPERTIES

Two groups of claims are held by William and George Dumont. One group of five claims and one fraction is on Slate Creek in sec. 30, T. 40 N., R. 44 E.; the other group is northeast of Uncas Gulch, in sec. 28, T. 40 N., R. 44 E., and contains six claims and two fractions.

The group on Slate Creek is in the dolomite at and near the dolomite-slate contact. This contact is exposed in three places in the shallow workings; in each of the three the contact is a fault. Most of the dolomite is typical of the recrystallized beds below the slate. In one place, however, about 50 feet below the slate, there is a thin layer of black limestone with white spots, similar to the type found in the section below the nodular cherty limestone. Coarse white calcite is widely distributed, but the dolomite is noticeably less siliceous than in most other mineralized deposits. In one shallow adit a lamprophyre dike about 9 feet thick was cut. This dike trends N. 85° E. and dips 85° N. The bedding, taken on the black spotted limestone layer mentioned above, trends N. 70° W. and dips 30° N. The strike, if continued, would abut against the slate. It seems likely that a fault with a throw of probably 200 to 300 feet lies between the dolomite and slate. Smaller cross faults trending northwest are common, and in one place the slate southwest of the fault has moved northwestward about 200 feet.

The ore is distributed in the dolomite, so far as seen, within about 200 feet stratigraphically below the slate. Both sphalerite and galena are present, and one stringer of high-grade galena was uncovered. No shipments have been made. A few diamond-drill holes were sunk by the Pend Oreille Mines & Metals Co.

The upper or Uncas Gulch group of claims is at a lower(?) horizon than the group on Slate Creek, although both are below the slate. The country rock at the Uncas group is fine-grained magnesian limestone that in places contains numerous chert nodules. It is, however, interbanded with dark-gray or black phyllites that resemble the Orodovician slate except for light-colored limy bands. The top of the hill is Ordovician slate, as a few deformed graptolites were found in it. The strata trend about N. 20° E. and dip steeply to the west, although a few eastward dips were recorded. Where followed along the strike toward Uncas Gulch, the beds abut against the phyllites. Uncas Gulch is for this reason considered to be the site of a fault trending about N. 45° W.

Considerable prospecting has been done on this property, and surface cuts are widely distributed. No drilling or underground exploration has been attempted. The surface showing consists of sphalerite and galena in small amounts distributed throughout much of the dolomitic limestone. In two cuts considerable milky-white quartz is exposed. This quartz contains, in addition to galena and sphalerite, a few small grains of tetrahedrite and is stained blue and green from copper carbonates.

OTHER PROPERTIES IN THE SLATE CREEK DISTRICT

Much of the Slate Creek district has been staked at least once, but very little active exploration has been attempted. During 1937 some assessment work was done; this consisted almost entirely of shallow cuts or adits in dolomite or dolomitic limestone. Considerable work has been done on the Ira Troyer properties, particularly in the southeast corner of sec. 22, T. 40 N., R. 44 E. One adit has been started in black slate and is being extended to intersect the contact with the magnesian limestone. On the Sanborn property, near the international border west of the Bailey and Hanson group, a little exploration has been done on a high-grade streak of galena.

OUTLYING AREAS

MULE DEER

The Mule Deer property is in the west-central part of sec. 15, T. 35 N., R. 44 E. It is controlled by the New Deal Mining Co., in charge of J. R. Delvendahl, of Seattle. The workings are on the divide between LeClerc Creek and Middle Creek, at an altitude of about 3,050 feet. They are accessible by road from the Panhandle lumber camp.

The property was operated for a while during 1937, but work was suspended late in the summer. In 1938 it was reported that a small mill was being constructed. An old shallow adit, reported to have been driven about 50 years ago, and a new shaft sunk about 30 feet are the only workings.

The ore occurs in an altered and sheared facies of the Kaniksu batholith. Not enough work has been done to define the shape of the deposit, but superficially it suggests a pipe rather than a tabular fissure zone. The altered rock is light greenish-gray and contains much micaceous material. A few small vugs are lined with quartz crystals, and in places small quartz stringers cut the rock. Black, brown, and red spots of iron oxides give part of the rock a mottled appearance. All the altered rock seen is also weathered.

Small quantities of galena, sphalerite, and pyrite are recognized, and silver is reported to be present. The mineralization persisted in the bottom of the shaft.

This prospect is particularly interesting, as it is one of the few places where mineralization is known to have occurred in the quartz monzonite mass away from contacts.

LITTLE NOISY

The Little Noisy prospect is in sec. 17, T. 38 N., R. 44 E., about half a mile above the mouth of Little Noisy Creek. The property is owned by a group of Ione businessmen, and during 1937 one man was employed prospecting. Two adits were open, a lower and an upper, each driven into the hill north of Little Noisy Creek. The lower adit was driven N. 25° E. for 250 feet, then N. 75° E. for 70 feet. This adit penetrated about 290 feet of slide rock before entering solid material. The upper adit contains about 940 feet of workings (paced). This adit was driven 162 feet N. 12° E., to a crosscut. From this crosscut drifts have been opened in every direction in an attempt to locate minable ore. Another short adit is reported to have been driven in a branch gully northeast of the upper adit. This was not visited. Several shallow cuts and adits have been opened in the creek walls below the main adits.

The country rock is phyllite intruded by a small granitic mass. In the neighborhood of the prospect bedding has been almost destroyed, and such remnants as are found are jumbled and too few to give a clue to the structure. The rock is best classified as a hornfels. The mineralized zone was cut at 162 feet (paced) from the portal of the upper adit. This zone trends N. 70° E. and dips about 75° SE. It contains considerable gouge (about 1 foot) and irregularly distributed lenses of quartz, with a maximum observed width of 4 feet. Much of the mineralization has occurred along the intrusive phyllite contact. Only a small amount of work in solid rock has been done in the lower adit; where a badly disturbed zone of quartz, intrusive rock, and phyllite was found. More quartz is present here than in the upper adit.

The lode contains scattered grains of galena, sphalerite, and chalcopyrite, in places with much pyrite. Pyrrhotite and molybdenite in small amounts were identified, and one seam of molybdenite was found in the granitic rock. Sparse black tourmaline and white carbonate that weathers brown are also present.

GYPSY COPPER CAMP

The Gypsy copper camp is on the north slope of Sullivan Creek in the southeast corner of sec. 18, T. 39 N., R. 45 E. Considerable drifting and surface prospecting have been done in the vicinity in the past, but the properties were idle when visited.

The country rock is massive greenstone of the Leola volcanics, and the ore minerals are mainly chalcopyrite and pyrite in quartz veins and stringers. Considerable white carbonate is scattered through the quartz, and chlorite is abundant in bands and fragments that are remnants of the country rock. The veins are small, few being more than a foot wide, but they seem to be persistent along the strike, in places for several hundred feet or more.

The veins described are typical of a group of similar deposits in the greenstone and greenstone schist (Leola volcanics).

COFFIN

The Coffin property is in sec. 16, T. 38 N., R. 42 E., northwest of Ione, on the west border of the Metaline quadrangle. The developments consist of only a few shallow cuts and tunnels, but they show the hard, unweathered country rock and the type of mineralization fairly well. During 1937 a right-of-way for a road was cleared to the property from the Smackout Pass road west of Ione.

The country rock is mostly a medium-grained white marble, with beds of dense buff marble, which in places is interbanded with and grades into hornfels (phyllite). The marble effervesces freely with cold 1:1 hydrochloric acid. The lime-phyllite rocks have been intruded by the Kaniksu batholith, and the ore deposit is in the limestone near the contact.

The contact metamorphism of the strata has been similar to that shown in many places along the border of the intrusive mass, but more sulfides were seen here than elsewhere. In some of its features the deposit resembles those on O. K. Mountain, on Timber Mountain, and near the intrusive-sedimentary contact in Dry Canyon about 2 miles north of the Caldwell Lake road, where molybdenite was found in metamorphosed limestone.

The marble at the Coffin property is generally silicified, in some places intensely. Diopside is abundant, and serpentine, sphalerite, galena, pyrrhotite, molybdenite, tourmaline, jefferisite, talc, pink diopside, and other minerals are disseminated through the silicified marble.

METALINE DISTRICT

BELLA MAY

The Bella May mine portal is between the main north-south highway and the Pend Oreille River, about half a mile south of old Metaline. The mine is owned by the Metaline Mining & Leasing Co., a subsidiary of the American Zinc, Lead & Smelting Co. During 1936 and 1937 the property was developed, and in October 1937 extraction of ore was begun. The mine was closed April 1, 1938, because of adverse economic conditions, but reopened November 1, 1938. The zinc-lead ores are trucked to the flotation mill at the Grandview mine, and the flotation concentrates are shipped to the American Zinc Co.'s smelter in St. Louis.

The value of the metal produced from the Bella May is not exactly known. Mineral Resources lists shipments in 1917, 1918, 1923, 1924, 1925, and 1926. Jenkins[61] stated (December 1924) that 18 carloads of ore had been shipped from the Bella May. Much of the production before 1937 was obtained from high-grade, hand-picked galena, although at least one unsuccessful attempt was made to mill and produce zinc and lead concentrates. Jenkins[62] also reports a shipment of 5 tons of galena from the Blue Bucket claim, one of the present Bella May group.

The Bella May workings are divided into three groups—the old Bella May, the Blue Bucket, and the new adit level. The old Bella May contains about 2,000 feet of accessible underground workings, mainly on two adit levels. (See fig. 10.) Considerable gophering has been done in these old workings, and numerous shallow stopes and cuts have been made wherever the mineralized ground looked encouraging. (See pl. 29.) The Blue Bucket workings were apparently opened from a shallow shaft, which was inaccessible when visited. In 1936 a new adit was started on the west bank of the Pend Oreille River and when last visited in 1937 had been driven 4,800 feet into the hill. (See pl. 30.) In 1938 the adit had been extended to 5,724 feet from the portal; the inner 876 feet was turned to due west. Inclined raises (55°) and drifts were being pushed to intersect zinc-lead ore shown by diamond drilling to exist beneath both the old Bella May and the Blue Bucket workings. An extensive diamond-drilling campaign was undertaken before starting the new tunnel, and as the work progressed diamond drilling was continued both on the surface and underground.

The country rock exposed in the new adit comprises Metaline limestone and Ledbetter slate. The portal is in the spotted black and white member of the Metaline limestone, probably more than 1,200 feet above the phyllite. The rocks in the adit are too much broken to furnish a continuous recognizable stratigraphic

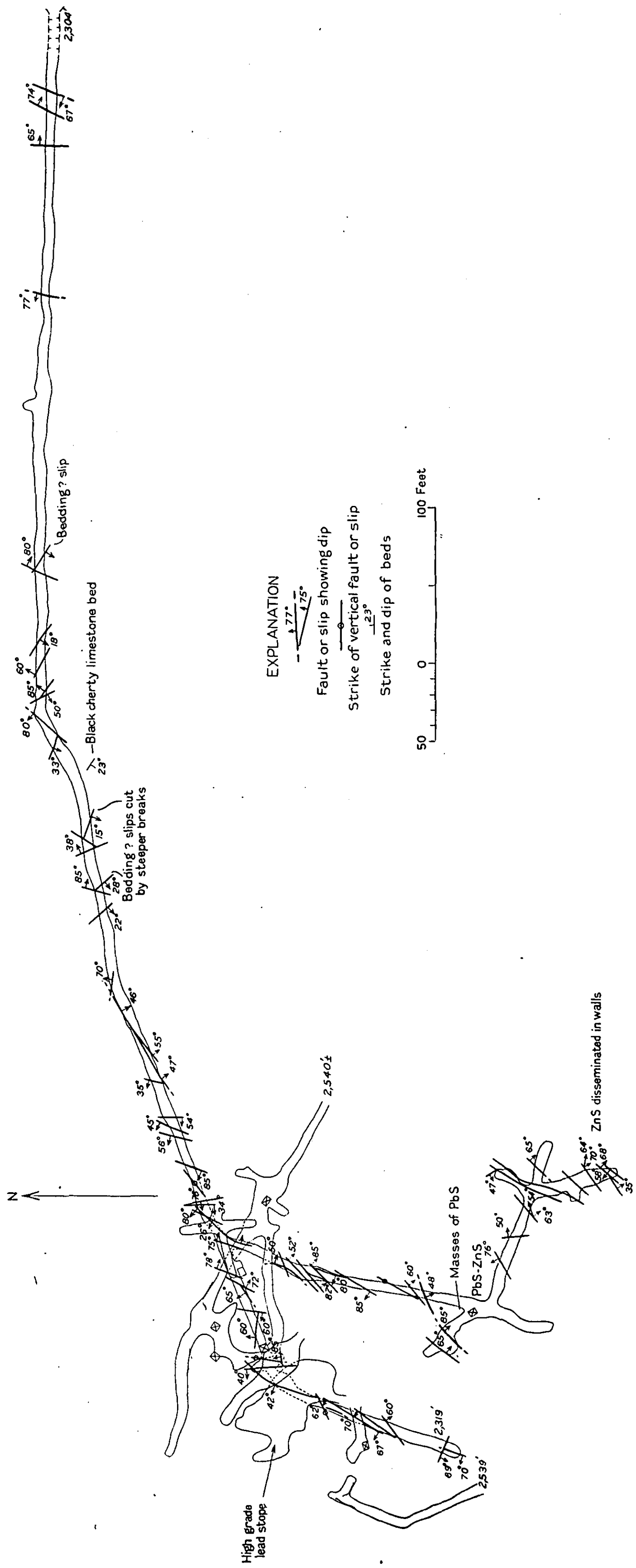
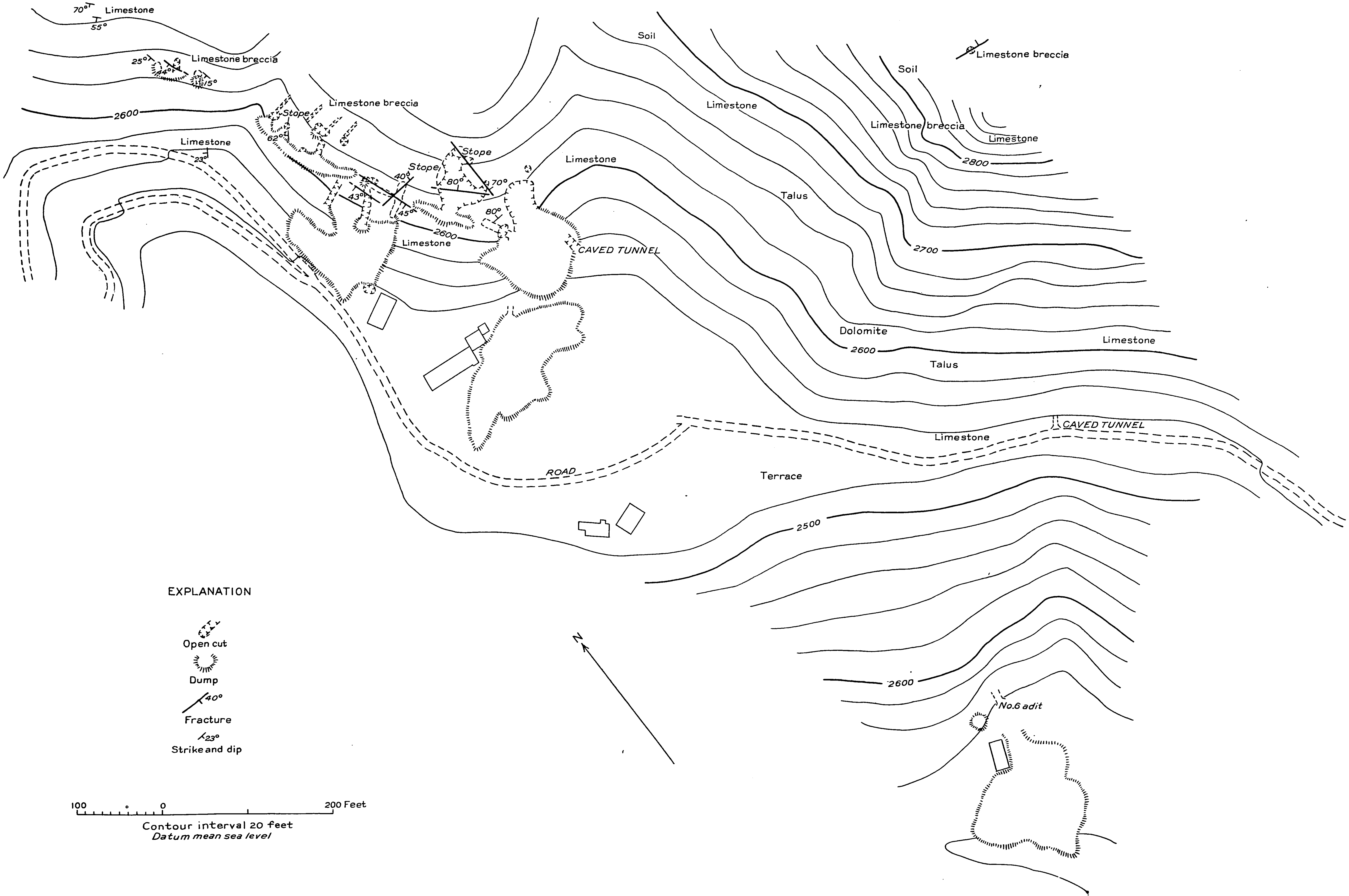


FIGURE 10.—Upper workings at the Bella May mine. Geology shown only on old main level (No. 6 adit).

[61] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Conservation and Development, Div. Geology, Bull. 31, p. 65, 1924.
[62] Idem, p. 67.



EXPLANATION

Open cut

Dump

Fracture

Strike and dip

100 0 200 Feet

Contour interval 20 feet

Datum mean sea level

column. Two narrow lamprophyre dikes were cut, and many clay- and gravel-filled caves along enlarged cracks were found in the first 700 or 800 feet of the adit. Some of these caves are 500 feet or more below the present terrace surface, although probably much nearer the actual rock surface. The old Bella May and Blue Bucket workings are both in crystalline dolomite that stratigraphically is below the slate and above the fine-grained, dense limestone in the upper part of the Metaline limestone. Much of the limestone is dolomitized, and two or possibly three types of silica were recognized. One type is nodular chert, abundant in the lower part of the fine limestone; the other type is dark-gray jasperoid abundantly associated with the ores. Large bodies of light-gray fine-grained silica are also cut in the workings. It is not known whether or not this light-gray silica is the same as the darker jasperoid. In the lowest tunnel of the old Bella May workings a band of black shaly material, less than 4 feet thick, is found. This may be a slate band squeezed along a fault.

Bedding is recognized in many places. Generally, in the new adit, it strikes northeast and dips northwest. Some reversals were seen, and in places the rocks are much broken and sheared. Throughout the workings narrow gouge seams trend northeast and dip less than 30° SE. The movement on these seams was slight, probably at most a few feet. Wherever recognizable, it was of the reverse type and was sufficient to cause a little gouge to develop, and, particularly near the surface where leaching has been active, these seams are easily confused with bedding.

Four major faults were cut in the new adit at distances of 1,830, 2,580, 2,800, and 4,180 feet from the portal. The faults, together with many smaller slips, are shown in plate 30. Each of the four major breaks marks a boundary between slate and carbonate rock. Those at 1,830, 2,800, and 4,180 feet appear to be normal faults, and the one at 2,580 feet is reverse; the amount of displacement on any of the faults is, however, unknown. The attitudes of the breaks at 2,580 and 4,180 feet are shown with confidence, as they have been cut in raises. (See pl. 30.) The dips of the other two faults are less certain, as the irregular zones of disturbance and the small exposures in a drift will not permit accurate projection very far.

As interpreted in the general section on structure (p. 31), the Metaline limestone exposed in the tunnel between 2,580 and 2,800 feet is part of a block thrust over the slate and preserved between two normal faults. The carbonate rock in this thrust block at the Bella May mine is probably less than 400 feet thick and appears to be the beds that, stratigraphically, should be just below the slate. It is highly probable that the thrust block is not a simple unit, but, to judge from the meager exposures, is an intricately faulted and shattered mass.

The ore bodies appear to be typical sphalerite and galena masses, formed by the replacement of carbonate rocks. So far as now known, they lie in dark cherty zones, generally less than 500 feet below the slate. Numerous spots of sulfides are found elsewhere in the carbonate rocks, usually near or along faults, and it is entirely possible that ore will be found at other horizons. The ore bodies are as yet too poorly exposed to permit discussion of their localization and physical features beyond a very few observations. The unbroken nature of the ore minerals in the breccias of the major faults indicates that mineralization followed the period of most severe faulting. Evidence of post-mineral faulting is abundant in the Pend Oreille mine, though the movement on the faults was usually small, and it is likely that somewhat similar late faulting has affected the Bella May ore bodies.

The ore minerals are galena and sphalerite of two colors, reddish-brown and yellow. Jasperoid, creamy-gray crystalline dolomite, with locally some dense fine-grained dolomite, and coarse white calcite are the dominant gangue minerals. A little fine-grained barite with sphalerite was picked up on the lowest dump in the old Bella May workings. A few small globules of carbonaceous material (anthracite composition) were found in the dolomite, and a little flake graphite was found in the dolomite along one of the major faults.

Smithsonite and anglesite are developed in the oxidized ores, but in places galena persists to the surface. A few crystals of wulfenite were found in one ore pile and in the new adit, and vugs with beautiful projecting crystals of cerussite are found in some of the larger nodules of galena.

CLIFF

The Cliff is a patented claim in the north-central part of sec. 22, T. 40 N., R. 43 E. The workings are east of the road between Ledbetter Lake and Russian Creek, about 10 miles from Metaline Falls. The property was idle when visited and apparently had not been worked for several years. Bancroft[63] reported a small shipment from the claim prior to 1910, and Mineral Resources mentions some production in 1924 and 1925. Probably the entire production has been high-grade, hand-picked galena. Two shafts and an old surface stope were inaccessible when visited, but the country

[63] Bancroft, Howland, Ore deposits of northeastern Washington: U. S. Geol. Survey Bull. 550, p. 49, 1914.

rock and the mineral bodies were exposed in a trench about 30 feet long and 10 feet deep.

The country rock is a medium-grained dark-gray dolomite breccia that in places has been changed to jasperoid; its exact stratigraphic position is not known. Weathered dark greenish-gray shale is on the dump and is exposed on the hillside east of the workings. It is reported that this shale was found in the bottom of one of the shafts, which would indicate a steep northwest dip. Slips in the cut that might be bedding planes agree with this dip. The shale, as estimated from the poorly exposed outcrop, is about 25 to 50 feet thick. East of the shale on the hill a white cherty dense marble is conspicuous.

Two sets of fractures, in addition to the bedding, are seen in the open cut. One set strikes N. 35° E. and dips 65° SE.; the other trends N. 30° E. and dips 60° NW.

Galena is the only sulfide recognized, but some iron-stained cavities may represent former sphalerite grains. The galena is in streaks and coarse irregular patches in the jasperoid and dolomite breccia.

DIAMOND R

The Diamond R is a patented claim near the center of sec. 30, T. 39 N., R. 43 E. about 1 mile west of the old Bella May workings. No work has been done here in recent years, but Patty[64] reports a carload of ore shipped in 1918 and a few scattered shipments prior to that time. An adit, reported to contain about 200 feet of drifts, and several open cuts constitute the development workings.

The country rock is a gray brecciated crystalline medium-grained dolomite near the top of the Metaline limestone. A little coarse white calcite is also present. The exposures are poor, and the region around the workings is covered with a tangled growth of alder in an old burn and windfall which is not conducive to a search for outcrops. The attitude of the bedding is not known. A few hundred feet south of the adit, black Ordovician slate is exposed in an old cut. Its relation to the dolomite is not definitely known although probably the formations are separated by a fault.

Most of the work was done on small irregular streaks of high-grade galena, which in places formed mineable pockets. A little sphalerite was seen on the dump, and holes thought to have contained sphalerite before weathering are fairly common. Smithsonite, cerussite, and wulfenite were noted in the oxidized ores.

FLUSEY GROUP

The Flusey and Hoopalula are patented claims on the west bank of the Pend Oreille River about 1 mile north of the mouth of Slate Creek, in sec. 26, T. 40 N., R. 43 E. The property has been prospected by several surface cuts and two tunnels, both inaccessible when visited.

The country rock is light gray-white fine-grained dolomitic limestone that in places contains many small chert nodules. Much of the rock is limonite-stained, and several bodies of partly oxidized iron sulfide are exposed in the canyon walls. The carbonate rocks strike in general N. 10° E. and dip 35°–40° W. East of the workings in the river gorge some of the dolomitic limestone contains black bands with white spots typical of the Cambrian limestone 600 feet or more below the top of the formation. On the dump galena, sphalerite, and marcasite are found. The country rock on the dump is mostly recrystallized gray even-grained dolomite.

GIANT

The Giant claim, owned by James Ehle, of old Metaline, is east of the road near the center of sec. 22, T. 40 N., R. 43 E., about 1½ miles south of Z Canyon. A few cuts have been made on a mineralized outcrop on the hill east of the road. During the summer of 1937 a compressor was installed and an adit was started from the road to undercut this outcrop. In 1938 the adit had been opened 200 feet, and two men were driving it ahead. The country rock consists of dense white cherty magnesian limestone and large irregular patches of black or dark-gray jasperoid, gray crystalline dolomite, and coarse white calcite. The rock, as on the adjoining E. J. Hoage property, is considered to be stratigraphically within 200 feet below the black slate. The attitude is vague, but the strike seems to be about N. 10°–20° E., with westward dips of about 20°.

Considerable disseminated fine-grained sphalerite and numerous spots of galena are found, particularly in the jasperoid. A little smithsonite was seen in one of the cuts.

GRANDVIEW

The Grandview group of 15 patented claims is on the bluff east of the Pend Oreille River about 1 mile north of the town of Metaline Falls. During 1937 control of the property was obtained by the Metaline Mining & Leasing Co., and an intensive diamond-drilling campaign was begun. The old Grandview mill was remodeled and in October 1937 began to treat ore from the new Bella May adit south of old Metaline.

Small production from the Grandview is recorded for 1924, 1925, and 1926, and in 1929 most of the production of the district, $179,592, is credited to the Grandview.[65] In 1937 two carloads of concentrates that had been stored at the mill were shipped to the smelter. During the years 1928–29 the property was the scene of an unjustified boom, with all the stock

[64] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 86, 1921.

[65] Production data from Mineral Resources: U. S. Bur. Mines.

manipulation that such a boom implies. Some development work, particularly along the main haulage adit (see pl. 31) and some churn drilling were done during this time. No attempt has been made to mine at the property since the boom collapsed.

The main adit contains about 3,000 feet of workings. It is connected by raises to the old workings, which contain about 1,500 feet of drifts. Two large open-cut stopes that feed into the tunnel furnished most of the mill heads, but considerable gophering for high-grade ore has been done on the cliff above the river. Most of the workings are shown on plate 31.

The country rock of the deposit is dolomite and limestone, considered to be just below the Ledbetter slate. The attitude of the beds is, in general, about N. 20° E., with eastward dips that are flat near the river and appear to steepen toward the east. On the river cliff the beds are typical fine-grained dolomitic limestone that carries numerous small rounded chert nodules. In at least one new diamond-drill hole a narrow band of shaly material that probably marks the transition zone to the phyllite series below the limestones was cut.

Much of the dolomite is recemented breccia, of a crackle type in which the individual fragments have moved very little. No large faults have been recognized in the mine workings, although many minor slips and cracks are present. An idea of the number and heterogeneous distribution of these fractures can be had from plate 31. The earliest recognizable slips are nearly flat-lying, along what is interpreted as bedding planes; a thin layer of gouge is customarily formed on these planes. These flat slips are offset along those of steeper dips. Some of the stronger faults have gouge zones 1 or 2 feet wide, with several feet more of intensely brecciated rock. Many of the fracture planes are slick and smooth, with no gouge developed; grooving, however, is conspicuous. Measurements on the directions and dips of these grooves suggest no orderly arrangement.

As explained in the section on structure (p. 31), Grandview Hill is thought to be part of a block thrust over the Ordovician black slate. The economic significance of this hypothesis may be considerable, as, if true, there is a good chance of finding additional ore in the favorable beds below the slate. The depth to this horizon is, however, not known, although it is probably close enough to the surface to permit exploration without excessive cost.

The mineralogy of the deposit is simple. Galena and sphalerite are the two minerals sought. These are widely scattered, generally in small amounts, through much of the dolomite. A little jasperoid is present, particularly along the edge of the river bluff. Coarse white calcite is common throughout the mine workings. The grade of ore exposed in the old stopes, used for mill feed, is low, probably running 3 to 5 percent combined lead-zinc. Jenkins[66] mentions the condition of the mine in 1924. He says, "Prospecting had been done by open cuts and in natural caves and by a 125-foot tunnel into the bluff, where the ore body was reached 75 feet from the portal. In one cave * * * broken-off pieces of brecciated rock containing galena partly filled the cave."

Oxidation of the ore is not much in evidence, although a little smithsonite was found in one of the upper drifts. Limonite is abundant in fissures, particularly near the cliff that overlooks the river. A small bare dolomite knob south of the large low-grade stopes is smoothed and grooved by glacial action, and it is likely that oxidation products, particularly on the exposed high points, were removed by the ice scour.

E. J. HOAGE

The E. J. Hoage group of seven claims is about 1¾ miles south of Z Canyon in the southeastern part of sec. 22, T. 40 N., R. 43 E. It is developed by two short adits and by several pits and open cuts. The country rock comprises dense white cherty dolomitic limestone. dark bluish-gray jasperoid, and coarse creamy-gray dolomite. Coarse white calcite is irregularly distributed on much of the surface, and in one cut a lamprophyre dike about 2 feet wide was seen. This dike strikes N. 70° W. and dips 85° N.

The attitude of the bedding is difficult to determine, but from vague composition banding it is thought to strike a little east of north, with a dip of about 10° W. The beds are probably those that normally are about 200 feet below the black slate.

A little disseminated sphalerite and patches of galena are generally found in the jasperoid and in a few places in the dolomite and magnesian limestones.

LAKEVIEW

The Lakeview property is on the slope north of Crescent Lake in sec. 1, T. 40 N., R. 43 E. It is developed by an adit that trends N. 30° W. for 255 feet. The property was idle when visited.

The country rock is a medium- to fine-grained creamy-gray dolomite, thought to be below the nodular cherty horizon in the Cambrian limestone beds. A few beds of black carbonate rock with spots of white dolomite are exposed in the adit. Near the mineralized ground veinlets and irregular patches of recrystalline dolomite are abundant and a little "zebra" rock is seen. The dolomite strikes N. 10° E. and dips 20° W. At 200 feet the adit cuts a fault that strikes N. 80° E. and dips 50° S. This fault contains 6 inches to 2 feet of gouge and breccia. The dolomite north of the fault contains only creamy-gray dolomite, but south of the

[66] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Conservation and Development, Div. Geology, Bull. 31, p. 60, 1924.

fault are a few bands of black carbonate rock with white dolomite spots. For this reason, the south side of the fault is thought to be down relative to the north side (a normal fault).

North of the fault the dolomite is sparingly mineralized. Sphalerite and galena are the principal minerals, but a little pyrite was seen. The ore minerals and the dolomite are arranged concentrically, like those especially well developed at the Z Canyon property. One well-formed nodule about 1½ inches in diameter has a center of galena surrounded by a band of sphalerite and a border of crystalline dolomite. Most of the sulfides are bordered by coarse cream-colored dolomite that is lighter than the country rock. Two colors of sphalerite are present—yellow and reddish.

Much of the sphalerite along and near the fault has been leached. The cavities formerly filled with the zinc mineral are lined with a pale-brownish powder, probably iron-stained carbonate.

LEAD KING

The Lead King property includes seven claims about 2 miles northwest from the mouth of Slate Creek and mostly in the east half of sec. 27, T. 40 N., R. 43 E. It is owned by the Pend Oreille Mines & Metals Co. and was idle when visited. Mineral Resources reports small shipments of ore in 1917, 1925, and 1926, and Jenkins [67] says that two or three carloads of ore, principally lead and zinc, are reported to have been shipped in 1918. The property is developed by an adit trending S. 70° E. for 191 feet (paced), driven from the level of the road from Ledbetter Lake to Russian Creek to intersect the mineralized rock on the slope above. Considerable gophering has been done on the outcrop, and apparently the high-grade shipping ore was obtained here. A few other shallow diggings have been sunk on the claims, and several diamond-drill holes have been put down.

The country rock is fine-grained soft gray limestone, in places dolomitic and, particularly near the ore bodies, recrystallized to a lighter-gray dolomite. Much of the limestone contains irregular spots of calcite, generally less than 1 inch in longest dimension. Veinlets of coarse light-gray dolomite cut irregularly through the fine-grained, slightly darker limestone. The veinlets are bordered by narrow zones (less than one-eighth inch) of nearly black carbonates. Dark-gray or black jasperoid is abundantly developed, particularly near the ore bodies and in the crystalline dolomite, and spots and veinlets of clear colorless quartz are common. Several large patches of coarse white calcite are exposed on the hill above the workings. Toward the east the limestone loses its gray color and cherty nodules become more conspicuous. To the west is a narrow alluvium-filled valley bordered by poorly exposed black slate.

The attitude of the rocks near the mineral bodies is difficult to determine, as much breccia is developed and slips and cracks are numerous. To the east just above the workings the bedding is better defined; it strikes N. 10° E. and dips about 35° W. The alluvium-filled valley may be the site of a fault trending N. 10° W., with the slate to the west faulted down.

The ore consists of galena and sphalerite, mainly in the jasperoid but locally in the crystalline dolomite and the fine-grained limestone. No oxidized zone exists, as fresh sulfides are found on the surface. The ore body appears to nearly parallel the bedding, and, if this is so, the continuation should be looked for to the west under the alluvium rather than in the hill to the east.

ROBERT E. LEE

The Robert E. Lee patented claim is on the west bank of the Pend Oreille River about half a mile west of the mouth of Slate Creek, in the NW¼ sec. 35, T. 40 N., R. 43 E. The property has been idle for years, but a short inclined shaft and a few shallow pits can be seen. A few diamond-drill holes were sunk by the Pend Oreille Mines & Metals Co., which held the claim under option for a short time. The workings are reached by trail from the Ledbetter Lake road, about a mile to the west.

The country rock (Metaline limestone) is medium to coarse even-grained gray dolomite, with scattered spots of white calcite less than an inch across. Black Ordovician slate overlies the dolomite and is particularly well exposed in the trail to the property and at the portal of the inclined shaft. The slate has yielded a few graptolities. A lamprophyre dike, rich in biotite and showing a few grains of olivine, is exposed near the inclined shaft. This dike, about 3 feet wide, trends N. 60° W. and is either vertical or dips about 85° SW. Two faults, approximately parallel to the dike and about 100 feet part, were recognized. One of these faults is shown in figure 11. On both breaks the south side is down relative to the north side; the offsets are not exactly known but are of the order of magnitude of 100 feet. It is probable that other faults of this system are present but not exposed; this is suggested by the distribution of the slate and dolomite on the slope. The complex structure in the canyon of the Pend Oreille River just north of Slate Creek appears to be related to the fault structure at the Robert E. Lee workings, although the details have not been studied.

The dolomite contains scattered spots of galena. Sphalerite has not been recognized, but some of the vugs in the rock near the surface resemble those seen elsewhere and known to have been filled with sphalerite.

[67] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Cons. and Devel., Div. Geology, Bull. 31, p. 60, 1924.

LUCKY STRIKE

The Lucky Strike group is in the northeastern part of sec. 35, T. 40 N., R. 43 E., east of the Pend Oreille River and north of Slate Creek. The property is owned by R. L. Lakin, of Spokane. Nothing but assessment work has been done in recent years, although Mineral Resources reports a shipment of ore in 1926.[68] The property is developed by an inclined shaft and several drifts which were mostly inaccessible when visited.

The country rock (Metaline limestone) is crystalline dolomite, probably 600 feet stratigraphically below the black (Ordovician) slate. The topography is rugged, although the relief is not great. The prospect is in a breccia zone, probably related to the fault in nearby Slate Creek. Patches of coarse white calcite are common and much of this mineral is found on the dump. In the river canyon the strike of the beds is N. 5° W. and the dip 40°–65° W. Much limonite is present, particularly along fissure zones and solution channels. Galena and sphalerite are found on the surface and in shallow cuts. The workings are reported by Mr. Lakin to have been stopped in heavy iron sulfide, and a large part of the dump consists of radial pyrite and limonite. Some of the limonite appears to contain smithsonite or hemimorphite. Several specimens of a very fine grained light waxy sphalerite were found on the dump at the shaft. This sphalerite is iron-free but is found in hand specimens that are largely pyrite.

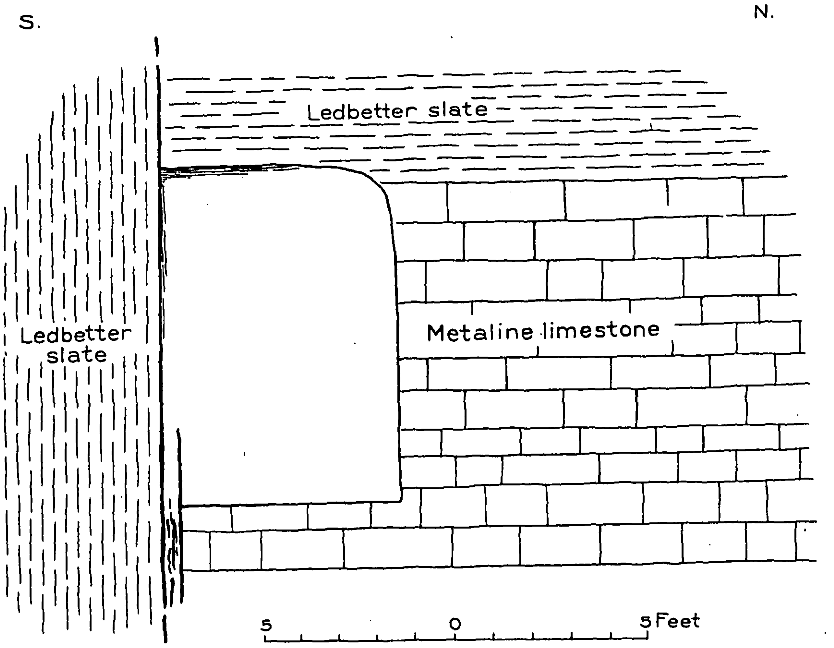


FIGURE 11.—Dolomite-slate contact at inclined shaft at Robert E. Lee claim. Vertical section.

METALINE CONTACT

The Metaline Contact Mines Co., of Spokane, controls several large blocks of ground in the Metaline district. One block, from which the company takes its name, is a group of claims and homesteads around the Oriole, O. K., and Bella May properties. A second group of claims lies west, north, and east of the Lead King property, and a third group, staked in 1937, covers a large part of the drainage basin of Threemile Creek. In addition, the company has smaller holdings north of the Cliff patented claim and has recently staked much of the open land west of the Pend Oreille River and north of Z Canyon.

No mining other than assessment work has been done on any of the company's holdings.

MORNING AND MAMMOTH

The Morning and Mammoth property of the Metaline Metals Co. is in the west-central part of sec. 15, T. 39 N., R. 43 E., on the east bank of the Pend Oreille River north of the Grandview mine. The property was one of the early discoveries in the district[69] and much underground work has been done, although, so far as known, no production is recorded. According to Elmer Berglund,[70] who was in charge of the underground work during the period of greatest activity, the shaft is 430 feet deep. Brinsmade[71] mentions levels at 80 feet, 200 feet, and 400 feet, in addition to two adits; the workings aggregate almost a mile of drifts. The property was idle when visited, and only one adit was accessible. A small amount of diamond drilling has been done.

Rock exposures near the mine workings are poor and are limited to a strip along the river and a cliff

[68] Mineral Resources U. S., 1926, p. 468, Bur. Mines.

[69] Adair, J. B., Mineral resources of the State of Washington—The Metaline district: Northwest Mining Jour., vol. 7, pp. 54–56, 1909.

[70] Personal communication, 1937.

[71] Brinsmade, R. B., Two Washington mining districts: Min. and Sci. Press, vol. 113, pp. 743–745, 1916.

between the shaft and the Grandview workings. The country rock (Metaline limestone) consists of dolomite and limestone, in places intensely silicified. Irregular patches of coarse white calcite are also present, particularly in the dolomite. In the river bed, at low water, black graptolite-bearing slate can be seen. The accessible adit is driven S. 35°E. for 372 feet (paced), and a crosscut to the southwest contains 135 feet of additional drifts. Most of the rock is coarse- to medium-grained grayish dolomite, similar to the dolomite commonly found just below the slate. Fine-grained soft dense limestone is entered at 96 feet from the face of the adit and continues to the face. It is reported by Mr. Berglund that similar limestone was found in the deeper workings.

The details of the structure near the Morning and Mammoth are practically unknown. In the river bed to the west and also to the south and southeast the strikes of the dolomite and limestone beds are about north-south and the dips are low to the east. In the adit a few narrow shaly seams trend north to N. 10° W. and dip less than 15° E. The structure is complicated by numerous faults that strike from north to N. 45° E. and dip steeply east. One of these faults is reported to have been found in the shaft, and others can be seen in the adit and in the nearby exposures. In these faults the east side appears to be up relative to the west side. The contact between the slate and dolomite in the river bed is one of these nearly vertical faults.

The ore consists of galena and sphalerite disseminated in the jasperoid and brecciated dolomite. Some fine-grained sphalerite is also scattered through the dense limestone. Seams of paligorskite are conspicuous in the accessible adit. It is reported that evidence of mineralization decreased in depth and that sulfides were practically absent in the deeper workings.

PEND OREILLE

The Pend Oreille mine is on the west bank of the Pend Oreille River about 1 mile north of Metaline Falls, in sec. 16, T. 39 N., R. 43 E. (See pl. 32.) It is owned by the Pend Oreille Mines & Metals Co., of which L. P. Larsen is president and C. A. R. Lambly is mine manager. The mine is on one of the early discoveries in the district and in 1906 was known as the C. W. Clark property; at that time control passed into the hands of Mr. Larsen.

Mining was started about 1910 in a mineralized outcrop on the Josephine claim and was carried on more or less continuously on a small scale until 1919, when the property was shut down. During this period about 40,000 tons of ore was mined and milled, and 4,000 tons of concentrates yielded $275,000 from smelter returns.[72] In 1928 an extensive diamond-drilling campaign was started and large tonnages of low-grade zinc ore were indicated; a little later a body of high-grade zinc-lead ore was discovered on the 300-foot level northeast of the Josephine shaft. Further drilling greatly extended the limits of this high-grade ore, and most of the recent mining has been done on this body. A 300-ton flotation mill was completed and production was begun in November 1930. In May 1932 the property was shut down again but in June 1933 was reopened for about 11 months. Early in 1936 production was once more started, although handicapped by power shortage. In September 1937 a power plant on the Pend Oreille River was completed, the flotation mill was overhauled, and production stepped up to about 600 tons a day.

The concentrates are trucked to the railroad at Metaline Falls; the zinc is shipped to the American Zinc Co.'s plant at St. Louis, Mo., and the lead to the Bunker Hill & Sullivan plant at Kellogg, Idaho.

The principal mine development has been carried on through three connected openings—the Josephine shaft, the Cascade or 500-foot level adit, and a new shaft about 675 feet N. 27° E. from the Cascade. Much of the early work was done in the Josephine shaft from two levels, the 100-foot and the 300-foot. This shaft was not accessible when the mine was examined, and the 100-foot level could not be entered. Most of the 300-foot level was also inaccessible, as the water had backed up from the sump at the shaft. Part of the 300-foot level and the stopes driven from this level were entered through an inclined raise from the Cascade adit. The Cascade adit was started on the north bank of Flume Creek and driven to the northwest to intersect the ore body found on the 300-foot level. About 2,350 feet of drifting has been done on the 500-foot level, and most of the stoping to 1937 was from this level. The level is connected to both the 300-foot and 700-foot levels by inclines. (See pl. 33.) The new shaft, sunk about 250 feet, was completed in 1936. It contains one hoisting compartment and one other compartment; ore and waste are trammed to the shaft from one level, the 700, although a station was established at the 650-foot level for unloading supplies. Development work in the block of ground between the 500-foot and 700-foot levels was being rapidly pushed in 1937.

The distribution of the workings from the 300-foot, 500-foot, and 700-foot levels as of October 1, 1938, is shown in plate 33. The block diagram (pl. 34) shows also the 100 level and the zero level, an adit driven into the hill west of the Josephine shaft. From the mineralized outcrop shown at the west end of the diagram mining has been pushed gradually eastward nearly to the west bank of the Pend Oreille River.

Several other adits have been driven on the property. One, the Chickahominy, driven from the river

[72] Larsen, L. P., The Metaline lead-zinc district: Arizona Min. Jour., vol. 16, no. 2, pp. 5–6, 1932.

bank south of Flume Creek, ended in 20 feet of sphalerite-bearing jasperoid and dolomite. Much of the property has been and is being explored with diamond drill.

Mining is done through a system of raises to the tops of the ore bodies, where cuts are made and the ore is "benched" to the raises. Drag-line scrapers are used in the stopes, as ordinarily the ore will not run. An effort is made, however, to keep inclined raises 45° or steeper.

The country rock consists of dolomite and limestone of Middle Cambrian age, overlain by black graptolite-bearing slate. Much of the carbonate rock, particularly within 200 feet of the slate, is recrystallized and thoroughly brecciated. In places, particularly near the ore bodies, the breccia is recemented by silica, and large masses of dark-gray or black jasperoid are found. Spots of crystalline gray or cream-colored dolomite and some limestone are generally present in the otherwise completely silicified rock. Irregular-shaped masses of coarse white or light-gray calcite are particularly numerous near the jasperoid. These calcite masses are customarily 10 to 20 feet across in any dimension, although exceptional bodies, such as that in the Flume Creek Gorge below Hidden Falls, are exposed for 100 feet or more. Below the jasperoid and mineralized rock is a fine-grained soft gray limestone that contains a few chert nodules and irregular narrow streaks of indistinctly outlined carbonaceous particles. (See pl. 8, A.) Remnants of this limestone scattered through the upper crystalline dolomite and a few in the jasperoid indicate that both the dolomite and jasperoid are later products, formed in the limestone. No igneous rock has been seen on the property, but diamond drilling has shown the presence of at least one lamprophyre dike.

Faulting is very common throughout the mine, but is particularly accessible to study in the abandoned open stopes on the 500-foot level. The faults are, with few exceptions, sharp, clean breaks, with small displacements, probably less than 10 feet, although at least one has a displacement of about 200 feet. The fault surfaces are generally smooth and slick, in places highly polished; elsewhere grooves are developed. Readings on many of these grooves are shown on plate 33. The larger faults have two or more smooth, slick surfaces, separated by black or gray limy gouge and finely ground breccia in which the individual particles are noticeably subrounded. Both calcite and ore are associated with faults, and many breaks cannot be traced through bodies of either type. For this reason both calcite and ore are thought to be mainly later than the faulting. Minor readjustments on many of the slips have brecciated and polished both materials.

On plate 33 all the faults mapped are shown and on plate 34 an effort has been made to plot only the larger breaks. At least two periods of faulting are distinguished; the earlier faults are flat-dipping and the later ones steep. The flat breaks (No. 1 fault, pl. 34) may in places be bedding slips; they are cut by the steeper faults. It is possible that steep fractures of several ages are present, but if so they have not been recognized. The steeply dipping fractures have two trends, one north-northeast and the other northwest; no regularity of dips is shown.

The attitude of the bedding planes is difficult to recognize. In a few places shale seams indicate an eastward dip in the fault blocks. The block diagram indicates a general eastward dip of the slate-dolomite contact. In the river bed east of the mine good bedding planes are exposed; they trend northeast and dip 20°–30° SE.

Echelon or steplike tension (?) cracks are present in many of the stopes. These cracks, filled with white quartz, calcite, and in places a few sulfides, are in general nearly at right angles to the faulting, but in one stope they are parallel to a prominent break. The cracks are generally less than 10 feet long and not more than 2 inches wide. They commonly stop abruptly at fault planes, although in a few places they cut directly across the faults. The tension (?) cracks are evidently in large part later than the ore, as they cut both ore bodies and barren country rock.

The dolomite breccia is healed by silica and ore and is thus presilica and preore. Some silica and ore have been involved in late movement, however, and in places form a poorly cemented breccia. The breccia is mostly of the so-called crackle type, in which the fragments have moved but little relative to each other. Black-shale particles are found in many places in the breccia, but they are more abundant near faults.

The ore forms irregular replacement bodies in the jasperoid and dolomite, with smaller amounts in the coarse calcite and the fine-grained limestone. The replacement bodies are followed approximately down the dip to the eastward; they correspond in a general way to the bedding but in detail are not confined to one single layer. This is shown by the range in thickness of the individual bodies; in several stopes the ore is 6 or 8 feet thick; elsewhere it is 25 or, exceptionally, about 50 feet thick. The depth of the ore below the slate is not constant; in some places it is nearly 200 feet; elsewhere it may be 50 feet or less; in one stope (7–19) a black-slate window shows in the back. (See pl. 33.)

A close association between ore and black or dark-gray jasperoid is readily noticed, even by a casual observer. That an increase in silica content accompanies an increase in sulfide content is shown both from a study of the graphs (pls. 21 and 22) and by field observation. The ore is in the jasperoid; where veinlets or irregular masses of jasperoid are isolated in dolomite, coarse calcite, or marble, the sulfides are generally in the silica rather than in the surrounding rock. In places the sulfides penetrate other rocks, although such material is likely to be of low grade. The sharp contacts between calcite and jasperoid seem to be a particularly favorable place for ore, which is almost entirely in the jasperoid but in places extends into the calcite.

The principal ore minerals are sphalerite and galena, with the sphalerite greatly predominant. The sphalerite is of two colors, reddish brown and pale yellow. A few small globules of hydrocarbon (classified as anthracite) are found in the dolomite. At least one shipment of ore from the 700-foot level contained sufficient copper to be paid for at the smelter. This copper is probably in the form of tetrahedrite (?), a few tiny pieces of which have been seen. Pyrite and marcasite are rare in the ore, but a little pyrite was seen on the 300-foot level, and a little marcasite is distributed in many of the caves and along other water channels. Limonite and pyrite are reported to have been present in considerable amounts in the workings from the Josephine shaft. Paligorskite (leather or asbestos of the miners) and limonite are also abundant in the caves; the paligorskite (pl. 17, B) causes considerable exasperation when dumped into the crushing machinery.

Caves are conspicuous features in the mine workings, near and above the 500-foot level. A few small caves nearly free of paligorskite are found on the 700-foot level. The caves are described on pages 38–39. Much good ore has been taken from them.

In the shallow oxidized zone the ore consists of galena coated with cerussite and scattered bits of cerussite and smithsonite. It is reported by Mr. Lambly that some smithsonite was shipped to the smelter during the early period of mining. A bright-yellow coating on pieces of sphalerite on the dump at the Josephine shaft has been identified by W. T. Schaller as the cadmium mineral greenockite (CdS_2). Galena appears to be concentrated near the borders of the sphalerite shoots.

RIVERSIDE

The Riverside property is on the east bank of the Pend Oreille River south of the mouth of Slate Creek, in the SE¼ sec. 35, T. 40 N., R. 43 E. It is owned by the Metaline Metals Co., but with the exception of a few diamond-drill holes no development work has been done for years. The workings are on a cliff that rises almost vertically above the river. As the dug trail from the terrace above to the workings was washed out, nothing was seen except along the edge of the terrace. The prospecting appears to have been done on several of the northeastward-trending fissures that are conspicuous in the river gorge.

The country rock is medium-grained crystalline gray dolomite, much brecciated and distorted. The dolomite is entirely surrounded by black slate and is an outlier from the plate thrust over the slate along the Slate Creek fault. (See pl. 1.) Many northeastward-trending fissures are exposed in the river gorge; these fissures strike about N. 55° E. and are nearly vertical or dip steeply northwest. Displacement of the strata has occurred on all the fissures.

Bancroft [73] describes the deposit as a fissure vein in dolomitic limestone. He says, "* * * the vein being exposed for a vertical distance of 250 feet. * * * The trend of the vein is N. 55° E. and the dip 70°–80° NW." The minerals are reported to be radial pyrite (marcasite?) with a little galena arranged in concentric bands. Bancroft identified gypsum, "steel" galena, and chalcopyrite and refers to the very heavy gossan. This gossan is conspicuous in many places in the gorge and arises from the oxidation of iron sufide. A little native sulfur was found in some of the limonite, and spots and bands of coarse white calcite were seen.

SCANDINAVIAN (LEAD QUEEN)

The Scandinavian (Lead Queen) prospect is in the south-central part of sec. 11, T. 40 N., R. 43 E., just east of Z Canyon. The property was idle when visited, and but little information was obtained. A few shallow pits were the only workings found.

The country rock is dense white fine-grained cherty dolomitic limestone, in most places covered with a thin layer of glacial debris. Several large irregular patches of coarse white calcite are exposed. The beds trend about N. 10°–30° E. and dip at low angles to the west.

A few spots of galena and some iron-stained vugs that may represent leached sphalerite were the only signs of mineralization seen.

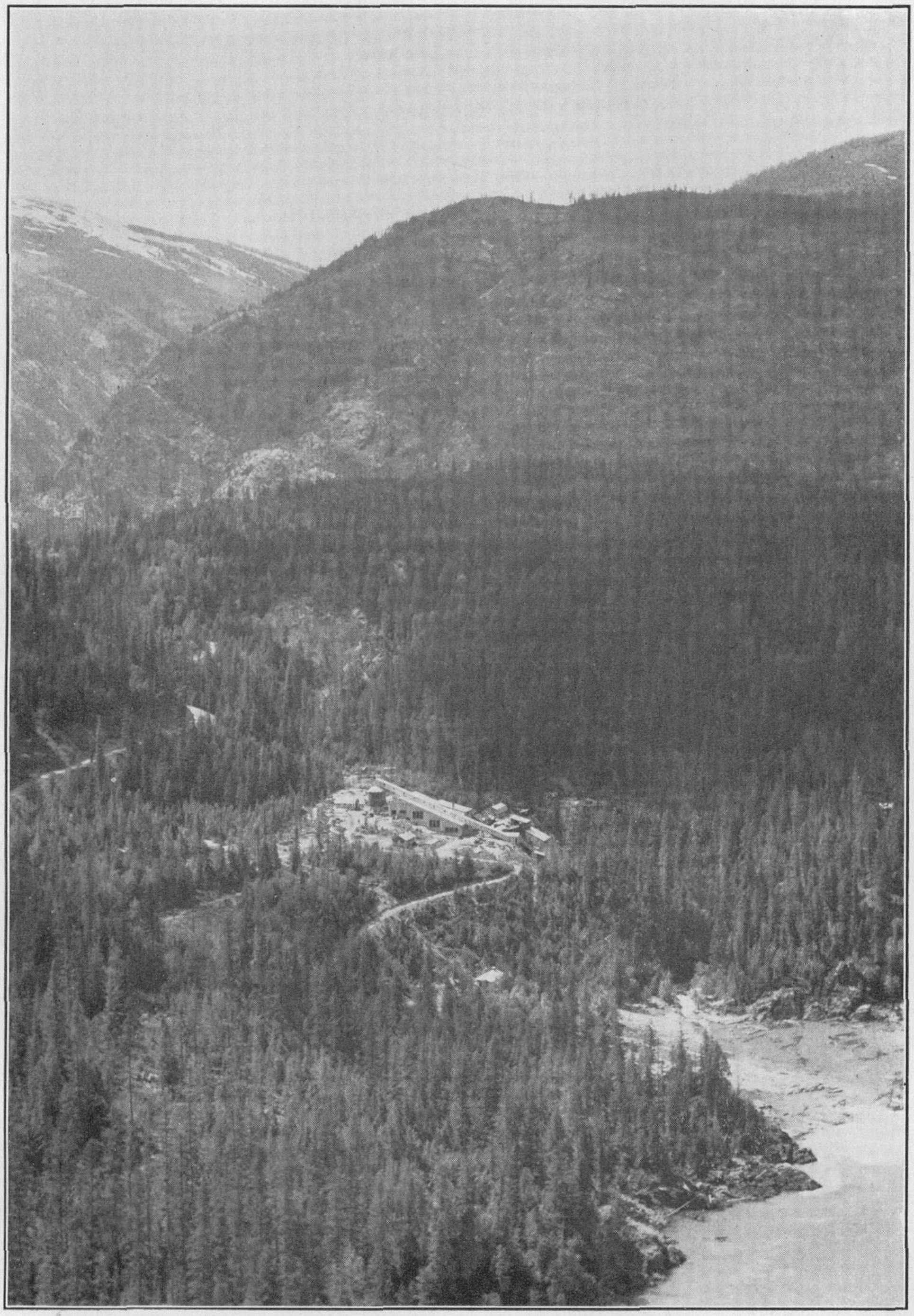
TOM CAT

The Tom Cat property includes two claims east of the road about 1 mile north of Z Canyon, on the border of secs. 3 and 10, in T. 40 N., R. 43 E. In 1937 the property was purchased by E. O. Dressel, of Metaline Falls. The development workings consist of one short adit and several small cuts.

The country rock is dark bluish-gray dolomite, in places brecciated and replaced by jasperoid. The trend of this jasperoid and dolomite is northeast. To the northwest is a terrace deposit, and to the southeast is a dense white cherty marble, separated from the mineralized zone by about 25 feet of jasperoid. The width of the mineralized zone is not known and the attitude of the beds is not clear but apparently the strike is northeast and the dip steep to the northwest.

The bluish-gray dolomite and jasperoid show numer-

[73] Bancroft, Howland, Ore deposits of northeastern Washington: Geol. Survey Bull. 550, pp. 50–51, 1914.



PEND OREILLE MINE AND MILL.
View west from Grandview workings.

ous spots and patches of galena and considerable finely disseminated sphalerite.

WASHINGTON AND METALINE FALLS

The Washington group and the Metaline Falls claim are on opposite sides of the river at Metaline Falls. They are owned by the Pend Oreille Mines & Metals Co. The company's new power plant is built on the Metaline Falls claim, east of the river. A shaft was sunk 150 feet on this claim but the amount of drifting from the shaft is not known. Several diamond-drill holes were put in from the bottom of the shaft and excellent exposures were seen in the large intake tunnel and the surge-tank excavation made for the power plant during the early summer of 1937. The work on the Washington group consists of a short adit about 90 feet long and several shallow cuts. The adit is described by Jenkins,[74] who mentions a body of solid pyrite mixed with galena at 60 feet from the portal.

The dolomitized limestone country rock is exceptionally well exposed on the walls of the river gorge near and below the falls. From 400 to 500 feet of dolomite section is represented. Near the river level the rock is banded black with white spots and creamy white, typical of the formation well down in the Cambrian limestone section. Ordovician black slate that has yielded a few graptolites is exposed on the west side of the river just north of the Washington adit and on both sides of the river north of the power plant. The slate was also found in the drill holes from the bottom of the Metaline Falls shaft.

The dolomite and limestone sections overlie the slate. The contact is a thrust-fault surface of unknown attitude but probably nearly horizontal. The dolomites are badly shattered, and bedding is difficult to recognize south of the slate outcrops, although farther north in the gorge bedding is readily recognized; it trends east of north and dips 20°–30° E. At one place on the east wall it is nearly horizontal. In the shattered dolomite the black and white layers have a general eastward dip, although in detail they are haphazardly oriented.

Galena and sphalerite in small amounts are widely disseminated through the dolomite. Much limonite, probably formed by the oxidation of pyrite, is spread over the dolomite and in places concentrated in fractures and caves. The limonite from one such cave on the Washington claim was mined by the Lehigh Portland Cement Co. for use in the manufacture of cement.

WOLF CREEK

The Wolf Creek property is near the mouth of Wolf Creek, in the NW¼ sec. 4, T. 38 N., R. 43 E. The developments consist of several shallow adits and surface cuts and an inclined shaft, inaccessible when visited. The country rock is coarse gray crystalline dolomite, locally brecciated and in places containing chert nodules. The exact location of the dolomite in the stratigraphic column is not known, although it is in the upper part of the Metaline limestone. To the south and southwest of the workings Ledbetter slate is exposed, apparently faulted against the dolomite.

The bedding in the dolomite trends N. 10°–25°E. and dips steeply east(?). The rock is considerably broken; the fractures seen all trend northeastward.

Galena is the principal ore mineral and is sparingly distributed through the rocks in the accessible workings and on the dumps. A little sphalerite, globules of hard brittle hydrocarbon, a little iron sulfide, and paligorskite were noted. Limonite is plentiful in several of the workings, and small amounts of gypsum and hemimorphite(?) were noted with it.

In the railroad tunnel west of the workings good exposures of the mineralized dolomite can be seen.

Z CANYON MUTUAL

The Z Canyon Mutual property is east of the Pend Oreille River in the north center of sec. 11, T. 40 N., R. 43 E. The developments consist of an adit trending N. 62°E., about 400 feet long, and a few pits and small cuts.

The country rock in the adit is mostly a medium- to fine-grained creamy-gray dolomite that contains some "zebra" banding, some coarse-grained white calcite, and a few fragments of black shaly material. The "zebra" banding here seems to be approximately parallel to bedding planes, striking N. 20°W. and dipping 40°SW. The rock of the last 100 feet in the adit is much mottled and contains considerable soft, weathered carbonates. Some concentric banding similar to that at the Z Canyon mine is also present (see pl. 26), although no sphalerite was seen. Some of the dolomite about 100 feet from the face of the adit contains small chert nodules in a fine-grained dolomite similar to the zone below the Ledbetter slate. Near the portal of the adit the dolomite contains black bands with white spots. Much of the dolomite throughout is a crackle breccia.

The adit was started to undercut a mineralized exposure on the hill to the northeast but was stopped short of its objective. Sparse sphalerite and galena can be seen in the small surface cuts.

Z CANYON

The Z Canyon property is east of the Pend Oreille River in the SW¼ sec. 11, T. 40 N., R. 43 E. It is controlled by the Pend Oreille Mines & Metals Co. A little assessment work was done during 1936 or 1937, and several shallow cuts and two adits were accessible.

[74] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington Dept. Cons. and Devel., Div. of Geology, Bull. 31, p. 56, 1924.

In addition to the surface workings, a small amount of diamond drilling has been done. Mineral Resources reports a small shipment from the property in 1926.

The country rock is medium-grained gray crystalline dolomite. A few hundred yards west and northwest of the workings black Ledbetter slate is exposed. The contact between these two formations is nearly vertical or dips steeply southeast; it is a fault surface (Z Canyon fault) of considerable displacement. The dolomite trends about N. 10°E. and dips 35°–40° W. Its place in the stratigraphic column is not known, but it is probably less than 500 feet stratigraphically below the slate. Much of the dolomite is brecciated and contains irregularly distributed and squeezed fragments and seams of black slaty material. A zone of minor fracturing, nearly parallel to the dolomite-slate contact, is exposed in the workings. Jasperoid and coarse white calcite in small quantities are found throughout the property.

A peculiar concentric structure of the ore is particularly well developed here, although recognized elsewhere in the district. (See pl. 26.) This concentric banding is described and its origin is discussed in the section on replacement deposits (p. 50). In places the ore minerals are in breccia; in this shattered material "zebra" banding and tiny vugs lined with dolomite crystals are common.

Galena and sphalerite are the ore minerals sought and are sparingly distributed through the jasperoid and dolomite. The sphalerite is in two colors—reddish brown and pale yellow, generally found together. Smithsonite, greenish-yellow stain (greenockite), and limonite are sparingly present in the ores near the surface.

O. K.

The O. K. group of seven claims was located and developed by E. J. Hoage but has been involved in protracted litigation. The claims lie along the quartzite-dolomite contact southwest of the Oriole property. The main workings of the group are on the O.K. claim, although considerable prospecting has been done throughout the property. The total workings on the O. K. group comprise about 1,000 feet of drifts, mostly in two levels, one at an altitude of 3,275 feet (aneroid) and the other about 100 feet higher. The lower adit contains about 300 feet of drifts and the upper adit 430 feet. At an altitude of 3,475 feet a 60-foot incline has been sunk; the remainder of the exploration work is in short adits and surface cuts.

The country rock is similar to that at the Oriole. It consists of sandy dolomite and schist of the Monk formation overlain by the Gypsy quartzite. The entire assemblage has been subjected to igneous metamorphism, and the dolomites and schists are recrystallized. Tremolite, diopside, tourmaline, and a few small red garnet crystals are present in the limestone, and coarse green amphibole occurs in the schist. Several coarse granitic and pegmatitic dikes (or sills) are poorly exposed, as they are softer than the metamorphosed rocks nearby. One fine-grained intrusive that consists of feldspar, jefferisite, quartz, tourmaline, and garnet was noted. In a few places rocks resembling hornfels are found.

The rocks trend in general northeastward and dip northwestward, into the hill, although considerable variation in attitude is seen. In a gully that drains into Sweet Creek, north of the O. K. workings, the dolomite-quartzite contact is exposed. The two rocks are gradational, and no fault was seen. Here, at the Oriole, the Flume Creek fault is in the alluvium east of O. K. Mountain. Most of the development work has been done in the coarse white sugary marble below the quartzite, and in no place has the contact been cut underground. A schist band is exposed at the face of the upper adit. The contact between the schist and dolomite trends nearly east-west and dips 26° N. Several adits and prospect pits have been opened on quartz streaks in the quartzite.

The mineralization is spotty and much scattered. Small amounts of tetrahedrite, galena, sphalerite, pyrite, chalcopyrite, and pyrrhotite have been found. Some gold and silver are reported to be present, but no assays were seen.

ORIOLE

The Oriole property, owned by W. L. Schulz, includes seven claims, mostly in secs. 19 and 20, T. 39 N., R. 43 E. Some production is reported in Mineral Resources for the years 1911, 1917, 1925, and 1926. Patty[75] states that "smelter returns on a carload of picked ore gave 42.1 ounces of silver, 21.9 percent of zinc, 15.3 percent of lead, and 1.12 percent of copper. Jenkins[76] mentions 4½ carloads of ore shipped before 1924. In recent years nothing but assessment work has been done.

Practically all the underground exploration has been done on one claim, the Oriole, which is about 1¼ miles northwest of old Metaline, in the southeast corner of sec. 19. Three adits have been driven in northwestward directions about 40 feet apart. At the time of visit the upper two of these adits were open but the lower was caved at the ore body. An inclined winze is reported to have been sunk 91 feet on the ore from the third level. From the bottom of this winze a short drift (40 feet) was driven on the lead. The workings total about 1,600 feet of drifts and raises.

The country rock is dolomite of the Monk formation just below the base of the Gypsy quartzite. The

[75] Patty, E. N., The metal mines of Washington: Washington Geol. Survey Bull. 23, p. 88, 1921.

[76] Jenkins, O. P., Lead deposits of Pend Oreille and Stevens Counties, Wash.: Washington State Dept. Conservation and Development, Div. Geology, Bull. 31, p. 68, 1924.

dolomite is hard; in places its contains about 50 percent or less of silica grains. It is pale buff or gray and even-grained. The quartzite exposed just above the workings is mostly sheared grits, although the entire Gypsy quartzite section is exposed on Linton Mountain, to the west.

The beds, both the dolomite and the quartzite, trend N. 25° E. and dip 30°–45° NW. The contact between these two formations was not seen, although it is reported to have been cut at about 240 feet beyond the cave-in on the lowest adit. The best information about this contact seems to be that it was tight and clean; no breccia or gouge was developed, although all the rocks in the drift were badly sheared. This observation checks with the data obtained from a diamond-drill core in possession of the Pend Oreille Mines & Metals Co. In this core the contact appears to be gradational, and no evidence for assuming a fault to be present was seen. East of Linton Creek is an entirely different type of carbonate rock—blue fine-grained dolomitic limestone similar to that assigned to Middle Cambrian age. The Flume Creek fault is therefore under the alluvium in the narrow Linton Creek Valley between the two carbonate rocks, rather than between the quartzite and dolomite, as has been suggested before.[77] The shearing in both the sandy dolomite and the grits is considered to be related to the Flume Creek fault.

The ore is apparently along a gouge-breccia seam that trends in general N. 65° W. and dips ± 60° NE. The ore deposit is a series of lenses, elongated down the dip and connected by narrow stringers of quartz. On the upper levels these lenses are narrow, probably not averaging more than 1 foot in width; in depth they widen, and on the third level seven lenses are reported to have been mined. These lenses were 1½ to 4½ feet wide by 12 to 20 feet long along the drift. Two lenses of a maximum width of 3 feet are reported to have been cut in the 40-foot drift at the bottom of the inclined winze. According to Jenkins, the ore was followed on the third level for about 175 feet to a point where it pinched out.

The ore consists of sheared quartz and sericite that contains sulfides, galena, sphalerite, pyrite, and chalcopyrite. The galena is reported to carry considerable silver. The ore from the deeper workings is said to contain more zinc than the ore in the upper levels.

Much of the quartz is limonite-stained, and malachite, azurite, smithsonite, and cerussite have been noted. The rocks are deeply oxidized for this region, and in the upper adits the geology is partly obscured by weathering.

LIMESTONE

The manufacture of cement has been the most stable industry in the region and is probably the greatest single factor in its development. As early as 1905 Landes[78] stated that steps had been taken to manufacture cement at Box Canyon, where "there are large deposits of pure limestone and beds of excellent clay." The Pacific Portland Cement Co. acquired 262 acres of land in 1905 and expended $20,000 in preliminary work. The plant under construction at that time was designed to produce 200 barrels daily. Shedd[79] discussed the status of the industry in 1913 and briefly mentioned the geology and reserves of the region. He rated the plant at Metaline Falls (Inland Portland Cement Co.) at a daily capacity of about 1,800 barrels. Glover[80] recently rated the Metaline Falls plant of the Lehigh Portland Cement Co. at 2,000 barrels a day.

Large tonnages of limestone near the base of the Metaline limestone have been obtained from three quarries in the hill southeast of Metaline Falls. The lower two of these quarries are abandoned, and the entire output is quarried near the top of the hill and carried by a gravity tram to the plant at Metaline Falls. Shale for the cement is quarried a few hundred feet north of the lime quarry and from a quarry in Ledbetter slate on the railroad at Sand Creek.

The limestone used at present is a fine-grained dark-gray rock with a few crystals of clear calcite. Part of the rock is mottled and contains irregular small patches and a few seams of white calcite. The quarrying is limited to one horizon between shale on the hanging wall and dolomitic limestone on the footwall. This bed is 20 to 30 feet thick and trends N. 10° E., with a dip of 33° W. It can be followed for 1,000 feet or more along the strike and is reported to be fairly uniform in composition. Dolomite is widespread throughout the region, and careful sampling and selective quarrying have been necessary in the past to maintain cement at specifications. The limestone quarried at present is near the base of the Middle Cambrian limestone and is at one of the two known fossil localities in this formation. To the east the limestone beds become fewer and the shaly beds more numerous until the formation is typical Maitlen phyllite. The so-called shale quarry is in one of the dark-gray limy phyllite beds.

The Sand Creek "shale" quarry is in typical Ordovician graptolite slate. It is of value principally because of its accessibility to the railroad.

The amount of limestone in the region suitable for cement manufacture is unquestionably large, but because of transportation and other economic factors the productive deposits are restricted to the easily accessible areas.

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77 Jenkins, O. P., op. cit., p. 69.

78 Landes, Henry, Cement resources of Washington: U. S. Geol. Survey Bull. 285, p. 382, 1905.

79 Shedd, Solon, Cement materials and industry in the State of Washington: Washington Geol. Survey Bull. 4, pp. 179–199, 1913.

80 Glover, Sheldon, Nonmetallic resources of Washington: Washington Dept. Cons. and Devel., Bull. 33, p. 86, 1936.

LEHIGH IRON PITS

The Lehigh cement plant uses limonite in the manufacture of certain grades of cement. This limonite is obtained from several sources. A minimum amount of iron sulfide and aluminum-bearing clays is desired, and for this reason most of the shallow oxidized sulfide deposits along the Pend Oreille River cannot be used. A deposit near the top of Washington Rock, west of the highway bridge at Metaline Falls, was worked in 1936. This deposit was at the solution-enlarged intersections of two groups of fissures; the stratification and crude banding parallel to the walls indicate a cave filling.

During 1937 two pits were worked. One is on the hill above and to the northwest of the Bella May mine. The other, on the Oriole claim, is a few hundred feet south of and across the Flume Creek fault from the Oriole workings. The hill slope on which these two deposits lie is covered with vegetation, and exposures are poor. Weathering seems to be deeper than is customary in the region. Although enough work to determine the origin of the deposits has not been done, that at the Bella May appears to lie nearly parallel to the bedding and may be an oxidized pyrite body along a bedding slip.

PLACER DEPOSITS

HARVEY BAR

The Harvey Bar is on the Pend Oreille River about 1 mile north of the Lucky Strike mine, in the north center of sec. 26, T. 40 N., R. 43 E. The property was abandoned when visited but is reported to have been reworked for years during low-water periods by one man, who recovered a small amount of gold. The pockety dolomite bedrock is shallow and is similar to that at the Scherding placer, described below. The Harvey Bar is one of a series worked in a very small way along the Pend Oreille River.

SCHERDING PLACER

The Scherding placer is on a large gravel bar on the east side of the Pend Oreille River about half a mile south of the international boundary and just below the mouth of Z Canyon Gorge. (See pl. 27, *C*.) The treatment plant was designed to handle 200 cubic yards a day. It consisted of a dragline scraper, a revolving grizzly, a screen and water jet, and two sets of sluice boxes lined with blankets and riffles. The plant was put into operation late in the summer of 1935 and, when visited in 1937, was temporarily shut down because of mechanical trouble. In 1938 the plant had been dismantled because it was not capable of handling the cobbles and coarse rocks encountered. Much of the equipment had been installed in a small suction dredge, and an effort was being made to dredge the bar.

The bar contains well-rounded river gravel, generally less than 6 inches in diameter but rarely as much as 1½ feet. Considerable clean sand and many tiny rounded pebbles of black slate are present. Most of the gravel and sand are quartzite and phyllite particles. In the small cut made by the scraper the gravel is crudely stratified. The bedrock is dolomitic limestone and is uneven and pockety.

Several pans of black sand reported to have been recovered from a test run were examined. All showed numerous small colors of gold, flat and 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. Sufficient work has not been done to obtain an estimate of the amount of gold likely to be found.

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