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STRUCTURAL GEOLOGY
OF THE COEUR D'ALENE MINING DISTRICT
AND ADJACENT AREAS

Part II

Precambrian Layered Rocks
and Precambrian and Mesozoic Diabase - Diorite Intrusions

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Hecla Mining Company
Wallace, Idaho
December 27, 1963

Part II

Precambrian Layered Rocks

and Precambrian and Mesozoic Diabase-Diorite Intrusions

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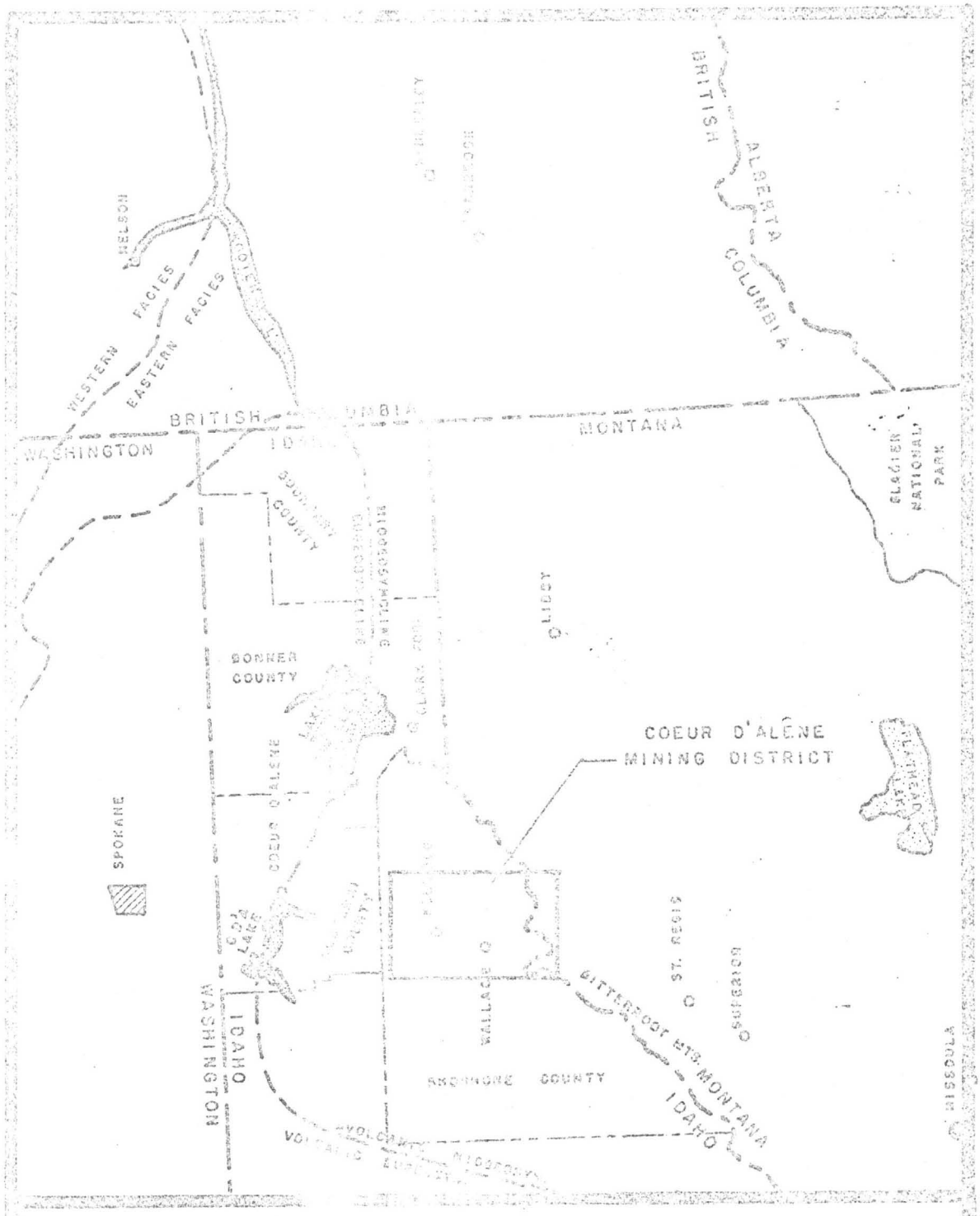

Fig. 1

Location Map

0 20 40 60 MILES

1" = 30½ miles (approx.)

STRUCTURAL GEOLOGY
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Part II

Precambrian Layered Rocks
and Precambrian and Mesozoic Diabase-Diorite Intrusions

ABSTRACT

Rocks of the volcanogenic-sedimentary western facies within the area of Fig. 1 comprise strongly deformed and metamorphosed eugeosynclinal-type volcanics and clastics of Carboniferous and Mesozoic age overlying sedimentary rocks of Precambrian and Lower Paleozoic age.

The sedimentary eastern facies comprise slightly to moderately metamorphosed miogeosynclinal-type Belt (Purcell) and Windermere series* in places overlain by Lower Paleozoic strata. Precambrian diabase-diorite sills and dikes, called Moyie intrusions, are common. Mesozoic diabase-diorite dikes, emplaced after regional folding, are common in northwestern Montana and northern Idaho.

Sedimentary rocks of northern Idaho are Precambrian and Cenozoic with the exception of a few downfaulted blocks of Lower Paleozoic strata, and remnants of a Lower Paleozoic or Carboniferous conglomerate found in limited areas. In northwestern Montana the present erosion surface cuts

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* The writer conforms, under protest, to the custom of applying the term "series" to the Belt sequence.

across large areas of Precambrian sedimentary rock, but in places there are found downfaulted blocks of Lower Paleozoic strata, or Lower Paleozoic strata lying on Precambrian Belt series and separated from the latter by a disconformity or small angular unconformity. In Canada and northeastern Washington the Precambrian Windermere series overlie the Precambrian Purcell (Belt) with a disconformity or small angular unconformity. Near Kootenay Lake, B.C., upper Windermere strata are gradational into Cambrian formations. In other places the Cambrian lies on Windermere with a disconformity or small angular unconformity.

Canadian geologists regard the Purcell-Windermere break as of greater tectonic importance than the Windermere-Cambrian one. However, in northeastern Washington the Windermere-Cambrian break appears to be of at least equal importance.

Belt (Purcell) formations were deposited during the Middle and early-Upper Proterozoic era, but the oldest formation is at least late-Lower Proterozoic. The rocks range in age from 800-1,600 m.y. or older. Windermere rocks are latest Proterozoic, ranging in age from 600-800 m.y.

Moyie intrusions were injected in at least three stages: Early intrusions were emplaced at the end of the Lower Proterozoic. Intermediate stage intrusions were emplaced at the end of the Middle Proterozoic. Late stage intrusions accompanied the East Kootenay orogeny during the middle- to late-Upper Proterozoic.

Amphibolization has affected all the diabase-diorite intrusions. Uralitization converted some pyroxene to amphibole during a stage of late-magmatic crystallization. A second wave of amphibolization affected those

diabase intrusions located in or near areas that were invaded by Mesozoic granitic plutons. This resulted from static thermal metamorphism aided by magmatic emanations. High grade amphibolization occurred only in areas of strong regional metamorphism and granitization in or near the eugeosyncline.

In areas of ore mineralization hydrothermal alteration was superimposed upon amphibolization. Feldspars were decomposed to clay and calcite, and ferromagnesian minerals were replaced by chlorite. That the diabase-diorite intrusions, including the Mesozoic dikes, antedate the ore mineralization is indicated by the fact that they have been extensively mineralized by secondary (i.e., epigenetic) sulfides.

THE VOLCANOGENIC-SEDIMENTARY WESTERN FACIES

Within the area of interest of this study, Fig. 1, the rocks of the western facies lie close to the eugeosyncline-miogeosyncline boundary. They show some features characteristic of both the "Eu" and the "Mio". Immediately west of the Eu-Mio boundary, as drawn on Fig. 1, are found areas containing miogeosynclinal-type strata, but these are overlain by strata of the eugeosynclinal facies. Precambrian rocks of the Windermere series (in Canada), Belt and Windermere (in Washington), and Belt (in Idaho) are present. These are overlain in places by argillites, graywackes, quartzites, limestones, slates, phyllites and schists of Lower Paleozoic age; and by eugeosynclinal-type sediments and volcanics of Carboniferous, Triassic and Jurassic age. The rocks are for the most part strongly deformed and severely

metamorphosed and granitized. Schists, gneisses, and metasomatic and igneous granites are widespread (10) (11) (12) (33) (34) (41) (45) (60) (61).

THE SEDIMENTARY EASTERN FACIES

The sedimentary eastern facies within the area of Fig. 1, are composed of Precambrian and early Paleozoic rocks. Middle and late Paleozoic, and Mesozoic sediments either were not deposited or they have since been eroded away. The facies is not characterized by basic volcanics, although small amounts of such volcanic rocks are found in limited areas. For example the Purcell and Irene volcanics of southeastern British Columbia, and similar volcanics in upper Belt formations of Glacier Park and on the divide between Yaak and Kootenai rivers in northwestern Montana, and the Leola volcanics of northeastern Washington. These are all of Precambrian age. Large basic sills and some dikes are common, however, especially in southeastern British Columbia, northern Idaho, and northwestern Montana. These were designated Moyie intrusions by Reesor (43). Basic dikes of Mesozoic age are also present.

Of the sedimentary rocks exposed at the surface most belong to the Belt (Purcell) and Windermere series. The term Purcell is used in British Columbia in reference to rocks equivalent to those called Belt in the United States.

A. Belt (Purcell) and Windermere Series

Most writers apply the term "series" when discussing the Belt rocks. Some use the terms "series" and "system" interchangeably in spite of the fact

that those terms have been well defined in the literature. This situation apparently indicates that the time interval represented by the Belt sediments has been considered by some investigators as equivalent to an "epoch" of geological time, and by other investigators as equivalent to a "period". The present writer objects to the custom of applying the term "series" to the Belt sediments on the ground that the rocks represent a long interval of geosynclinal deposition (57) (58) (54). Gradually accumulating evidence shows that Belt sediments were deposited throughout most and perhaps all of the Proterozoic era. The term "series" therefore should not be applied to the Belt rocks because it lacks sufficient rank. However, since the term has become so strongly entrenched in the literature the writer will conform, under protest, to this usage.

Belt (Purcell) formations consist of quartzites, argillaceous or sericitic quartzites, argillites and shales, limy argillaceous quartzites, and some limestones. That is they are predominantly of the quartzite-shale-limestone suite and are typically miogeosynclinal. Many of the rocks are colored in light tints such as green, gray, red and white, but dark colors are not uncommon. They are well consolidated but generally only slightly metamorphosed. In some areas the rock metamorphism can scarcely be classed as intermediate grade diagenesis as defined by Dapples (7). The formations appear to be conformable, with gradational contacts, but it is possible that some disconformities exist especially in upper units of the series. For example, the presence of occasional pebbly horizons in Striped Peak suggests the possible presence of disconformities in that formation.

Numerous Belt and Purcell sections varying from 30,000 to 40,000 feet in thickness have been measured (1) (4) (16) (43) (44) (46) (48). The

thinnest sections appear to be in Shoshone and Kootenai counties of Idaho. Here the maximum recorded sections are 17,000 and 25,000 feet respectively (42) (55) (2). One of the most complete Beltian sections of Montana or Idaho was measured in the St. Regis-Superior area of Montana. A.B. Campbell has reported this section as 30 000 feet in thickness (6).

Precambrian sedimentaries younger than Belt (Purcell) are found only in southeastern British Columbia and northeastern Washington. These are the Windermere series, named for the type area at Lake Windermere, B.C. (59). Windermere rocks are widespread in the big bend of the Columbia River north of Revelstoke, B.C. They are found on the east flank of the Purcell Mountains, but more especially on the west flank and in the Selkirk Mountains where they form a broad arc-like band extending southeasterly from Revelstoke to Kootenay Lake, thence southerly to the International border and southwesterly into Washington (10). A section of Windermere rocks 22,000 feet in thickness has been reported near Nelson, B.C. (45).

Earlier students of Belt geology were convinced that the various formations are strikingly persistent over wide areas. Clapp and Deiss claimed to have traced the Newland, Spokane, and Helena formations, and even the higher formations of the Missoula group from Glacier Park to southward beyond Missoula and from the Idaho border eastward to the Lewis and Clark range. They concluded therefore that the Belt formations had been deposited as continuous sheets in relatively broad troughs, and not as interlapping and restricted lenses in small isolated basins. Charles Deiss has stated that although the formations are locally thinned in different parts of western Montana, he could find no case either of complete disappearance of a formation as a result of thinning, or of interlapping of formations (8).

Later students, doing detailed work in limited areas, have found marked lateral changes within short distances. Such changes are especially noticeable in the higher formations (46). C.P. Ross states that no single formation has been traced throughout western Montana, and that "A basic concept in evolving a classification (of Belt formations) is that lateral variation is so prevalent that units of formational rank cannot be assumed to be recognizable very far from their type localities" (47). W.M. Johns says that the Belt sediments have presented a mapping problem because of rapid facies changes laterally, lack of diagnostic fossils, general absence of good marker beds, and general lack of good exposures (24). In view of these difficulties, Ross prefers to take the group, rather than the formation, as the essential unit in stratigraphic classification. In ascending order above the Prichard formation the groups are: Ravalli, Piegan, Missoula, and North Boulder. He also plans to subdivide some Belt formations into "many new formations" (47), and this appears to some field geologists as a rather frightening prospect.

However, correlation of the more persistent formations across State and National boundaries can and should be attempted, and it is hoped that what follows will be considered a contribution. In reading the section on stratigraphy it will be of help to refer to the correlation diagram attached herewith. (preceding p. 84).

Some unresolved questions regarding Precambrian stratigraphy are: What is the time-stratigraphic position of the Windermere series as compared to the Upper Beltian Missoula group of Montana? Is there a possibility that some rocks time-stratigraphically equivalent to Windermere may exist somewhere in western Montana? What is the time-stratigraphic position of the Helena, Marsh, and Greenhorn Mountain formations as compared to the Missoula

group? What is the time value of the lipalian interval between Belt and Cambrian rocks?

Stratigraphic marker horizons are few in the Belt. The Newland formation is so widespread that it is used by many geologists as a key to regional correlation. As Campbell states, it and its equivalents retain many of their characteristics throughout much of northern Idaho and northwestern Montana (6). It has a distinctive light and dark banded appearance and calcareous composition. Its thickness is relatively constant with the exception of a thickened belt extending along the west flank of the Montana dome from Superior to Libby, and a thinning of the formation at the easternmost extremities of Beltian deposition, as at Neihart.

Striped Peak formation has been found useful as a key in correlation by the writer.

The Purcell lavas are used as horizon markers in parts of British Columbia and Montana. But care should be taken not to confuse these with the Irene and Leola volcanics of the Windermere series. Another difficulty with the Purcell basalts is that they consist of several flows which are not continuous. Flows may be separated by up to 100 or 150 feet of sedimentary rock. This is a disadvantage in close correlation because in a particular area the field man can not be certain as to exactly which lava flow he is dealing with.

The Irene and Leola volcanics and their associated conglomerates are useful marker horizons in some areas.

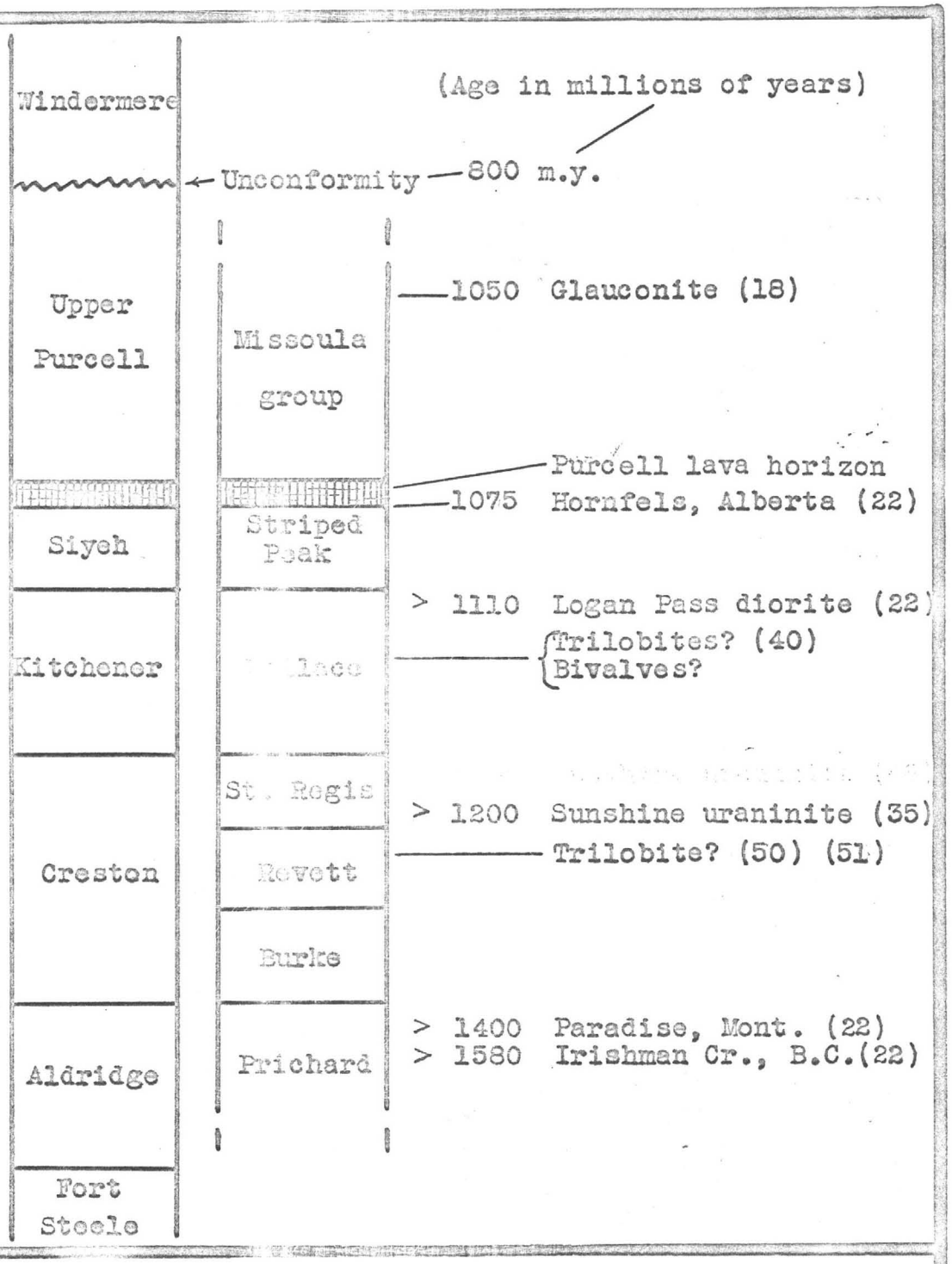

Fig. 4

MINIMUM AGES

OF PURCELL AND BELT SEDIMENTARY ROCKS

ACCORDING TO GEOCHEMISTRY

1. Stratigraphy

In Idaho the formations, with the exception of Striped Peak, are all of the lower and middle Belt. Frank Calkins described the formations of the Coeur d'Alene district (12) and named them. From oldest to youngest they are as follows, with the Canadian equivalents shown in parentheses: Prichard (Aldridge), Burke (Creston), Revett (Creston), St. Regis (Creston), Wallace (Kitchener), and Striped Peak (Siyeh). These are shown in Fig. 4.

Stratigraphically the Prichard is the lowest and oldest formation of the Belt series in Idaho. Since the base of the formation has never been seen in the State it cannot be said with certainty that other, older formations do not underlie it. In the Little Belt Mountains near Neihart, Montana, a coarse grained, reddish quartzite underlies the Ravalli group. This Neihart quartzite, which rests on granitic gneiss, could conceivably be older than Prichard (47). Small exposures of quartzite south of Philipsburgh were once supposed to be older than Prichard, but it is now thought that these rocks may belong to Missoula group. In the Cranbrook map area of British Columbia the Fort Steele formation conformably underlies the Aldridge. This is the only area in which a formation definitely older than Prichard (Aldridge) can be observed. Fort Steele is over 7,000 ft. thick, and consists of white and gray quartzite and argillite and black dolomitic argillite. Green or reddish horizons or bands are seen in some parts of the formation (44).

Montana geologists group the Burke, Revett, and St. Regis together under the name Ravalli, and this is approximately equivalent to the Creston of Canada. Also, in Montana the Wallace formation is known as Newland,

Piegan, or Siyeh, and overlying this are Upper Belt formations known collectively as the Missoula group. However, Piegan is sometimes described as consisting of Wallace or Newland and Striped Peak or its equivalents (47).

Upper Belt (Upper Purcell) formations are found over wide areas in Montana and British Columbia. Striped Peak of Idaho is largely correlative with red bed members of the lower Missoula group, of which the Miller Peak is basal member. Therefore, Striped Peak is the only formation of northern Idaho that can properly be referred to the Upper Belt. However, in Canada the Striped Peak (Siyeh) is considered the uppermost formation of Lower Purcell (43).

As already stated, the red and green banded Striped Peak and Siyeh, of Idaho and Canada respectively, are approximately equivalent to the red bed formations of the lower Missoula group. But the Siyeh of Glacier National Park is a dark gray or bluish black calcareous formation approximately correlative with Wallace and Newland. Therefore, the Siyeh of Montana is not the same as the Siyeh of Canada which is a non-calcareous, banded, green and reddish argillaceous quartzite.

A lava and tuff horizon known as Purcell basalt, lies at the top of the Canadian Siyeh, and at the top of the Striped Peak in the Libby and Yaak River areas of Montana. The lava horizon consists of several flows of basalt interbedded with uppermost Siyeh strata. The top of the uppermost lava flow marks the top of the Siyeh (Striped Peak) formation (44). In Canada the formation immediately overlying Purcell basalt is the Dutch Creek, and above this the Mount Nelson formation (59) (45). In the Libby district of Montana the formation overlying the lava is the greenish-gray Libby, and across this is carved the present erosion surface. Purcell basalts are

also found within the red bed formation of the Lower Missoula group in Glacier Park. Immediately above the volcanics lies the greenish-gray Shepard formation, and this in turn is overlain by the Kintla (46). The writer sees no reason why there should be hesitation in correlating the red bed formation of lower Missoula group with the Striped Peak of Idaho and the Libby district of Montana, and with the Siyeh of Canada; and the Shepard with at least the lower parts of the Libby and Dutch Creek formations. G.B. Leech has expressed the opinion that Dutch Creek includes everything from the top of the Purcell lava up and through the Kintla equivalent (31). If this is true then the entire thickness of Missoula group, in Glacier Park, is older than Mount Nelson formation of Canada.

Mount Nelson is probably the youngest formation of the Purcell series in Canada, and it is unconformably overlain by basal Windermere. Maximum measured thickness of Dutch Creek and Mount Nelson combined is over 7,700 feet (59) (45).

The Windermere series are separated from the underlying Purcell by a break which in places is an angular unconformity, but in other places a disconformity. Canadian geologists regard the Purcell-Windermere break as of greater tectonic importance than the Windermere-Cambrian one (31). J.F. Walker believed that the Purcell formations had been slightly metamorphosed by diagenetic processes prior to deposition of Windermere (59)

In the vicinity of Nelson and Salmo, B.C. there are sections of Windermere measuring over 22,000 feet in thickness (45) (33) (34). The series begins with a basal conglomerate which in Canada is referred to as the Toby, but in northeastern Washington it is called the Shedroof (41). This may be up

to 5,000 feet thick. The conglomerate passes upward into the Irene volcanic formation, and this is overlain by the Monk and Three Sisters (33) (34). The latter formation, in the vicinity of Kootenay Lake, passes upward by gradual transition into the Quartzite Range formation of Lower Cambrian age. The base of the Cambrian was arbitrarily drawn by Canadian geologists on the basis of paleontological evidence (33) (34). In the vicinity of Lake Windermere, Canal Flats, and Fernie the series is present only in part, and Cambrian formations lie on Windermere with a disconformity or slight unconformity (59) (29) (30). The break mainly represents erosion of Upper Windermere because the overlying Paleozoic rocks include Cranbrook formation of Lower Cambrian age.

No direct evidence is available as to the time-stratigraphic position of Windermere in relation to the Missoula group, or any particular part of Missoula group, of Montana. But it is possible to formulate a tentative inference regarding the relationship. Since uppermost Windermere is absolutely gradational into Lower Cambrian at Nelson and Salmo the series is obviously latest Precambrian. In Montana the Middle Cambrian lies upon upper Missoula group with a disconformity or very slight unconformity. The hiatus represents Lower Cambrian and latest Precambrian. The writer therefore agrees with Leech (31) that Windermere conglomerates, volcanics, and sediments were deposited during at least part of the interval represented by this hiatus. That is, they were probably deposited during the erosional interval that occurred following deposition of Missoula group. This erosional interval occurred during and after deformation caused by the late-Precambrian East Kootenay orogeny (63).

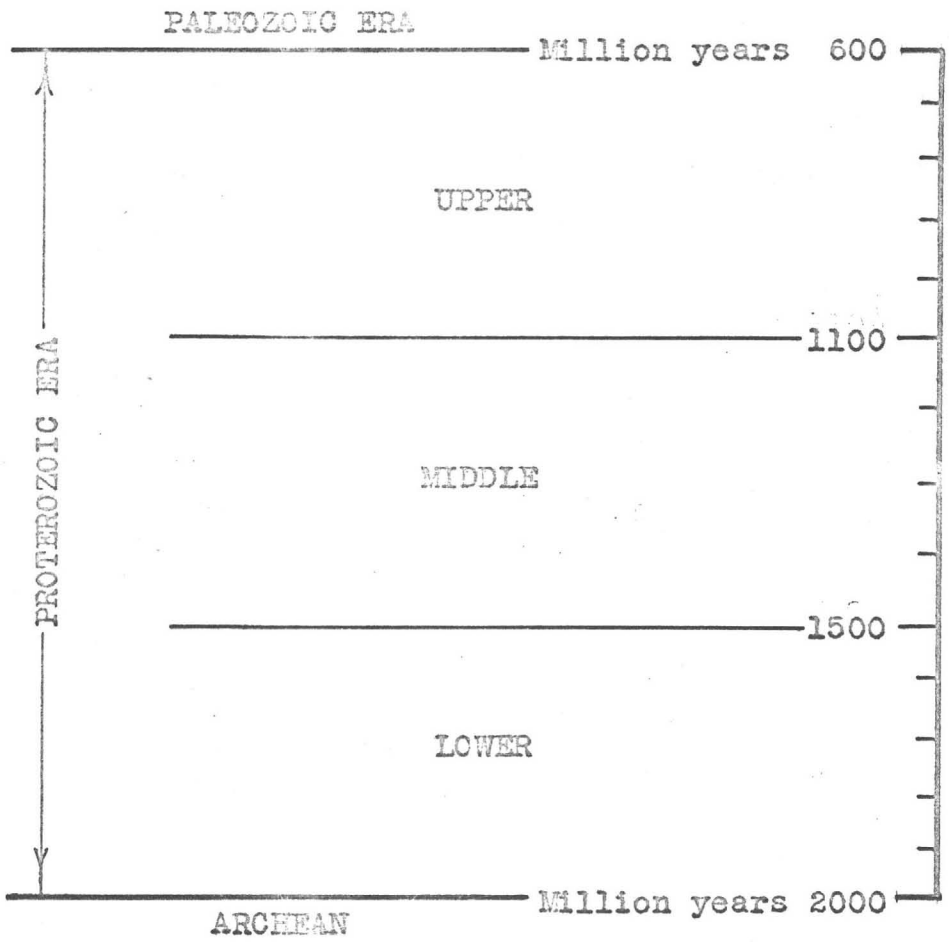

Fig. 5

DIVISIONS OF THE PROTEROZOIC ERA

Some confusion resulted when Kirkham and Ellis, in their bulletin on Boundary County, Idaho, assigned the Irene volcanics and the Irene conglomerates to the Purcell lava and Siyeh formation (28). This confusion has affected geological thought until the present time (47). The Irene volcanics are much higher in the stratigraphic sequence than are the Purcell lavas. They may be from 300 to 500 million years younger than the latter.

2. Age of the Sedimentary Rocks

Evidence regarding the age of Belt (Purcell) formations has been gradually accumulating. Much additional work needs to be done, but a beginning has been made and from this it is possible to form at least some tentative impressions regarding the age of the Precambrian formations.

Moyie intrusions at Paradise, Montana, and Irishman Creek, B.C. were emplaced and crystallized 1,400 m.y. ago in Prichard formation and 1,580 m.y. ago in Aldridge formation respectively (22). According to the time scale for the Proterozoic era used herein the Prichard and Aldridge were therefore deposited during the late Lower Proterozoic or earlier. See Fig. 5.

Uranium mineralization in the Sunshine mine, Coeur d'Alene district, was found by Professor Kerr and his associates to be at least 750 m.y. old (25) (26). Later calculations made to allow for lead loss showed the uranium mineralization to be approximately 1,200 m.y. old (35). This uranium occurs in the lower St. Regis formation. It will be shown in Part V of this study that the uranium may represent sedimentary-syngenetic-diagenetic deposits which were reworked during regional metamorphism and deformation, and again during sulfide mineralization. Lead was lost from

the deposits during one and perhaps both episodes of reworking. Presence of the uranium dates the lower part of the St. Regis as at least 1,200 m.y. old.

A basic sill (Moyie intrusion) in Siyeh formation at Logan Pass, Glacier National Park, contains amphibole which gave a K-A age of 1,110 m.y. (22). Obviously the sediments were deposited prior to injection of the sill, but the writer assumes that sedimentation was still in progress.

Hornfels in the contact metamorphic zone below a Purcell lava flow near Blakiston Brook, in the Rocky Mountains of Alberta, is 1,075 m.y. old (22). The hornfels is in rocks equivalent to uppermost Striped Peak (or lower Missoula group if Striped Peak is considered the lowermost member).

Gulbrandsen, et al., have announced the age of glauconite from the upper part of the Missoula group (18). The sample was collected from within a few thousand feet (stratigraphically?) of the Middle Cambrian Flathead quartzite. The Flathead lies unconformably upon Missoula group. Glauconite yielded a K-A age of 1,090 m.y., and a Rb-Sr age of 1,050 m.y. The average of the two ages is 1,070 m.y. Gulbrandsen points out that glauconite ages are commonly low. He states, "Hurley, et al., found that glauconite results may be 10 to 20 percent lower than ages measured for micas from igneous rocks whose positions can be reasonably determined stratigraphically". He concludes therefore that, "In view of the uncertainty of the isotopic ages for glauconites, the age of 1,070 m.y. for the Belt series sample should be considered a minimum age". The age determination seems reasonable, however, when compared to the age of the Logan Pass sill and the Blakiston Brook hornfels.

An interesting paleomagnetic study was completed during 1963 by R.F. Black (3). He attempted to date the Purcell system by comparing paleomagnetic

data obtained from a number of the formations with similar data obtained from Precambrian formations of North America whose ages are relatively well known. 75 samples collected from four magnetically stable Purcell formations were studied and the results tabulated. These suggested two possible interpretations. The interpretation favored by Black places Purcell at approximately 900 to 1,000 m.y. The second interpretation, previously suggested by DuBois (9) makes the Purcell about 1,120 m.y. old.

Tentative impressions, based on the various data compiled above, regarding the age of Belt and Purcell formations may be summarized as follows: The formations are, for the most part, not latest Precambrian as was formerly thought. They were deposited between about 800 and 1,600 m.y. ago. They are essentially Middle to early-Upper Proterozoic in age. Windermere formations are, on the basis of paleontological evidence, latest Precambrian and gradational into Cambrian.

There is little justification for assuming that, because the lead of the ore deposits is 1,400 m.y. old, the Belt sediments are Archean in age as has been suggested (35).

At this point will be mentioned an incident the significance of which the reader will have to judge for himself. In a letter to the Editor of Economic Geology, Mr. Fred Searls, Jr. stated that he once found a fossil on Kellogg Peak in the Revett quartzite (50). This mountain is about 2½ miles south of Kellogg, Idaho. In other correspondence, Searls stated that the object, which was found in 1909, was on a bedding plane of a slab of Revett. The slab was about 2" thick and a square foot in area. On the bedding plane were 3 or 4 (possibly 6) dimple-like marks, and then a

raised place, $\frac{1}{4}$" to $\frac{1}{2}$" high, that looked something like part of a bottle neck, with some markings on it. Searls gave the object to Lawson in Kellogg, and Lawson took it to the University of California in Berkeley. The head of the Department of Paleontology at that time was C.W. Merriam. It is not certain what person in the Department made the identification, but the object was identified as a trilobite. No other details are available, and it is not certain whether the identification was positive, tentative, or questionable (51).

In connection with the above paragraph one may recall that J.F. Pardee described some horizons in the Wallace formation in which forms suggestive of organic origin were found. This was in the upper St. Joe River basin. A lower horizon is about 1,000 feet above the Wishards sill. On the summit of Quarles Peak it is represented by a bed of grayish limy shale about 3 feet thick, crowded with flattened globular forms from $\frac{1}{2}$" to 1" in diameter. that suggest bivalves of some sort. An upper horizon, about 1,000 feet above the lower, is located 3/4 mile southwest of Quarles Peak in rock cuts along the line of the Chicago, Milwaukee (& Puget Sound) Railway about $\frac{1}{2}$ mile below the Adair loop (station 395 + 50 west of East Portal) and about 2 miles above the loop (station 243 + 50 west of East Portal). At these localities a bed of bluish limy shale or impure limestone contains numerous flattened cylindrical forms resembling mashed trilobites. C.D. Walcott examined some of the specimens and described them as, "elongated, more or less corrugated calcareous nodules, and some of them suggest organic origin" (40).

It is to be hoped that geochemists will eventually obtain additional age data for sills, dikes, and flows in Belt, Purcell, and Windermere rocks of many and widely separated areas. Good samples can be furnished from the

Coeur d'Alene and adjacent regions. An interesting Precambrian metagabbro intrusion is located in uppermost Missoula group rocks not far distant from the glauconite occurrence. The intrusion is a composite sill in Flathead County, Montana, just west of the Continental Divide, Lat. 48° N., Long. 113° 06' W. Geological information can be obtained from Plate II of U.S.G.S. Professional Paper 296 (46), and from U.S.G.S. unpublished maps of Marias Pass and Silvertip quadrangle (38). The sill is located 6 or 7 miles southeast of two small diorite stocks or bosses. The north end of the outcrop is covered by Cenozoic gravels, but at the south end it is cut off by the overlying Cambrian formation. By dating this sill it would be possible to obtain additional evidence on the minimum age of the Missoula group rocks at that locality. The matter of interest concerning this sill is not only that it is contained in upper Missoula group, but that it is cut off by Cambrian rocks.

Other Moyie intrusions that should be dated are sills enclosed in lower and middle Missoula group formations located in the Bonner quadrangle (a short distance north and east of Missoula), the Wishards sill at the crest of the Bitterroot Range; diabase dikes along Placer Creek south of Wallace and on the North Fork of Coeur d'Alene River; and a large sill on the west side of Fourth of July Pass in Kootenai County, Idaho. Sills in the Mount Nelson formation of Canada should be dated; and diorite boulders in the Sandpoint conglomerates as well as diorite dikes cutting the conglomerate (1). The writer can furnish good samples and data from all of these localities.

Problems to be considered when determing K-A ages of Belt sedimentary rocks are the fact that these are not only metamorphosed, but they contain small to appreciable quantities of clastic muscovite. The metamorphism, in

spite of its low grade, may be the resultant of a number of small metamorphic increments (Precambrian, Lower Paleozoic, Carboniferous, Permo-Triassic, Upper Jurassic-Cretaceous, and possibly even Upper Cretaceous-Tertiary). Close to mineralized areas wallrock has been impregnated with hydrothermal sericite. This Mesozoic sericite mineralization is superimposed upon regional metamorphic and clastic sericite.

B. Moyie Intrusions

1. Mode of Occurrence

Precambrian basic igneous rocks, known as Moyie intrusions, consist of sills and some dikes. The sills are concordant, or almost concordant, and can frequently be traced for miles along the strike of the inclosing sedimentary strata. They range from 20 feet to 2,000 feet in thickness, but individual intrusions may vary considerably in thickness along the strike.

The largest and most coarse grained sills are usually found in the oldest formations such as Fort Steele, Prichard (Aldridge), and Burke. Somewhat smaller intrusions are found in the Middle and Upper Belt (Purcell) rocks. Rice (45) has reported that sills 100 to 200 feet thick are found as high as the Mount Nelson formation, the topmost member of the upper Purcell of Canada. Leech states that no Moyie intrusions have been identified cutting Windermere strata (32), but Rice had previously reported basic intrusions in Windermere (45). However, these have been so sheared that identity of composition cannot be established. In Glacier National Park the sills and dikes occur in Siyeh formation. Some have been seen in Striped Peak formation of northwesternmost Montana (4). In the Rocky Mountains east of Flathead Lake,

on the east slope of Ringer and Cruiser mountains, the sills occur in upper Missoula group (46), but in the vicinity of Missoula, Montana, few if any sills are found higher than middle Missoula McNamara formation (39).

2. Relationship of Dikes to Sills

That at least some diabase dikes are related to the sills, and of the same age as the latter, was inferred by Rice for the Cranbrook area (44). As supporting evidence he described an observation made in the Kootenay Selkirk mine of British Columbia. A mineralized fracture was seen in the upper part of a large sill and in a dike-like offshoot from it. Other supporting evidence was seen in Boundary County, Idaho, where a "lamprophyre" dike appears as an offshoot from a sill (28). In southeastern Lincoln County, Montana, a metadiorite dike passes under gravels at the junction of Fisher and Kootenai Rivers. On the south side of the Kootenai the dike divides into two sills (23). In Glacier Park sills are found only in Siyeh formation. Dikes of similar composition are found in all formations up to and including Siyeh. A lava horizon occurs in the basal part of the Missoula group which overlies Siyeh. No case is recorded in which a sill or dike has been traced into the basalt lava horizon but a genetic relation between intrusives and lava is a logical assumption (46).

The above instances constitute evidence of a genetic relationship between dikes and sills. In other areas there is evidence that the dikes are not related to the sills in regard to time of intrusion although they may conceivably be related genetically. For example, in the Coeur d'Alene mining district are numerous diabasic dikes with mineral composition identical to that of the Precambrian Wishards sill. There are no sills in the mining

district, with the possible exception of a thin one on Willow creek 2½ miles southeast of Mullan (5). The dikes were injected after folding of the rocks was essentially completed, but Wishards sill was injected prior to folding. In the Libby district of Montana Gibson found diorite dikes compositionally similar to Precambrian sills. However, the dikes show crosscutting relationships to folded strata whereas the sills are concordant with the strata. Gibson therefore considered the dikes to be of Mesozoic age, and did not correlate them with the sills (15) (14). Although the source area of Mesozoic diabase magma may have been similar to the source area of Moyie magma, it is not related in time to the latter. It is therefore suggested that the term "Moyie" should not be applied to the Mesozoic diabase-diorite intrusions.

3. Regional Variations of Composition

The intrusions in general are composed predominantly of medium grained, dark greenish-gray to almost black rock. They are rather constant in composition and appearance, but individual sills may locally show variations in texture, grain size, and mineralogy (1). Zones or schlieren of lighter colored material may be found through the mass, as may dikes and apophyses of aplite or pegmatite and veins of quartz. Some of the larger sills are mineralogically stratified. These are invariably granitic at the top, dioritic at the centers, and gabbroic at the bottoms. This has been variously interpreted as due to gravitational differentiation during cooling, assimilation of siliceous sediments, and granitization of sediments along a narrow contact zone (4) (28). Thick sills also occasionally exhibit columnar jointing, with the joints perpendicular to the cooling surfaces (28). These factors have been cited as evidence that the sills were injected into flat-lying sediments.

Although Moyie magmas may all have had a closely similar chemical composition at the time of injection, the present day mineral composition shows that the intrusions can be grouped roughly into two general types: diabasic-gabbroic, and dioritic. This grouping, on an inter-regional scale, is empirical and gives no consideration to the possible or probable causes of the variations. The types occur in separate zones, with the diabasic zone on the south or southeast.

Much of the inter-regional variation is related to silica content. Some has been attributed to deuteric alteration and endomorphism, and some to hydrothermal alteration (4) (14) (16) (28) (43) (45). It seems likely that some may also have occurred as a result of metasomatism during retrogressive regional metamorphism of previously existing high temperature minerals.

It is interesting to speculate as to the effects on chemical and mineral composition when a crystallizing basic magma is injected into the unconsolidated or loosely consolidated and hydrated sediments of a trough in which marine sedimentation is still in progress.

The diabasic zone extends from the Coeur d'Alene district and the upper St. Joe River drainage basin, where the intrusions are most basic, into the Saltese-Superior district of Montana and thence into the somewhat less basic Flathead Lake and Glacier Park districts. In the Coeur d'Alene-St. Joe-Superior regions the intrusions are of diabase containing augite and labradorite; appreciable ilmenite, biotite, and chlorite; small amounts of quartz, [illegible], apatite, and hornblende (5) (40) (52) (54) (56) (62). In the Flathead Lake area the intrusions are classed as hornblende gabbro or metadiorite and are composed of hornblende and gray plagioclase of intermediate composition. The rock is appreciably silicified with cryptocrystalline quartz and chalcedony (23). Intrusions in Glacier National Park are called acidified gabbro or

metagabbro (46). These are composed of titaniferous augite, largely altered to hornblende, and decidedly calcic plagioclase. There are minor amounts of quartz, apatite, and iron oxides.

Adjacent to the diabase zone, on the northwest, there lies a more siliceous zone in which the intrusions are classed as quartz diorite and diorite. This zone is represented in Kootenai County, Idaho, by hornblende-quartz diorite containing up to 60% hornblende, 30% plagioclase, and 15% quartz. There are several percent of apatite and iron ore minerals (2). In the Clark Fork district of Idaho the rock is an abnormally quartz-rich diorite composed of an intermediate plagioclase, quartz, hornblende which has replaced pyroxene, and biotite (1). The sills in Boundary County and the northwestern corner of Montana are classed as diorite or metadiorite composed chiefly of hornblende, intermediate plagioclase and quartz plus some biotite, apatite and ilmenite (28) (4). Here also the hornblende crystals have cores of augite. In southeastern British Columbia, from Nelson to Cranbrook, the sills are classed as quartz diorite or meta-quartz diorite composed of secondary amphibole and albitized plagioclase. A few percent of ilmenite and quartz are present (43) (44) (45).

4. Age of the Intrusions

The Precambrian age of Moyie intrusions has been inferred partly because of the apparent relation between size or thickness of the intrusions with the stratigraphic position of the host rock, and partly because the fine grained facies of intrusions closely resemble the Purcell lavas (44). These factors were considered evidence that the intrusions were injected during the last stages of Belt deposition.

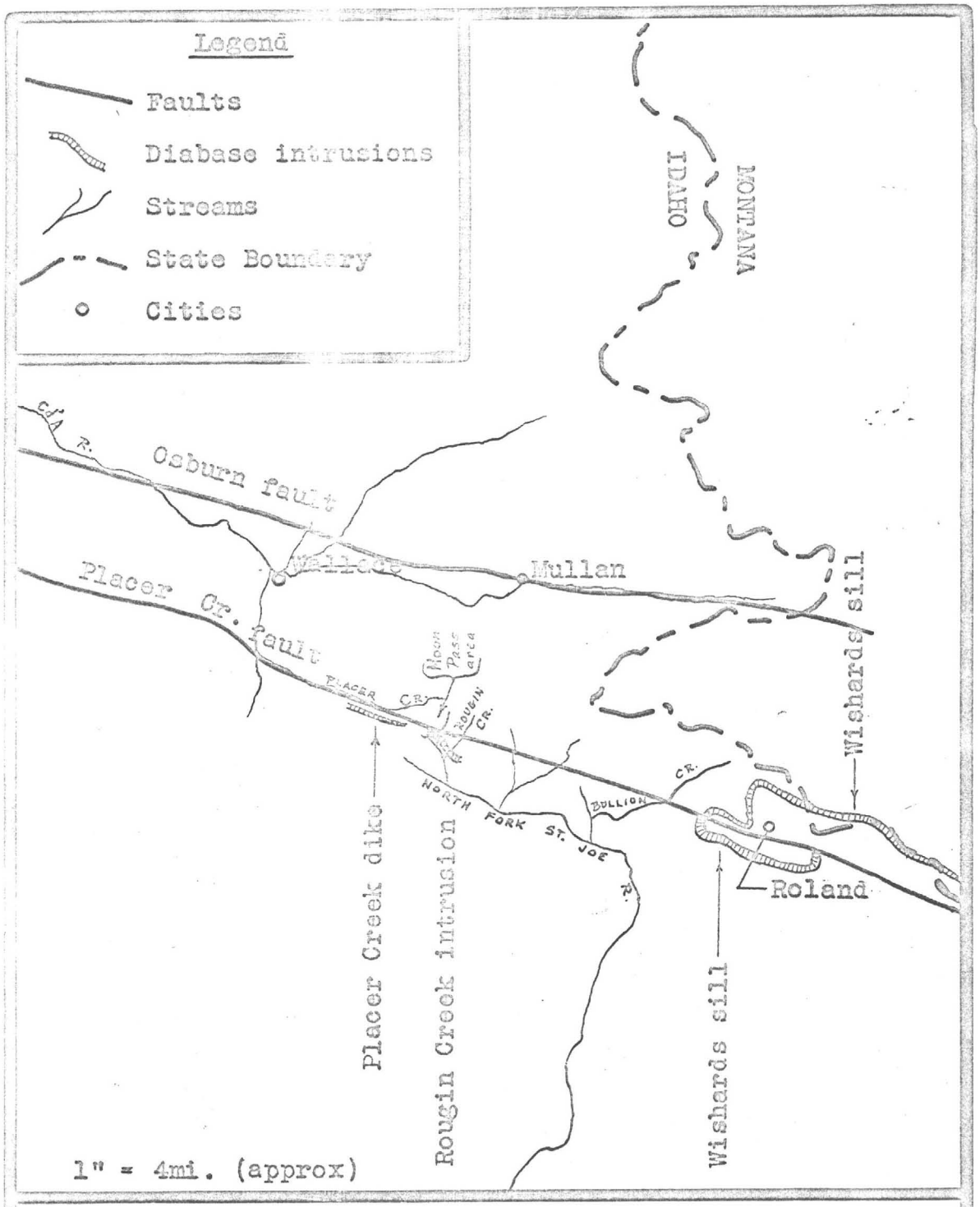

Fig. 6

LINE OF DIABASE INTRUSIONS

Placer Creek to Wishards sill

(Plate 1, USGS, Bull. 732)

That the sills were injected into the Precambrian sediments prior to folding, and while these were still flat-lying has been affirmed by numerous field geologists. Practically all state that these igneous bodies are clearly recognized as sills which have partaken in all of the orogenic movements that have affected the regions in which they are located (1) (2) (4) (5) (23) (28) (40) (55).

One locality in Idaho may furnish the possibility that K-A dating of Moyie intrusions may yield information on the age of regional folding. A line of diabasic intrusions is formed by the Wishards sill, the Rougin Creek intrusion, and the Placer Creek dike. The Wishards sill lying on the east, at the crest of the Bitterroot range, was injected prior to folding. It has been metamorphosed by the Idaho batholith. The east end of the Rougin Creek intrusion has been folded, but the intensity of folding decreases toward the west. At the west end, near Moon Pass, the intrusion has remained unfolded as far as can be determined from surface inspection. The Placer Creek dike, on the west side of Moon Pass, was apparently injected after folding of Belt rocks was essentially completed. These relations are shown on Fig.6.

North of Pend Oreille Lake, Idaho, the sills are cut off by the Sandpoint conglomerate. This conglomerate contains boulders of Moyie sills and of all Belt formations. A.L. Anderson has provisionally classed the conglomerate as Carboniferous (1). This writer suspects that the conglomerates could be Lower Paleozoic (pre-Devonian). They could conceivably be related to the Caledonian or East Kootenay orogenies. Although the conglomerate contains Moyie boulders, it is itself cut by basic dikes whose composition is similar to that of the Moyie boulders.

The sills were emplaced prior to regional metamorphism, and prior to emplacement of the great batholiths. Highly metamorphosed remnants of sills are seen in Prichard (Aldrich) rocks lying west of the Purcell trench in Boundary County, Idaho (28). In the Clark Fork district sills are cut by Mesozoic granitic stocks (1) (11). Where invaded by the granodiorite small engulfed masses or pendants of sill rock may be found in the granitic intrusions (1). The Wishards sill in the Bitterroot Mountains, Idaho-Montana boundary, has been locally metamorphosed by Mesozoic granitic stocks where these occur close to the sill (40) (55). In the St. Joe River basin the Mesozoic stock at Herrick cuts off a thin sill near Marble Creek (56).

Rice lists three volcanic formations to which the intrusions could be related (45): the Purcell lavas at the top of the Striped Peak (Siyeh) formation; the Irene volcanic formation in the Windermere series; the volcanic rocks in the Kaslo series of Triassic age. On the basic of structural and geochemical evidence the Triassic volcanics may be eliminated from the list of possible sources for the Precambrian intrusions.

Geochemical evidence confirms that the intrusions are Precambrian, and reveals that they were intruded in a number of separate stages. The geological fraternity is indebted to G.H. Hunt for performing the valuable age determinations. The following table lists some dated sills and dikes according to their stage of intrusion:

AGE OF CRYSTALLIZATION -- MOYIE INTRUSIONS	
Early Moyie Intrusions	
Irishman Cr. sill (B.C.):	1580 m.y. (22)
Paradise sill (Mont.):	1400 m.y. (22)
Intermediate Moyie Intrusions	
Logan Pass sill (Mont.):	1110 m.y. (22)
Blackiston Brook hornfels (Alb):	1075 m.y. (22)
Kimberley sill (B.C.)	1073 m.y. (22)
Late Moyie Intrusions	
Dipper Lake sill (B.C.):	883 m.y. (22)
sill 20 mi. north of Kingsgate:	835 m.y. (21)
St. Mary "A" sill (B.C.):	766 m.y. (22)
Sullivan mine dikes (B.C.):	765 m.y. (22)

Table 1

Early geochemical attempts to obtain age determinations were made by Urry prior to 1936. He used the helium method on specimens from two dikes and a sill located near Kimberley, B.C. The results gave 495 m.y. and 455 m.y. for the dikes, and 530 m.y. for the sill (45). Although these results are unreliable they do confirm that the intrusions are very old. Hunt used the more modern potassium-argon method and found that some sills are about 1,500 m.y. old, some are about 1,100 m.y. old, and others are about 800 m.y. old. He also found that a sample of contact metamorphic hornfels from the Rocky Mountains of Alberta was crystallized about 1,075 m.y. ago. The hornfels was collected close to the Purcell lava horizon (22). Other determinations obtained from hornfels and a quartz-biotite vein are questionable because of the altered condition of the rock, therefore these are not listed herein (21). The literature on geochronology records cases in which determinations made on samples of contact hornfelses or quartz-biotite veins indicate ages far younger than do minerals, such as amphibole, collected from the interiors of the associated igneous rocks.

On the basis of his age determinations, Hunt postulates an early Purcell plutonism, a late Purcell plutonism, and an orogeny which coincides with that which White called the "East Kootenay" (63). However, since Moyie sills also were intruded during this orogeny the present writer lists the Moyie plutonism in at least three stages: The early Moyie intrusions were emplaced at the end of the Lower Proterozoic. Intermediate stage intrusions were emplaced at the end of the Middle Proterozoic. This stage appears to have included the Purcell volcanic activity. Late stage intrusions accompanied the East Kootenay orogeny during the middle to late Upper Proterozoic. This stage appears to have included the Irene and Leola

volcanic activity. It is not known whether other intrusive stages occurred at the end of Proterozoic time, or later, but this remains a possibility.

5. Amphibolization

"Amphibolization" is the production, in a rock, of amphibole as a secondary mineral, i.e., a mineral that has replaced a previously existing mineral. The amphibole is usually hornblende, uralite, or actinolite derived from previously existing pyroxene (augite, diopside, hypersthene, etc.).

Most writers attribute the present dioritic or quartz dioritic composition of the Moyie intrusions to amphibolization of basic rock which was initially a diabase or gabbro. The amphibolization is thought by many to have been due to endomorphism or hydrothermal uralitization. The Glossary of Geology and Related Sciences (17) defines endomorphism as a phase of contact metamorphism in which attention is directed to the changes suffered by the intrusive body instead of to those produced in the invaded formations. The changes that take place in the intrusive are due to the partial or complete assimilation of portions of the rocks invaded.

Late-magmatic crystallization takes place during the later stages of the cooling of magma. Late-magmatic minerals are produced, and these are thought of as forming between the main stage of crystallization and the pegmatitic stage. They are more or less synonomous with "reaction" minerals.

Deuteric alteration occurs in igneous rocks during the later stages of, and as a direct consequence of, the consolidation of the magma. The term discriminates such alterations from the more strictly secondary changes due to a later period of alteration. Saussuritization and albitization of

feldspar are examples of deuteric alteration effects. Uralitization may be somewhat earlier than strictly deuteric affects.

Uralite is a fibrous or acicular variety of green hornblende found in altered rocks and pseudomorphous after pyroxene. Uralitization is the process whereby pyroxene is converted into hornblende, usually as a finely-fibrous aggregate. It is usually considered to be a late magmatic process. Uralitization amounts to low grade amphibolization.

Saussuritization is the replacement, particularly of plagioclase feldspar in basalts, diabases and gabbros, by a fine-grained aggregate of zoisite, epidote, albite, calcite, sericite and zeolites. It is frequently accompanied by chloritization of the ferromagnesian minerals. Albitization and decomposition of plagioclase in rocks of the Moyie intrusions have been explained by some writers as due to saussuritization.

Albitization is the production, in a rock, of albite as a secondary mineral. The sodic plagioclase (albite) forms by replacement of a previously existing more calcic plagioclase. Calcite, epidote, zoisite and clinozoisite are formed as by-products (17).

a. Amphibolization of Precambrian Moyie Intrusions

In Moyie sills of British Columbia most of the original pyroxene has been replaced by amphibole, and the plagioclase has been partly albitized. In some areas specimens can be found in which remnants of the original augite grains are still present (43) (45).

Kirkham and Ellis consider the sills of Boundary County, Idaho, as examples of endomorphism. "The original augite of the gabbro is nearly

all changed to a greenish-black hornblende in most places. Augite and hypersthene are minor minerals as the rock is now constituted. The main mass is made up of altered gabbro and diabase changed in many places by uralitization to a dioritic type (28).

In northwesternmost Montana the most conspicuous mineral, megascopically, is greenish-black hornblende, usually somewhat fibrous, but feldspar and quartz are recognizable. The microscope shows that orthoclase and biotite are present, but the common accessories are iron ore and apatite. Hornblende is the most interesting mineral because of its problematic origin. It has a rather pale green color in thin section, irregular boundaries, and splintery terminations. In some specimens it is deeper green and more massive. While the usual character of the amphibole is similar to that of uralitic hornblende, none of the specimens examined by Calkins contained augite. Many of the hornblende crystals formed later than the smaller plagioclase grains and enclose or partly envelop them. Some hornblende crystals penetrate crystals of feldspar which they have partly replaced, or contain inclusions of the latter(4) (14) (16).

Clark Fork district hornblende contains cores of hypersthene or augite, and it is probable that the hornblende has in every case altered from the pyroxene (1).

In Kootenai County the hornblende crystals are ragged, and the grains are usually bordered by a fringe of actinolite needles of lighter color but of the same optical orientation. The plagioclase grains are filled with needles of actinolite, which is a variety of green amphibole, hornblende and other secondary minerals. The relations of these minerals, according to A.L. Anderson, suggests that the original rock has been strikingly

endomorphosed since its consolidation, and that the actinolite and other minerals are late additions to the solid rock (2).

Gibson and Jenks (14), and Gibson (16) studied Moyie intrusions of the Libby district, Montana. They concluded that both the sills which were injected prior to folding, and the dikes of similar composition which were injected after folding, have suffered both amphibolization and hydrothermal alteration. The amphibolization has produced long, interlocking euhedrons of hornblende derived by replacement of augite. Only one sill could be found which still contained augite, and the mineral was partly replaced by hornblende. The amphibole is later than plagioclase. Its crystals enclose, penetrate, and wrap around the plagioclase. The latter is mostly oligoclase-andesine, but this has been extensively replaced by albite-oligoclase plus epidote-clinozoisite. The albitization of calcic plagioclase is more striking in the sills than in the dikes. The dikes, however, are more altered than the sills, and near ore prospects the plagioclase has been completely replaced by sericite, clinozoisite, epidote, and carbonate, The amphibolization is attributed to hydrothermal solutions which soaked the region after the intrusion of numerous granitic stocks. The stocks are mostly small but it was assumed by Gibson that they merge at depth into one huge granitic batholith which was the source of the heat, hydrothermal solutions, and later ore solutions.

As an afterthought, at the end of his paper, Gibson pointed out that although the dikes are Mesozoic the sills are Precambrian. "It is recognized that there may have been two periods of amphibolization, the earlier of which followed intrusion of the sills but preceded the Mesozoic intrusives" (14).

There are no sills in the Coeur d'Alene district, with the possible exception of one or two very thin ones, but some have been found toward the south in the St. Joe Mountains, and toward the east along the crest of the Bitterroot Range.

Wagner describes the Rougin Creek intrusion of the St. Joe Mountains as varying in composition from gabbro to diorite. Plagioclase laths lie in a groundmass of hornblende and minor pyroxene. The pyroxene is augite, and it occurs only as cores in hornblende crystals. The plagioclase is saussurized and the hornblende considerably chloritized. Much of the ilmenite has gone over into leucoxene. Another sill along the North Fork of St. Joe River, near the mouth of Kelley Creek is made up of hornblende, often with augite cores, and plagioclase. This sill has been strongly chloritized and the feldspars are decomposed (56).

Wishards sill, in the Bitterroot Range, has been petrographically described in the literature in only a sketchy manner. Pardee has stated that it is of a characteristic diabase but basaltic at the margins. It is composed essentially of labradorite, augite and ilmenite (40). Other writers state that minerals visible to the naked eye are white feldspar, dull greenish-black augite and amphibole, and black iron ore of metallic luster (5). Although it has in places a very high content of magnetite or ilmenite, in other places it is nearly void of mafic minerals, and elsewhere has various amounts of magnetite, pyroxene, and amphibole (62).

b. Amphibolization of Mesozoic Diabase Dikes

Gibson classifies all of the diabase-diorite dikes of the Libby district as of Mesozoic age because they cut across the Mesozoic folds.

He assumes that they are genetically related to the numerous small Mesozoic granitic intrusions which occur in that part of Montana. The rock of the dikes, where not hydrothermally altered, is made up chiefly of hornblende and andesine-oligoclase, or less commonly of sodic labradorite. Where the hornblende is fresh there is little or no biotite. One dike contained up to 40% of augite, all of it partly altered to hornblende. According to Gibson, probably all of the hornblende in the dikes was formed by replacement of pyroxene. If this is true, replacement has been so thorough and re-crystallization so complete that all traces of the pyroxene have disappeared from most of the dikes. Hornblende grains in the dikes resemble those in the Precambrian sills except that they are more uniform in size, and smaller on the average than are those in the sills. To a less extent than in the sills, hornblende penetrates and replaces plagioclase. Albitization of plagioclase is less common in dikes than in sills, although hydrothermal alteration in dikes is much more advanced than in the sills. Metalliferous deposits occur in dikes more often than in sills (14) (16).

In the Coeur d'Alene district all of the diabase dikes are younger than the Mesozoic folds but older than the Mesozoic monzonite intrusions. Frank Calkins, in describing the diabase of the district implies that some "supposedly original hornblende" is present and this is distinguished from green splintery uralite by its deep greenish brown color and good crystallization. The augite is more or less uralitized and also gives rise to some material resembling iddingsite. There is in some specimens a very little biotite. Labradorite is semiopaque from decomposition, and in greater part replaced by sericite, zoisite and some scapolite (42). P.J. Shenon says that Calkins re-studied the dike rocks some years later (1935?) and found that the Placer Creek dike contains a little hornblende and biotite. Chief constituents are

violet-brown titaniferous augite, plagioclase which is largely saussuritized, and ilmenite in large skeleton crystals. Another dike in the Murray district was studied. This dike, at the mouth of Cement gulch, is located very close to a monzonite stock. The rock is considerably amphibolized, apparently by contact hydrothermal metasomatism. Pale amphibole has wholly replaced the augite "and is edged in places with deeper green hornblende which may be original" (52).

The writer has petrographically examined samples from two Coeur d'Alene district dikes. One 50 ft. wide, herein called the "North Fork dike", is located on the North Fork of Coeur d'Alene River about 2½ miles above its junction with the South Fork. It is seen in a steep, cliff-like bluff overlooking the river from its southwest side. Sedimentary beds strike northeasterly, but the dike strikes west-northwesterly. The diabase has suffered considerably more from weathering than has the enclosing sedimentary rock. Large sheets of diabase have spalled off from the steep to almost vertical face of the exposure. Thus the resulting face is smooth, but much angular talus lies at the base. Freshly fractured surfaces of the rock are dark gray in appearance and contain numerous white feldspar grains. Megascopically the feldspars appear irregular in outline, but this is because the grains are composed of interlocking groups of crystals. It is difficult to find a really fresh fracture surface, however, because the rock is decomposed from exposure to weather. It contains numerous closely-spaced, intersecting, iron-manganese stained cleavages, joints, and fractures. In thin section the rock appears non-directional and diabasic. Its mineral composition is: plagioclase 20%, augite 20%, hornblende 12%, and ilmenite 11%. Accessory minerals in the order of their abundance are: sericite 8%, and biotite, clinozoisite, chlorite and apatite. Minor amounts of quartz, limonite, and hematite are present. The texture is intergranular rather than ophitic,

because the augite forms discrete grains among the feldspar crystals although some augite grains envelop feldspar laths. Augite, which shows slightly reddish pleochroism, is surrounded by rims of green uralitic hornblended plus some chlorite. Some green splintery hornblende crystals are separate from augite, but for the most part they are intergrown with the pyroxene. There seems little room for doubt that the amphibole has formed by replacement of pyroxene. Ilmenite is closely associated with augite, hornblende, and biotite. Skeleton ilmenite crystals in places form a network in which one single augite crystal fills the spaces between the parts of the ilmenite crystal. Brown biotite also frequently surrounds or fills spaces in ilmenite. The plagioclase, augite, ilmenite, and brown biotite appear to be almost contemporaneous in crystallization. Brown biotite grades into green biotite or forms lamellar intergrowths with it. Both types occasionally form large plates, but the fine grained green biotite is difficult to distinguish from the fine grained green uralite forming reaction rims around augite. The green biotite is frequently replaced by chlorite and is distinguishable from it only by its high birefringence and bird's eye texture, and in that it is a lighter shade of green than is the chlorite. The fact that brown biotite is more usually associated with ilmenite whereas green biotite is admixed with chlorite suggests that the brown is an earlier biotite which has formed at higher temperature than the green. These relations seem to suggest that the uralitic rims and the green biotite and chlorite formed by crystallization during declining temperature. They are probably late magmatic or deuteric. The plagioclase is mainly labradorite. Many of the crystals have been strongly sericitized.

The second dike examined is located in the Silver Summit mine about 1½ miles west of Osburn. The dike is approximately 9 ft. wide. It is

located in St. Regis formation, the beds of which strike west-northwesterly and dip 80°-85° N. The dike almost parallels the beds in strike, but it dips about 74° S. Since this dike has been strongly decomposed by hydrothermal solutions it will be discussed in more detail under "Hydrothermal Alteration". Seen in thin section the dike rock has a texture and appearance similar to that of the fine grained basaltic rock at the chilled footwall border of the North Fork dike. Plagioclase, amphibole, and biotite have been completely decomposed to hydrothermal minerals. Augite grains have been much attacked but a considerable proportion have survived. Augite shows the same pinkish pleochroism as that in the North Fork dike. Ilmenite is frequently triangular or polygonal in outline, but there are also skeleton crystals consisting of thin parallel rods connected by cross bars. It exhibits the same appearance and relationship to augite as does the ilmenite of North Fork dike.

c. Relations of Amphibolized Rocks to Metamorphic Areas

Many of the metadiorite sills of S.E. British Columbia are located in the Cranbrook-Kimberley region. In this region are areas in which metamorphism appears to have occurred during late Precambrian time. Leech describes this metamorphism as of relatively high grade, and locally intense (32) (36). In the Clark Fork district are numerous outcrops of granitic igneous rock and pegmatites. Anderson states that the degree of schistosity or metamorphism increases directly with the number or abundance of pegmatite. The sills are strongly amphibolized (1)(64). In the Libby district of Montana there are, according to Gibson and Jenks, numerous small granitic intrusives and some larger ones. W.M. Johns, who is now mapping in that part of Montana, has described the metamorphism as being of "medium grade" (14) (24).

The sills in Boundary County, Idaho, are located only a few miles east of the large areas of intense regional metamorphism and granitization forming the core of the Selkirk Range (28). The slopes of Mica Peak, west of Coeur d'Alene Lake, are characterized by high grade regional metamorphism. Anderson found thick bands of dark-colored hornblende gneiss on the slopes of the peak. These bodies of gneiss, he states, may have been sills (of the same kind as the pre-Cambrian intrusives) transformed to gneiss during the intrusion of Mesozoic batholiths (2). In the Coeur d'Alene district metamorphism is of very low grade, and Mesozoic granitic intrusives are absent with the exception of a row of small monzonite stocks near Gem, and a small group of tiny stocks near Dago Peak. Amphibolization of the basic intrusions has been slight to moderate in amount. But toward the south in the St. Joe Mountains, and toward the east in the Bitterroot Mountains, metamorphism of Belt rocks is variable in degree and is seen at the surface in highly irregular outcrop patterns. In a general way, metamorphism in the St. Joe Valley increases toward the west, and toward the south as the Idaho batholith and its outliers are approached (40) (20). Pardee states that the various diabase sills have suffered radical change of texture and mineral constitution as a result of metamorphism. Where metamorphism has been thorough the diabase is altered to a black schistose amphibolite studded with red garnets. The Wishards sill in the Bitterroots is relatively little amphibolized, but near granitic outliers of the Idaho batholith where the enclosing Belt rocks have been altered to mica schist, the sill has been altered to schistose amphibolite (40).

d. Late-Magmatic vs. Metamorphic Amphibolization

Peter Misch states that in the static recrystallization of basic igneous rocks under mesozonal temperatures during regional metamorphism,

"There are all passages from completely recrystallized rocks (amphibolites and hornblendites) to such in which only incipient stages of formation of uralitic hornblende are observed, with the original calc-plagioclase quite often still preserved. Such rocks often resemble rocks which have undergone deuteric alteration. Whether rocks of this kind owe their alteration to deuteric processes or to true metamorphism can often only be decided from the whole geologic setting". Also, "Static metamorphic recrystallization of basic plutonic or volcanic rocks may also occur locally due to heating under medium temperatures, usually aided by action of water. Such more local heating may be true contact metamorphism in igneous contacts, or it may be due to heating in the border zone of a rock body heated by infiltrating metasomatising solutions or emanations which act under static conditions so that no schistosity is produced" (37). Harker, in his text on metamorphism, points out that, "--- the genesis of an igneous rock, starting from a fluid magma and ending normally in a crystalline aggregate, covers a wide range of declining temperature, and the several constituent minerals, as we now see them, belong to different stages of the prolonged process of cooling". --- "Later minerals may be derived in part at the expense of earlier ones which, crystallized at a higher temperature, cease to be stable at a lower temperature in contact with the changed magma, and are attacked by it". --- "Whenever the early crystals of important minerals have not been removed or in some way protected from contact with the magma, they will often be liable to partial or total resorption at a later atage; but whether such reactions, demanded by chemical equilibrium, actually take effect or not will depend upon the conditions, and in particular upon the rate of cooling".--- "If, owing to a too rapid rate of cooling or any other cause, these reactions making for equilibrium did not take effect as the magma cooled, some of the constituent minerals of the

resulting rock must be in a metastable state. It cannot be doubted that a rock of such constitution will be eminently susceptible of thermal metamorphism". "--- we may confidently infer that a mineralogical change in the direction of equilibrium with falling temperature, such as the uralitization of pyroxene, having failed of effect in the first instance, may be precipitated when the rock is again brought to a suitable temperature in the course of thermal metamorphism" (19). In accordance with Harker's thoughts, one may visualize the process of uralitization of pyroxene in the basic sills as proceeding during the stages of late-magmatic crystallization and deuteric alteration. The process did not proceed to completion, however, because of the cooling and freezing of the rock. Heating of the rocks as a result of Mesozoic granitic intrusion could induce a continuation of the process of uralitization. Near areas of extensive granitic intrusion the process may be carried practically to completion; all the augite will disappear and the rock will be converted to amphibolite. The enclosing sediments must also be metamorphosed, but not as strikingly as are the basic rocks. Mafic igneous minerals are more susceptible to alteration than are sedimentary minerals, especially where the sediments are non-calcareous. In areas of strong regional metamorphism and granitization schistose amphibolites and garnet amphibolites may be produced.

e. Interpretation of Amphibolization

Petrographic analyses of numerous investigators have shown that pyroxene has been uralitized to some degree in all of the examined diabase-diorite intrusions of the map area. This is true of both Precambrian and Mesozoic diabase-diorite intrusions. That some of the observed uralitization has occurred as a result of crystallization during the declining

temperatures of a late-magmatic stage is indicated in diabase dikes of the Coeur d'Alene district. Here the high temperature pyroxenes were partly replaced during a somewhat lower temperature stage of late-magmatic crystallization by green hornblende and brown biotite. As the temperature of crystallization became still lower there was a transition from the deposition of brown biotite into that of green biotite. At the lowest temperatures there were deposited green biotite and chlorite.

Amphibolization did not take place as a result of "endomorphism" as this is defined in the Glossary of Geology (17). It took place in all of the diabasic intrusions as a normal part of the process of magmatic cooling and crystallization. It cannot be correlated with the assimilation of enclosing sedimentary rock by the magma.

A second wave of amphibolization affected those diabasic intrusions which were located in or near areas that were invaded by Mesozoic granitic plutons. This amphibolization resulted from thermal metamorphism caused by heat introduced by the plutons. Magmatic emanations may have played a part, especially in amphibolization of dikes located in faults and fissures.

Regional metamorphism of Belt sediments was in general of too low a grade to cause amphibolization of diabase. Thin sections of diabase show that the rock contains no evidence of distinguishable metamorphism. However, there are areas, for example in or near the eugeosyncline, where Belt rocks were more strongly metamorphosed and even granitized. Here the diabase intrusions were regionally metamorphosed to the garnet-amphibolite facies while inclosing rocks were converted to schists and gneisses.

The effects of weathering are quite evident in diabasic rocks at outcrops. The rocks spall off in sheets which break or crumble easily. They are full of minute fissures and cracks coated with iron and manganese oxides. Yet, the minerals, with the exception of feldspar, appear fresh under the microscope. Feldspars of the North Fork dike are frequently strongly sericitized, although some grains are only slightly sericitized. It is difficult to say whether the altered feldspars have suffered saussuritization due to deuteric alteration, or sericitization due to weathering, or a combination of the two alterations.

6. Hydrothermal Alteration

Hydrothermal alteration has in areas of ore mineralization been superimposed upon the earlier types of alteration. Hydrothermal effects show that the diabase-diorite intrusions were emplaced prior to ore mineralization. In the Libby district, where metadiorite dikes (petrographically similar to Precambrian sills) contain metalliferous deposits, they are in general more thoroughly altered than are those not containing metalliferous deposits. In the altered dikes the hornblende has disappeared. "No important metalliferous deposits were seen in dikes or parts of dikes that contained much hornblende or plagioclase, for these minerals were destroyed by the solutions that deposited the ore minerals (14). In the vicinity of metalliferous deposits the dikes are altered to chlorite, sericite, carbonate, quartz, and biotite, with lesser amounts of clinozoisite, epidote, and other minerals. In the Coeur d'Alene district the writer has seen similar alteration in dikes which were formerly diabasic. For example, in the Silver Summit mine a diabase dike is highly altered. Fine grained augite

is still present, but it appears much corroded. The plagioclase has been completely converted to clay and calcite. Practically all of the biotite, hornblende, and most of the augite has been converted to chlorite. The St. Regis wallrock adjacent to the dike has been bleached and impregnated with chlorite and calcite. The writer attributes the extreme alteration of this dike to hydrothermal solutions which travelled in the fractures or planes of weakness in or adjacent to the dike. They were solutions similar to those that caused wallrock bleaching or ore deposition in the nearby Silver Summit vein (54).

Other dikes that show the effects of hydrothermal alteration superimposed upon amphibolization are located in the Murray district. Shenon has recorded some of Calkins' findings regarding these dikes (52). It is stated that the rock near Cement gulch is dark greenish-gray and finely granular. Its texture is similar to that of the Placer Creek dike, but the minerals are blurred in outline and the plagioclase contains many secondary inclusions even where not clouded by saussuritic alteration products. Hydrothermal alteration did not proceed to such a degree as to eliminate contact metamorphic amphibole. A more thoroughly altered dike is located about 3 miles east of Murray Peak, its southern end outcropping in Butte gulch. It lies at a greater distance from the row of Gem monzonite stocks than does the one in Cement gulch. However, it strikes N-S, and the cleavage and bedding directions of enclosing country rock strike so as to form an extension of the row of Gem stocks. This dike is of a more greenish-gray color than is the one at Cement gulch. Thin sections show the minerals all to be secondary. The texture is not typical of that of igneous rock, but is confused by abundant inclusions of ore mineral in another. The most

abundant constituent is albite. Second is deep-green chlorite forming large felted aggregates. A good deal of olive-brown biotite is evenly distributed. A good deal of quartz is present. Areas of calcite sometimes enclose grains of all other minerals. The iron ore is a clue to the origin of the rock. It consists of grains embedded in the felted chlorite. Its grains show the triangular patterns of ilmenite.

7. Sulfide Mineralization in the Intrusions

Pyrite, pyrrhotite, and chalcopyrite are frequently seen as small specks in sill rock. They are generally scarce, but locally may be abundant enough to form disseminated sulfide deposits. In British Columbia two types of deposits are associated with the Precambrian sills: 1.) Quartz-calcite veins, and 2.) Disseminated deposits. The veins cross the sills at large angles and only extend a short distance or not at all into the sediments on either side. The veins contain sulfides near the upper sill contact and to a slight extent near the lower contact, but are otherwise barren. Metals contained in the veins are principally copper and iron, with subordinate zinc, lead, and usually some gold. Silver is present in some of the veins. The disseminated sulfides are of the same minerals seen in the vein occurrences. These deposits show that the ore mineralization occurred after the intrusions had become emplaced and consolidated.

The disseminated deposits were considered by some to be primary deposits formed by magmatic segregation. But Rice has pointed out that the disseminations are particularly abundant in the vicinity of fractures. The fractures have obviously formed after the rock had become consolidated. Locations of the disseminations have apparently been controlled by the

fractures. There appears also to be transitions between vein deposits and disseminations. (45)(65).

In Boundary County, Idaho, most of the metallic deposits are associated with large sills and metamorphosed Precambrian sediments. The veins occur either within, on the contact, or immediately adjacent to the contact of the sills. Very rarely do they pass from the sills into the adjacent country rocks or vice versa; instead, they parallel the general strike of the sills. The veins are short. Locally they swell to a thickness of several feet, elsewhere they narrow to mere stringers or pinch out. In places the broad, short veins are more like lenses or elongated pods. Veins are located in fractures which have resulted from shearing and tensional stresses. Ore has resulted from deposition in open fissures and by replacement. Exceptional deposits of disseminated sulfides are thought to have formed by magmatic segregation because they are concentrated at the base of a sill and no field evidence can be found of a structure which might have allowed introduction of sulfides into the sill (27). The ore of magmatic segregation deposits contains nickel and copper, but the ore of the vein deposits is lead, zinc, and silver.

In the Libby district of Montana the metadiorite dikes and sills frequently contain silver-lead veins, whereas the gold-quartz and copper veins are all in sedimentary rock. The sills, though they are larger, more numerous, and more widespread than the dikes, contain fewer veins than the dikes, and only one prospect in a sill has been productive (16). However, some mines and prospects have been opened in the extensive sills between Perma and Plains, Montana. A mine on Revais Creek produced ore from the contact

between a large sill and Raverdil country rock. Ore contained copper, gold, platinum, palladium and silver. Little data is available on the deposit.

Some diabase dikes of the Coeur d'Alene mining district contain secondary quartz, carbonates, and sulfides. For example, a highly altered dike along the Osburn fault contained quartz, calcite, pyrrhotite, pyrite, chalcopyrite, sphalerite, and galena. A dike exposed on an intermediate level of Merger Mines Corp. was reported to contain quartz, calcite, and chalcopyrite (53). A strongly altered dike in the Silver Summit mine contains small amounts of pyrite.

In the St. Joe basin of Idaho the sulfides frequently occur in shear zones, brecciated areas, small fissures and joints in diabase sills and dikes, and in irregular, scattered bunches which have replaced diabase or adjacent country rock. These are quartz-siderite or quartz-calcite veins which contain chalcopyrite and auriferous pyrite (40) (56).

As is indicated by the above examples, there is little doubt that the Moyie intrusions and the Mesozoic diabase-diorite dikes were emplaced prior to ore mineralization. With the exception of a few rather small magmatic segregation deposits containing nickel or platinum* the sulfides are secondary minerals brought in by solutions from outside sources which invaded the intrusions along faults, fractures, shear zones or other discontinuities.

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* usually also containing copper, iron, and some gold and silver.

SUMMARY AND CONCLUSIONS

Within the area of Fig. 1, the volcanogenic-sedimentary western facies comprise Precambrian strata of the Belt, Purcell, and Windermere series overlain by eugeosynclinal-type sediments and volcanics of Lower Paleozoic, Carboniferous, Triassic and Jurassic age. These are strongly deformed and severely metamorphosed. Metasomatic and igneous granitic rocks are widespread.

The writer objects to the custom of applying the term "series" to the Belt (Purcell) sequence. These rocks represent most, if not all of the Proterozoic era. The term "series" therefore lacks sufficient rank, and should be discarded in favor of the term "system" which is used by some Canadian geologists. However, since the term "series" is so strongly entrenched in American literature the writer herein conforms, under protest, to the usage.

The sedimentary eastern facies comprise miogeosynclinal type Belt, Purcell and Windermere sediments (in which are intercalated a minor thickness of Precambrian basic volcanics) overlain in places by sedimentary rocks of Lower Paleozoic age. Diabase-diorite sills, and some dikes, called Moyie intrusions are common. These are of Precambrian age. Diabase-diorite dikes of Mesozoic age are present especially in northwestern Montana and northern Idaho.

Belt (Purcell) rocks are well consolidated but generally only slightly metamorphosed. The formations appear conformable, with gradational contacts, but it is possible that some disconformities may exist, especially in the upper parts of the series. Sections have been measured varying from 17,000 feet to 50,000 feet in thickness. However, the base of the series has never been seen except near Neihart, Montana, at the eastern extremity of Beltian deposition. Purcell formations are separated from the overlying Windermere by a stratigraphic break which in places is a disconformity but in other places an angular unconformity. In Montana Middle Cambrian rocks lie on Upper Belt formations with a small angular unconformity or disconformity. In Idaho the Belt formations are cut by the present erosion surface. Features which may be used in some areas as stratigraphic marker horizons are the Newland and Striped Peak formations, the Purcell basalt lavas, and volcanics and conglomerates at the base of the Windermere series.

Windermere rocks are found only in southeastern British Columbia and the northeasternmost corner of Washington. Sections up to at least

22,000 feet in thickness have been measured. In the vicinity of Lake Windermere the series is present only in part and Cambrian formations lie on Windermere with a disconformity or slight unconformity. In the vicinity of Kootenay Lake the Windermere is completely conformable and gradational into overlying Cambrian. In northeastern Washington the relations are slightly unconformable.

Canadian geologists regard the Purcell-Windermere break as of greater tectonic importance than the Windermere-Cambrian one. However, in northeastern Washington the Windermere-Cambrian break appears to be of at least equal importance.

Evidence is presented which indicates that the Belt (Purcell) formations were deposited between about 800 and 1,600 m.y. ago. They are essentially Middle to early-Upper Proterozoic in age, but the oldest formation is at least late-Lower Porterozoic. Windermere rocks are latest Proterozoic. They were deposited during the erosional interval that followed deposition of Missoula group sediments.

Moyie plutonism appears to have occurred in at least three stages: Early intrusions were emplaced at the end of the Lower Proterozoic. Intermediate stage intrusions were emplaced at the end of the Middle Proterozoic. This stage included the Purcell volcanic activity. Late stage intrusions accompanied the East Kootenay orogeny during the middle - to late - Upper Proterozoic. This stage included the Irene and Leola volcanic activity.

Diabase dikes of Mesozoic age are compositionally similar, or identical to Moyie intrusions. They are especially numerous in northwesternmost Montana and northern Idaho. Although their source area

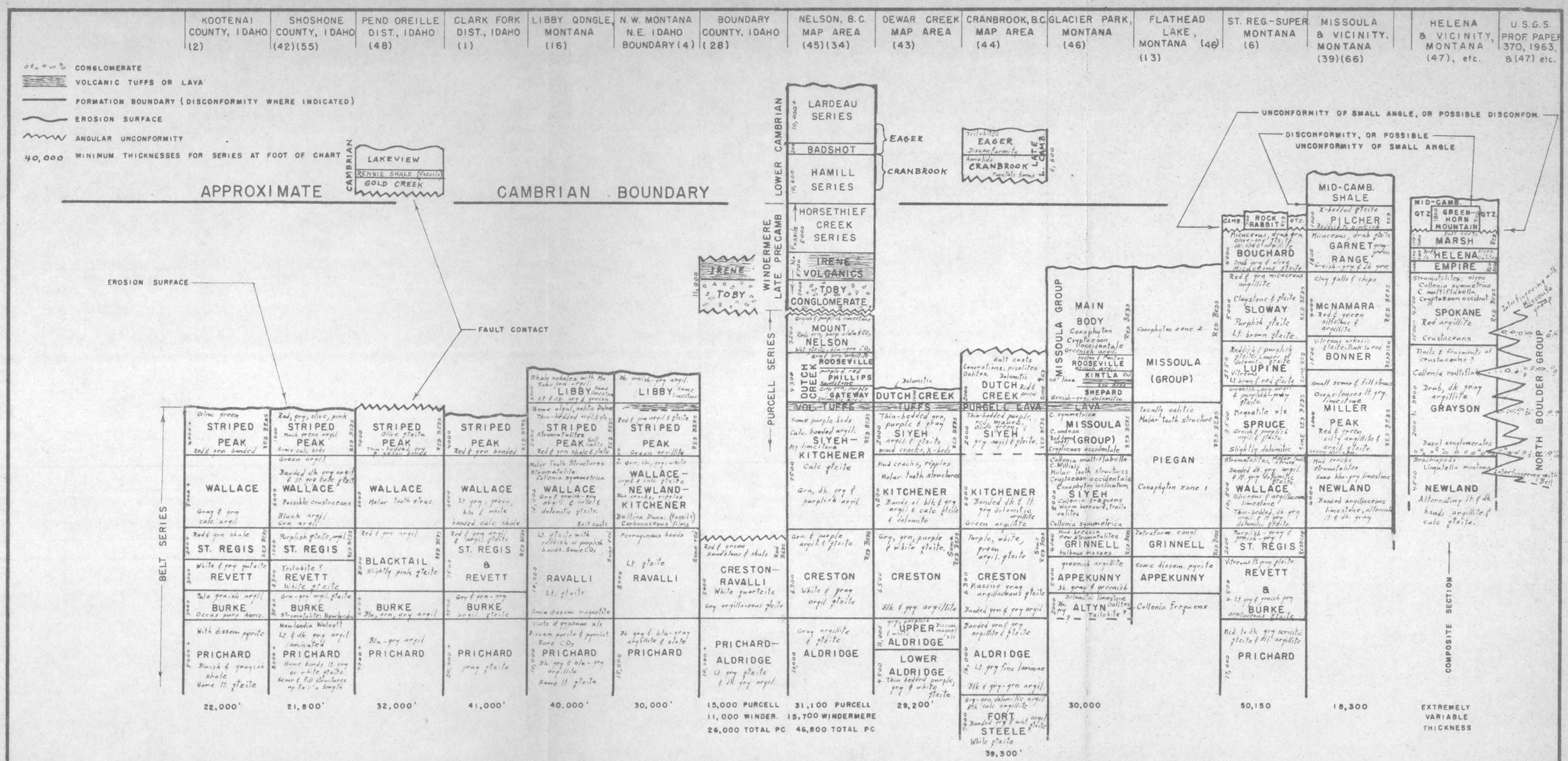
may have been similar to the source area of Moyie magmas, they are not related in time to the latter and therefore should probably not be included under the term "Moyie intrusions".

Amphibolization has occurred in all of the basic intrusions, Precambrian as well as Mesozoic. A low grade of uralitization took place during a late-magmatic stage of crystallization of the magma. It was a normal part of the process of magmatic cooling and crystallization, and cannot be correlated with the assimilation of enclosing sedimentary rock. A second wave of amphibolization affected those diabasic intrusions which were located in or near areas that were invaded by Mesozoic granitic plutons. This amphibolization resulted from thermal metamorphism, aided by magmatic emanations, caused by heat introduced by the plutons. High grade amphibolization occurred only in areas of Belt rocks that were strongly metamorphosed and granitized on a regional scale. Here there were produced amphibolite schists and garnet-amphibolites.

Hydrothermal alteration has in areas of ore mineralization been superimposed upon the earlier types of alteration. The hydrothermal alteration tended to eliminate pyroxene, amphibole, biotite and feldspar. These were replaced by hydrothermal minerals such as clay, chlorite, and calcite.

Hydrothermal alteration and ore mineralization in the intrusions shows that Mesozoic diabase-diorite dikes, emplaced subsequent to folding of the rocks, are older than the ore deposits.

Engineering and Geological Office
Hecla Mining Company
Burke, Idaho, U.S.A.
December 27, 1963



N. IDAHO — S.E. BRITISH COLUMBIA — N.W. MONTANA

PRECAMBRIAN SEDIMENTARY FORMATIONS

CORRELATION DIAGRAM

A.H.S.
1961–1964

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64. In the Pend Oreille district the sediments are described as, "--- much metamorphosed by igneous emanations from the intrusive magmas." About 1/5 of the surface is supposed to be underlain by igneous rocks, and although not much pegmatite is found around the granodiorite bodies, "contact metamorphism is striking" (Gillson, J.L., 1927, Granodiorites of the Pend Oreille district of Northern Idaho: Jour. Geol., vol. 35, p. 1-31).

65. The view that Rice held in 1941 (Nelson Map-Area) that the disseminated deposits in diorite were genetically related to the quartz-calcite-sulfide veins, and that these, "--- clearly were deposited from solutions migrating through fractures that obviously must have formed after the diorite had consolidated" differed from that

65. (Cont'd)

which he held in 1937 (Cranbrook Map-Area) that, "The disseminated copper deposits and the quartz-calcite veins occurring with them are believed to have been derived from the magmas from which the sills were formed and are, therefore, Precambrian in age." That is, in 1937 he had "concluded with some confidence" that their source was the magma from which the sills were derived. In a still earlier paper he had described small ore deposits composed almost entirely of chalcopyrite and pyrrhotite occurring in diorite sills. These had amphibole as the only important gangue mineral. The abundance of amphibole in the ore, its similarity with the "primary" amphibole of the sills, and the fact that it was, in part at least, clearly cutting the sulfides suggested a close relationship between the ore and the sills (Rice, H.M.A., 1935, Amphibole from the Purcell Sills, British Columbia: The Am. Mineralogist, vol. 20, p. 307-309).

66. Guidebook to Field Trips, 1959, The Geological Society of America, Rocky Mountain Section, 12th Ann. Mtg., Montana State University, Missoula, Montana, May 14-17, p. 47-57.

Wallace, R.E. et al. "Tectonic Setting of the Coeur d'Alene District, Idaho"
USGS Prof. Paper 400, p. B25-27 (1960)

Tectonic History given as follows:

1. Folding of Pre-€ rks.
2. Bending of fold axes by reorientation of stress
3. Strike slip faulting of Osborn Flt. system
4. Intrusion of monzonite stocks
5. Metallization
6. Post-mineral renewed strike slip along Osborn Flt system
7. Minor normal faulting

Fry Klund, V.C. "Origin of the main period veins, Coeur d'Alene District, Idaho" USGS Prof Paper 400, pp B29-30, 1960

---

1) Concludes ore deposition was all in Cretaceous and assoc. w. intrusion.

---

2) Rejects Pb isotope age dating as pre Є because the original magma may have had an unusual lead content.

Coeur d'Alene

(1960)

Long, A. et al "Isotopic Composition of Lead and Pre-Cambrian Mineralization of the Coeur d'Alene District, Ida," Econ Geol. V. 55, pp. 645-58

1. Galena samples from throughout the dist (many samples) have an average age of 1400 m.y. or Pre-Eombrion as determined by Pb isotope ratios

2. Field observations such as mineralization cutting younger than pre-E dikes, explained by tertiary remobilization of sulfides.

Weis, P.L., "Bleaching in the Coeur d'Alene District, Idaho," USGS Prof Paper 400, pp. B27-28 (1960)

States: alteration in the district when studied in detail is mild and could have been produced by "warm water." The water need not have been a "hydrothermal solution"

HISTORY OF THE SUNSHINE MINE

By

R. L. ANDERSON*

For the information of those men unfamiliar with the Coeur d'Alenes, I should like to begin with the early history of the entire county, then proceed in more detail with the Sunshine. Many individuals here today have helped make, have been a part of this early historic development, and could add many interesting details.

I wish to acknowledge here excerpts from an article by L. C. Richards in the Kellogg Evening News, also from "First 100 Years of the Coeur d'Alene Mining Region" by W. E. Greenough, and oral statements from many other individuals.

Shoshone County was originally created in 1858 as part of Washington Territory, then, after five years, became part of Idaho Territory which was created in 1863.

Prior to this, however, in 1846 - 105 years ago - a Jesuit mission was established just outside the present county line near Cataldo, and in 1851, 100 years ago, the erection of the present Mission structure was begun. Earlier still, in 1805, Lewis and Clark skirted the southern end of the county (as it was originally described) fifteen miles south of the present town of Pierce, Idaho.

The area once contained in Shoshone county, consequently, was a part of the national picture as early as 1805 when crossed by the Lewis and Clark expedition. The Coeur d'Alene Mining District was crossed later by Captain Mullan as he made a reconnaissance in 1854 and 1855 and later, from 1858 to 1862, built a wagon transportation road through Mullan, Wallace and Kellogg from Fort Benton to Fort Walla Walla.

Although Shoshone County was created in 1858, it had no county government at the time that E. D. Pierce caused national recognition of the county's importance by discovering gold at the place which to this day bears his name, Pierce, Idaho. The cry "Gold!" blazed thru the nation causing the usual influx, and by the summer of 1861 several thousand men milled about the Pierce area. County elections were held that summer, making Pierce the first <u>local</u> seat of government in the present state of Idaho, and Montana as well. Major gold production from the Pierce area continued through 1865, dwindling by 1870 to a trickle. From these dates it may be seen that Shoshone County made a sizeable contribution to the North in winning the Civil War. This old camp is no longer part of Shoshone County, being now in Clearwater County.

In 1882, when Pierce had practically attained the position of a ghost camp, the shout "Gold!" again echoed across the nation from Shoshone County, this time from Eagle and Prichard Creeks, north of Wallace, in the vicinity of the present towns of Murray, Prichard, and Eagle. By the summer of 1883, the rush was on and by 1885, with upwards of ten thousand men in the "North Side", the county seat was moved from Pierce to the thriving town of Murray.

A common fallacy persists in this district today that following the gold placer mining at Eagle and Prichard Creeks, prospectors overran the South Fork country from Mullan to Kellogg and made the <u>first</u> lode discoveries in the district. It is true that all the important discoveries were made by these men, but not the first. Andrew Prichard, discoverer of gold on the "North Side" in 1882, had found the Evolution lode four years earlier, in 1878, but did not record it until April, 1882, four months prior to the recording of the gold claim on the "North Side". Probably the first recording of a lode claim in the county was the Glen Beula, made by William Gardner, on August 18, 1881, near the mouth of Pine Creek, and now known as the Coeur d'Alene Antimony. This recording was made in Kootenai County, as was Prichard's, because of the inaccessibility of Pierce, the county seat of Shoshone County. Prichard, however, later relocated his claim in 1885 to "change the records from Kootenai to Shoshone County." It is true that the district's first shipper and greatest producer, the Bunker Hill, was discovered in 1885 by prospectors from the "North Side". Likewise, one year before, in 1884, "North Side" prospectors located, up Canyon Creek, the Tiger, the Poorman, three days later, the Ore-Or-No-Go, Black Bear, Frisco, Gem and others. Near Mullan in the same year were staked the Gold Hunter, the Evening, the Morning, and the Castor. Furthermore, in this important discovery year of 1884, the present "Silver Belt" or "Dry Belt" was the scene of two discoveries, the first, the Polaris Lode in August, and one month later the Yankee Lode, on September 25, 1884, by the brothers True Blake and Dennis Blake. The Yankee Lode became the nucleus of the present Sunshine Mining Company holdings.

The Blake boys, as they were known, located other claims adjacent to the Yankee claim and patented the group in 1909. From 1884 they worked intermittently but diligently for thirty years. At the time they patented their claims their energy was shown by ten tunnels, numerous open cuts, and a shaft for a total valuation of $18,140.00, exclusive of raises and stopes. All this work was done without

* Chief Engineer, Sunshine Mining Company

the aid of any hired men. In addition, they found time to establish a ranch at the mouth of Big Creek, now occupied in part by Sunshine Housing Project and the Shoshone Country Club.

Very little is known of the production or receipts from shipments made by the Blake boys, but estimates and assumptions tend toward $100,000, perhaps as high as half a million dollars. The grade of their ore varied from 120 ounces per ton to 300 ounces per ton, probably in few cases exceeding 300. Although some people had the idea that the Blakes were most secretive, they almost always let anyone visit their workings, even take specimens. The Blakes worked hard and long, hand-picking the ore from tiny stringers, mostly less than an inch thick, and at times hand-jigged their product before shipping to East Helena. Always hopeful of a bigger, richer vein, they were elated when 1200-ounce ore was discovered across the creek and a little north of them in the upper workings of the Big Creek property where work had been done for some years by G. Scott Anderson and associates. This property, now owned by the Bunker Hill, has been renamed the Crescent.

Some time about 1914, the Blakes relinquished their mining activities to leasers, the principal ones being Sidney Shonts and later, Dan Price. In attempting to cut at depth the ores of the early day workings, Mr. Price expended a large sum of money driving a 1500-foot adit 500 feet below the lowest previous workings. His resources exhausted and success not in sight, he interested Mr. John Sawbridge of Yakima, Washington in the venture in 1920. Mr. Sawbridge, in turn, interested Mr. A. E. Larson, Mr. Alexander Miller and Mr. N. P. Hull and with their backing some of the work was carried on. These parties soon acquired the Sunshine Mining Company which had been organized under the laws of the State of Washington in 1918 and through this company Mr. Price's lease and bond for deed were obtained; the Sunshine Mining Company then proceeded to develop the ground.

Later on, in 1924, Sunshine Mining Company purchased the Yankee Girl Mining Group in which Mr. J. B. Cox of Kellogg was interested. It was at this time that Mr. Cox became interested in Sunshine Mining Company.

During this time a small mill was constructed, capacity about 25 tons per day. Mill equipment consisted of a small Blake crusher, a set of 10-inch rolls, three sets of Hartz jigs, a set of Zeigler cells, a Wilfley table, and a three-foot diameter P & M conical ball mill for grinding middlings. A product was made averaging 150 ounces per ton of concentrate.

A 150-ounce concentrate now seems poor for the Sunshine, but let us look at the vein at that time. Below the Price tunnel the stopes were in a vein from which assays of 1500 ounces per ton were common, but most of the time the width of the ore in the vein was a half inch and less, in places widening out to 8-inch or 10-inch blebs. From this section of the mine an attempt was made to hold the mill heads up to 15 ounces of silver, but the attempt was often unsuccessful. The ore was hoisted up the vertical shaft from workings as deep as the 400 level, dumped where chunks of waste could be hand-sorted out, then transferred into the pocket to be trammed by mule to the mill.

During this same period there were months when the company continued deeper into the red. Each miner was given a set of steel consisting of a starter, a second, and a third. When the steel was too dull to drill - no more was available - the miner left his working place for the surface, got his three pieces of steel sharpened, and went back to his working place to try to finish his round. Many times the coffers were empty, could not supply money for wages. Men were given orders for groceries and asked to take stock for the rest.

When the vertical winze was extended to the 500 level, the crosscut to the vein disclosed a slightly better value of ore and drifting proved even more encouraging. Stopes above the 500 level known as Chinatown, finally paid off the company indebtedness, reportedly about $200,000, and at the same time allowed further exploration and development at greater depth. The company after the summer of 1927 never again was in dire straits.

Prior to 1926, numerous capable but unfortunate men directed operations, names such as Merriam and Beaudry, to name but two. In 1926 C. C. Samuels was made manager. Shortly afterward, a two-compartment incline winze was started down from the 500 level and progressed intermittently to the 1900 level. During this time an inclined shaft raise was driven from the 500 level to the Sunshine Tunnel which had been driven to replace the old Price Tunnel.

It should be of interest here from the standpoint of labor costs to note that a large portion of the 2-compartment incline winze was sunk at day's pay - $6.00 per shift. Nine men progressed about 65 feet per month. This meant a labor cost averaging $21.00 per foot. Later, when a bonus system was instituted, one month's advance of 108 feet was made by two three-man crews. They were paid $6.00 per shift. After 60 feet of advance, they were given a bonus of $5.00 per foot for the first additional five feet, $10.00 per foot for the next five feet, $15.00 per foot for the next five feet, and $20.00 per foot for the remainder. The men

made that month slightly over $11.00 per shift. They were elated! Value received by the company was 108 feet of two-compartment shaft at a labor cost of $16.00 per foot. The company management also must have been elated.

But to get back to production and profit, a dividend was paid for the first time late in 1927, and "Chinatown" continued to enable the payment of dividends for several years. At the same time, it enabled the further sinking of the incline winze to the 1700 level. Without the "Chinatown" stopes, it likely would have been "touch and go" from the 500 level to the 1700 level. But in 1931 a bonanza was struck on the 1700 level. The vein, in not a few places, 20 to 23 feet wide, was sometimes solid high grade. The low price of silver made profits small, but production was great. Sunshine ranked in 1931 as the largest silver producer in Idaho, second largest in the United States. Sunshine production increased yearly, breaking its own record every year, until, in 1937 it produced 12,147,719 recoverable ounces of silver. This placed Sunshine as the largest known producer of silver from any one mine in 1937 in the world.

In 1934, Mr. A. E. Larson, who had been President of Sunshine Mining Company for a number of years, passed away. Immediately thereafter, the Board of Directors, acting in accordance with one of Mr. Larson's expressed wishes, elected Mr. R. M. Hardy, an associate of Mr. Larson in other ventures, as a Director and as President of the company. Soon thereafter, in January, 1935, Mr. Frank Eichelberger was designated Vice President in charge of operations and was in active management of the property until his departure the next year. Then, in 1936, Mr. R. D. Leisk became General Manager, retaining that position to the present. During this time, as production increased yearly until the war, unique working agreements between Sunshine Mining Company and its neighbors allowed and necessitated an ever-growing program of exploration and development underground, and of surface plant expansion, all of which continues today.

Meanwhile Mr. Joshua Green of Seattle had become a member of the Board of Directors, as had Mr. C. M. Hull of Yakima upon the death of his father, Mr. N. P. Hull, and Mr. Frank M. Hardy upon the death of Mr. Alexander Miller.

Probably the most important discovery in recent years in the district was made at Sunshine in 1943 when high-grade lead and silver ore was found in the Chester-Syndicate vein and fault zone. It proved, in the "Dry Belt" at least, that valuable ore deposits may be found at great depth without encouraging values in the same structures at or near the surface. In 1945 and 1946 a serious underground fire halted production for two months and hampered production for several more months. Disclosed in July, 1949 was the presence of primary pitchblende in and near the north side of the Sunshine vein at its west end. This is, at present, of questionable economic importance.

Starting 20 years after the initial discovery of the Yankee Lode by the Blake Brothers, recorded production for the period from 1904 through October, 1951 is as follows:

Tons produced	4,273,429
Ounces Silver Recovered	132,664,769
Ounces Gold Paid For	1,248
Pounds Lead Recovered	82,579,680
Pounds Copper Recovered	34,499,567
Smelter Returns	$97,801,652
Dividends Paid	$29,969,969

In addition to the listed dividends paid directly to Sunshine stockholders, Sunshine has paid neighboring participating companies in excess of $12,500,000 as their share of production from their areas.

A matter of varying consequence to practically every mining company in the west and of first importance to Sunshine is the price of silver. During Sunshine's lifetime, silver has ranged from a low of 25.01 cents in 1932 to a high of 132.827 cents in 1920, and is now purchased by the Treasury Department at 90.5¢. The arrangement provided by Act of Congress under which the silver produced by the Sunshine and other domestic mines is sold to the Treasury Department is not too well understood by the general public. Briefly, it is as follows:

When newly mined domestic silver is delivered to the United States Mint, the Treasury Department pays for 70% of this silver at its coinage value of $1.29 per troy ounce. The remaining 30% becomes the property of the U. S. Government without payment. The 70% of the silver is then converted into money either by coining it into dollars at $1.29 per ounce or by printing silver certificates exchangeable for silver dollars on demand, and in this manner the Treasury Department is reimbursed for what it has paid the producer.

The 30%, which is retained by the Government without payment, is called seigniorage. Frequently this silver is minted into subsidiary coinage, half dollars, quarters and dimes, in which the coinage value of the silver is slightly more than $1.29 per ounce. Whenever this seigniorage silver is minted into coins, a profit is realized by the Government of close to $1.29 per ounce.

As an example, if the some 132,600,000 ounces of silver that have been produced by the Sunshine mine had all been delivered to the mint under the present regulations, the Government would have received 30%, or 39,780,000 ounces of this silver without payment, as seigniorage. This converted into silver dollars would have netted the Government approximately $51,000,000. This hypothetical example is merely given to illustrate the extent to which the Government is a silent partner in the mining of silver.

If all the recorded production of silver from the Sunshine had been minted into silver dollars and if these dollars were placed edge to edge, they would form a silver band 4,050 miles long diagonally across the United States from Maine to California or from Washington State to Florida and overlap into both oceans for miles. If these same dollars were stacked like poker chips, they would form 1,426 stacks as high as the 1250-foot Empire State Building.

Sunshine - - rebuked, derided and rejected during its infancy by most of the prominent mining men of the district and nation, hampered intermittently by forest fire, flood, labor strife, and underground fire, eventually became the "Cinderella of the Coeur d'Alenes", and continues to increase the nation's wealth by an amount which already exceeds ninety-seven million dollars.

G.S.A. Berkeley Meeting 1939.

With respect to ground water, the region can be divided into at least four provinces whose extent is determined by geologic, geomorphic, and climatic factors. These four are: the Northern Coast Ranges province, the Puget-Willamette Trough province, the Columbia Plateau lava province, and the Northern Rocky Mountain province.

The mode of ground-water occurrence and the major ground-water problems of each province are described; the status of systematic ground-water surveys in the region is also reviewed.

INFLUENCE OF STRUCTURE ON ORE DEPOSITS IN THE COEUR D'ALENE DISTRICT

BY JOHN B. PLATTS

All the phenomena of structure, igneous intrusion, and ore depositions in the Coeur d'Alene district may be referred to the action of a recurring lateral thrust or pressure from the northwest toward the southeast that was general over a large area, including much of the Pacific Northwest.

The lateral thrust folded the competent Belt sediments into a series of northeast-striking folds with their steep sides toward the southeast. Igneous intrusion followed the planes of weakness in axial shears of anticlines. Discussion centers around one of these folds called the Coeur d'Alene anticline.

Periods of heavy thrust alternated with quiet periods. After stocks of quartz monzonite had been intruded into the folds, further movement developed a regional shear and a system of major tear faults.

High temperatures accompanied the monzonite intrusion, and each succeeding thrust caused a temporary rise in temperature during the long cooling period. Old fractures were reopened by each recurring thrust, mineralizing solutions found their way into regions of tension in the fracture system, and a series of ores corresponding to falling temperatures were deposited.

The principal mineralized areas in the Coeur d'Alene district are described in a general way. Conditions found there support the above generalizations. The practical application of structural data to the search for ore is discussed briefly.

ALASKA'S AGRICULTURAL FUTURE

BY W. A. ROCKIE

Opinions differ widely regarding (1) possibilities of Alaska agriculture, (2) amount of suitable land, (3) location of these lands, and (4) success of present agriculture, but a study of the physical factors points to ultimately successful agriculture. Although many natural and economic factors are important, the individual seems to be a dominating factor for or against success.

Present estimates indicate that $1/9$ of Alaska's 384,000,000 acres is agricultural, $1/14$ grazing land, $1/500$ now in farms, and only about $1/50{,}000$ of the Territory yet uncultivated. The best lands are around Cook Inlet and around Fairbanks. Occasional truck, dairy, fur, and diversified farms are successful, but there are many that have failed. The government colony at Palmer is the present agricultural center of the Territory, with half of all cultivated land in Alaska within 10 miles. The other cultivated lands are scattered in hundreds of localities. A wide variety of crops and of livestock is grown.

The first detailed land-use studies in Alaska are now in progress in the Matanuska Valley. Aerial photographs show large areas of both good and waste land including an almost inconceivable variety of physiographic forms.

Wind erosion presents a real threat to cleared lands around Cook Inlet, and soil washing and sinking of land are serious land problems in the Fairbanks region.

Agriculture has shown relatively little development to date, but, judging by successful farms in many localities, no fundamental reasons exist why agriculture in Alaska should not become a successful major industry. It can become another Scandinavia.

EPOCHS OF VOLCANISM IN THE SALT LAKE CITY REGION

BY HYRUM SCHNEIDER

The geologists of the "United States Geological Exploration of The Fortieth Parallel" mapped seven areas of extrusives east and west of the Central Wasatch Mountains as trachytes and apparently considered them all essentially alike and all younger than the Eocene sedimentary rocks of the region.

A field and microscopic study of the volcanic rocks mapped as trachytes in City Creek Canyon, just outside Salt Lake City, and of the extrusives along Silver Creek about 20 miles east of Salt Lake City, shows the rocks to be Paleocene andesite breccias instead of post-Eocene trachytes.

An oil well drilled about 2 miles north of the Salt Lake Airport passed through a 2½-foot bed of pumiceous tuff at a depth of 1308 feet. Elmer Berry determined the fossils of the associated beds as late Pliocene.

At 60th West and Magna road near the Whittier School, there is exposed in the bottom of an irrigation ditch a volcanic breccia much like the breccia in City Creek Canyon but more basic. The rocks at 60th West are a basalt breccia with an interbedded tuff. The age of the basalt breccia cannot be definitely determined, but since it outcrops 1400 feet above the tuff bed in the oil well it is probably post-Pliocene.

Within a radius of 9 miles from Salt Lake City there are three different types of volcanic rocks produced from different volcanoes at different times.

GEOLOGY OF THE SHASTA COPPER BELT

BY G. F. SEAGER

The Shasta County copper belt lies in the extreme southern part of the Klamath Mountains. Except for important gossan operations for gold, the district is idle today after 35 years of mining during which it yielded much copper, zinc, gold, silver, and sulphur.

Two sedimentary formations occur in the western part of the copper belt, the Kennett (middle Devonian) and the Bragdon (Mississippian). Also, remnants exist of a thick and extensive pre-middle Devonian andesitic complex, known as the Copley meta-andesite. A large, irregular intrusion of soda alaskite porphyry of late Jurassic age introduced the copper deposits. The intrusive is intensely altered hydrothermally and locally cataclastically deformed.

The copper deposits are of two distinct mineralogical and morphological types and are classed as (1) massive pyritic deposits and (2) chalcopyrite lodes. The former are massive replacement bodies of pyrite, with subordinate chalcopyrite and sphalerite, whereas the latter are veinlike partial replacements of alaskite porphyry by chalcopyrite, yielding a concentrating ore.

Convincing evidence exists that the deposits were formed by replacement of soda alaskite porphyry essentially similar to the wall rocks. The occurrence of the deposits along a pronounced shear zone in the intrusive indicates that replacement was governed chiefly by the physical condition of the rock and that the sulphide deposits were localized at places of maximum comminution. The deposits are

STRUCTURAL GEOLOGY

OF THE COEUR D'ALENE MINING DISTRICT

AND ADJACENT AREAS

Part I

The Geosynclinal Environment and Regional Tectonic Framework

Arthur H. Sorensen

Hecla Mining Company

Wallace, Idaho

December 1, 1963

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STRUCTURAL GEOLOGY OF THE COEUR D'ALENE MINING DISTRICT AND ADJACENT AREAS

PART I: THE GEOSYNCLINAL ENVIRONMENT AND REGIONAL TECTONIC FRAMEWORK

ABSTRACT

A study of the locations of many major ore districts has lead the writer to infer that the presence of a volcanic geosyncline is essential to the formation of economically important primary sulfide deposits related to mobile belts.

Indirect physical evidence, supported by recently acquired isotopic evidence from mining districts, indicates that a eugeosyncline, at least in ancestral or prototype form, existed during Proterozoic time in the region of central or eastern Washington and south-central British Columbia west of Kootenay Lake. The area now containing Belt and Purcell sedimentary rocks is therefore considered herein to represent the miogeosyncline.

The Coeur d'Alene mining district is located in a triangular area bounded by the Columbia River arc, the Kootenay arc, and the Purcell geanticline. The district is situated in a miogeosynclinal re-entrant, at the junction of arc systems; and is at the most deeply sheared portion of the Coeur d'Alene-Missoula-Red Lodge lineament.

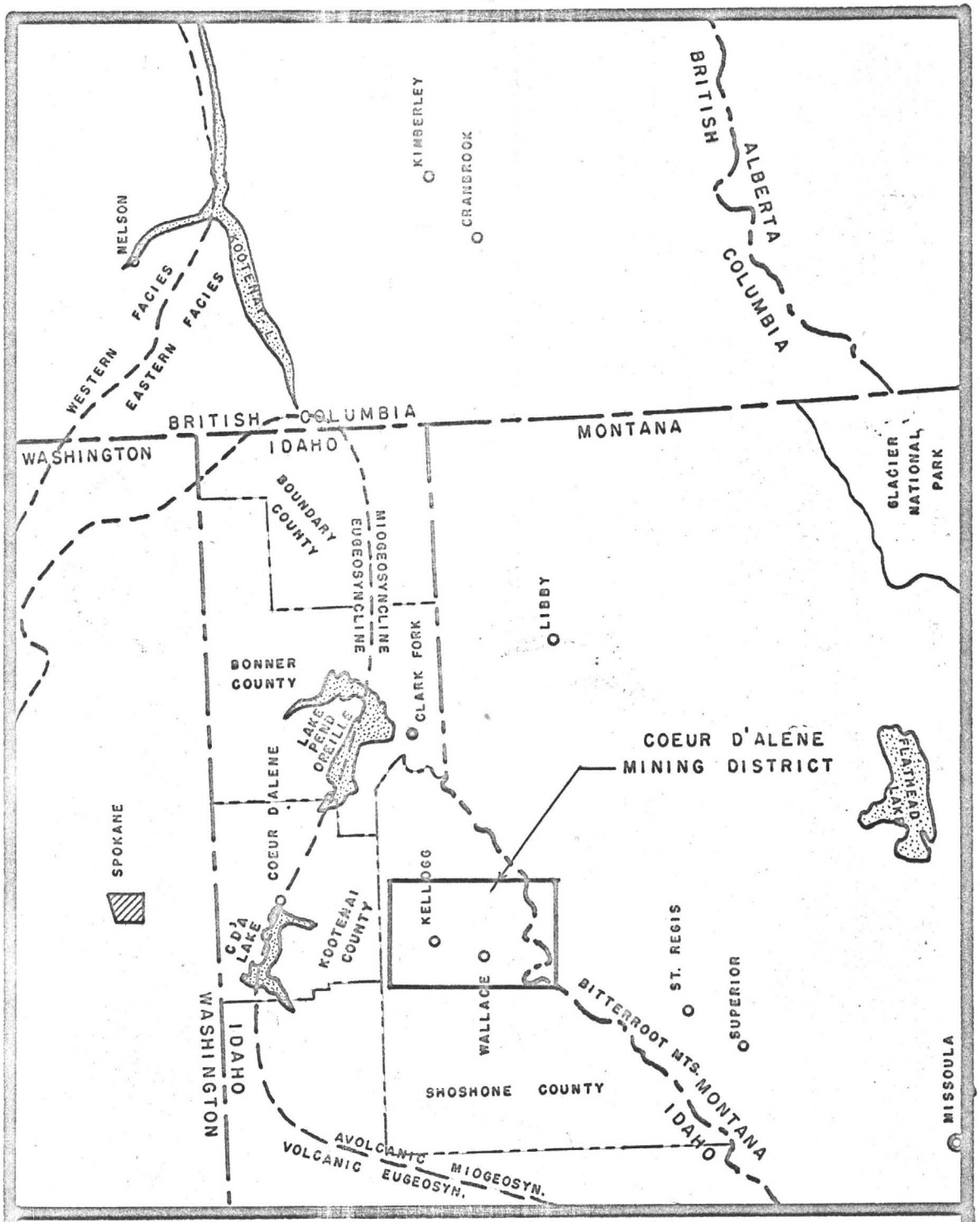

Fig. 1

Location Map

0 20 40 60 MILES

1" = $30\frac{1}{2}$ miles (approx.)

THE GEOSYNCLINAL ENVIRONMENT

A. Role of the Geosyncline in Ore Genesis

Since the turn of the Century it has become increasingly apparent that major ore districts are related in a number of ways to geosynclines. Billingsley and Locke noted that major ore districts were frequently clustered at "nodes" within the continental framework (6). These nodes, they found, were determined by deep-seated breaks in the earth's crust; orogenic belts and their intersections; and chains of granitoid batholiths (25). Other geologists have found that the nodes are determined by arcuate structures (4), and intersecting fracture systems and lineaments (27) (34). Actually, most of

these features are parts of, or have their locations determined by, deformed geosynclines and the adjacent foreland.

Deep seated breaks, intersecting fracture systems and lineaments, and arcuate structures are phenomena which are related to ore deposits in a structural sense. They have influenced the movement of ore solutions and have provided favorable loci for ore deposition, or have opened entry ways into favorable loci.

Orogenic belts and their intersections, and chains of granitoid batholiths are related to ore deposits in a genetic sense in that they have generated the deposits; although the ultimate place of origin of the metals probably lies in the mantle. A study of the locations of many major ore districts has lead the writer to conclude that the presence of a volcanic geosyncline (eugeosyncline) is essential to the formation of economically important primary sulfide ore deposits in, or related to, mobile belts. A geosyncline which has not had a history of volcanism cannot generate ore deposits to any appreciable extent.

If the borders of the Cordilleran geosyncline and its subdivisions are mapped for the entire continent it will be seen that the boundary between eugeosyncline and miogeosyncline is a sinuous one with numerous embayments and re-entrants. A protuberance of eugeosyncline into miogeosyncline will herein be referred to as an "embayment". A protuberance of miogeosyncline into eugeosyncline will be termed a "re-entrant". The same terminology will apply to embayments of miogeosyncline into foreland, and re-entrants of foreland into miogeosyncline.

Embayments and re-entrants often form important geologic crossroads at or near which are located major mining districts. Many nodes, arcuate structures, intersecting fracture systems and lineaments are located in or

near the axes or limbs of embayments or re-entrants.

Since it is so important to view the Coeur d'Alene, or any other mining district, in relation to the geosyncline with which it is associated, and to its regional tectonic framework, the first parts of this study will be concerned with those portions of the geosyncline lying in northern Idaho, northeastern Washington, southeastern British Columbia, and northwestern Montana. The area is illustrated in Fig. 1.

B. Divisions of the Geosyncline

The Cordilleran geosyncline is thought of by many as consisting of a "eugeosyncline" on the west and a "miogeosyncline" on the east. Other geologists feel that the usage of these terms should be avoided because they imply a genetic dependence of the latter type of geosyncline in respect to the former, and because of doubts as to whether the Precambrian Belt sediments actually do represent a miogeosyncline.

Peter Misch prefers to use the term "volcanic geosyncline" rather than eugeosyncline because basic to intermediate volcanism is a principal characteristic of the type. He uses the term "avolcanic geosyncline" in place of miogeosyncline since the latter is by definition non-volcanic (29) (30), and no genetic dependence upon the volcanic geosyncline is implied.

In some writings the rocks of the western and eastern belts are merely referred to as the "western facies" and the "eastern facies".

This study will utilize the terms "eugeosyncline" and "miogeosyncline". The former is an orthogeosyncline in which basic to intermediate (geosynclinal-type) volcanism has been extensive. The latter is an orthogeosyncline in which basic to intermediate (geosynclinal-type) volcanism has been absent. A genetic relationship between the two types of geosynclines is implied. The miogeosyncline lies between the eugeosyncline and the foreland of the ancient continental platform (craton), and it is underlain by crystalline rocks of the foreland.

C. Difficulties of Defining a Eugeosyncline-Miogeosyncline Boundary

It is extremely difficult to define the "Eu-Mio" boundary because of the incompleteness of the stratigraphic record. Also, our observations are confined to a shallow range in the crust. As drawn herein, the boundary separates rocks of different facies, but due to circumstances of orogeny and erosion these differ greatly in age.

Not much information is available concerning the pre-Paleozoic history of the Cordilleran geosyncline. It has been thought that no eugeosyncline existed during Proterozoic time when the Precambrian Belt sediments were being deposited. The Belt sediments are of miogeosynclinal character, but they were not considered to represent "the miogeosyncline".

On the basis of present knowledge, derived from the study of visible surface features, geologists have concluded that there had not occurred a conspicuous differentiation of the geosyncline into "eu" and "mio" until the Middle Paleozoic. Misch has stated that, at least as far as can be determined from surface geology, "--- the differentiation into miogeosyncline and eugeosyncline was not established until sometime in the Middle Paleozoic, and was not pronounced prior to the Carboniferous. It was probably established in Ordovician time, but as far as volcanics are concerned differentiation did not become conspicuous until the Carboniferous (29). Thus, if any eugeosyncline existed prior to the Paleozoic era the direct physical evidences of this have been destroyed or are covered by Paleozoic and Mesozoic rocks.

Is it possible that an ancestral volcanic eugeosyncline could have existed west of the miogeosyncline while Belt sediments were being deposited? There is some indirect evidence that at least a prototype eugeosyncline could have, and probably did exist, and recently accumulated isotopic evidence supports the probability.

D. Indirect Evidences of a Prototype Proterozoic Eugeosyncline

It is known that a volcanic orogenic belt existed during Lower Paleozoic time at the approximate present location of the Pacific coast (8). Through geologic time this orogenic belt shifted sometimes westerly and sometimes easterly. It had moved as far east as the present longitude of Richland, Washington, during the Devonian and again during the Permian periods according to tectonic maps of A.J. Eardley (8). It is not at all impossible that this belt could have existed at least in prototype during the Proterozoic era, and that it perhaps was located as far east as central or eastern Washington and south-central British Columbia.

1. Physical

Indirect physical evidence of a Proterozoic eugeosyncline west of Kootenay Lake, British Columbia, exists in the form of Precambrian basalt flows which have invaded the miogeosyncline. These were accompanied by the intrusion of numerous basic sills and dikes of similar age. The intrusions and flows in the aggregate represent a very large movement of basic magma. They are: the Purcell basalts and Moyie intrusions; and the Irene and Leola volcanics. The thickness of the volcanic flows is not large compared to the thickness of the sedimentary column in which they are enclosed, but they increase in volume as the eugeosyncline is approached.

2. Isotopic

An extended discussion on ore genesis will be presented in a later part of this study. At present will be mentioned only the preliminary results of isotopic studies, and the apparent significance of these. Data derived from sulfur isotopic analysis may eventually be somewhat revised because it is planned to re-run some of the samples with more refined equipment. However, the data represent close approximations to the expected final results.

The data from isotopic studies of sulfide deposits of the Coeur d'Alene mining district are interpreted as pointing to the existence of a prototype eugeosyncline. For example, lead isotopic ratios indicate that the lead, and presumably other metals, was separated out of it source material approximately 1,400 million years ago. It was thereafter held,

presumably as concentrated sulfide deposits, isolated from further contamination by radiogenic lead (26) (35). That these early concentrated deposits were not the same as those that exist in the Coeur d'Alene district today is evident from the structural and stratigraphic relations. The lead of the deposits is Precambrian in age, but it occurs in fissure veins cutting folds which are principally Mesozoic. The metals and sulfur of which the present deposits are composed have evidently existed in some other location at a time prior to the Mesozoic era. This earlier location must presumably have been closer to the source area of the metals, in rocks which probably were not appreciably folded, deformed or metamorphosed.

Sulfur isotopic ratios, and the spread of the ratios, show that the Coeur d'Alene deposits have the same isotopic characteristics as that class of deposits designated by M.L. Jensen as "metamorphic hydrothermal" (17) (13) (38). The sulfur isotope spread is greater than 22 permil. Average S^{32}/S^{34} ratio is 22.05, indicating enrichment in the heavy isotope, S^{34}, in comparison to mantle or meteoritic sulfur.

Consideration of these data lead to the hypothesis that the Coeur d'Alene deposits have been derived through some mechanism of deep-seated remobilization of previously-existing concentrations of ore materials which had been contained in crustal rocks of a volcanic geosyncline (38) (18). The previously-existing concentrations of ore materials were deposited as blanket-like, or lens-like, bodies of metal sulfides around volcanic vents or along deep-penetrating geosutures. The sulfides were deposited by submarine sublimation out of H_2S - rich gases issuing from the ultrabasic mantle. This occurred during Proterozoic time approximately 1,400 million years ago. Deposition in this manner accomplished separation of the metals and sulfur from their sources in the mantle, and the sulfur isotopic ratios had the required spread.

The sulfide lenses, localized along geosutures, may have been deposited in interfingering relations with the more widespread volcanic flows and clastic sediments of volcanogenic-sedimentary origin. They would be deposits of the type classed by Amstutz as "syngenetic exhalative" (1). Since the metals were frozen in sulfide minerals which were embedded in rocks characterized by quite low concentrations of uranium and thorium they were protected from contamination by radiogenic isotopes.

E. The Nature of the Prototype Proterozoic Eugeosyncline

By "prototype eugeosyncline" is meant a eugeosyncline in its earliest developmental stage. According to the author's interpretation this stage was characterized principally by downwarping. Folding, if any had yet occurred, was probably localized. If volcanos were present these were principally submarine, therefore the seas were rather deep compared to those in the Beltian miogeosyncline. If any volcanos or upwarps projected above the surface these were subject to erosion and thereby contributed sediments to the eugeosyncline from internal sources. As a whole, sedimentation was probably rather thin as compared with true eugeosynclinal sedimentation, or even as compared with Beltian sedimentation. The source of Belt sediments is not known. Large proportions of these sediments probably came from the Craton which lay to the east. If they came from the west the eugeosyncline would have to have been far livelier, in the tectonic and volcanic sense, than is herein postulated.

Tensional forces must have predominated over compressional forces in the Proterozoic eugeosyncline. Deep fracturing occurred. The early history of geosutures such as the Osburn fault may date back to this Proterozoic fracturing.

The amazing outpouring of metallic sulfides from the geosutures has been attributed by some geologists to degassing of the earth. According to Amstutz (1) the syngenetic exhalative interpretation of the main sulfide deposits in sediments "leads to the possibility that the formation of deposits could be an attendant phenomenon of the degassing of the earth, and that both, namely, the degassing and the formation of mineral deposits have decreased since the formation of the earth's crust".

It is postulated that the Prototype Proterozoic eugeosyncline was located in central or eastern Washington and in southern British Columbia west of Kootenay Lake. Basic extrusive magmas occasionally moved into the miogeosyncline in the form of basalt flows, and basic intrusive magmas were injected into Beltian formations in the form of diabase and diorite sills and some dikes.

F. Location of the "Eu-Mio" Boundary

Because of the evidence for the existence of at least a prototype ancestral eugeosyncline during Proterozoic time, it is here suggested that the eastern facies, as represented by Belt (Purcell) formations, may be correctly referred to as a miogeosyncline. Within the limited area covered by the map on Fig. 1 the boundary is shown as a dashed line. This boundary is, of course, not absolutely realistic because there has been overlap of one facies upon the other, and vice versa, during various parts of geologic time. However, it probably represents a close approximation because it is unlikely that the eugeosyncline has ever moved farther east than the position shown (42).

The boundary has been drawn so as to include with the western facies all areas containing Mesozoic volcanics and the great crystalline complexes

of metamorphic and granitic rocks. The latter have formed through the combined processes of metasomatism, synkinematic granitization, rheomorphism, palingenetic fusion and both syn- and post-kinematic intrusion. Areas containing no volcanics (or volcanics of small thickness) and no granitic complexes as described above are included with the eastern facies. Numerous granitic bodies are common in the eastern facies, but these are mostly stocks. A few are large enough to be referred to as "batholiths". They are post-tectonic igneous intrusions which cut across regional tectonic trends.

By applying the above criteria the boundary is drawn through the Idaho panhandle so as to include the main body of Loon Lake batholith with the western facies even though that area is underlain by granitized Belt sediments which in themselves are typical of the eastern facies. Similarly, in the vicinity of the Idaho batholith many of the rocks included with the western facies are Belt formations but these are overlain by basic volcanic rocks of Mesozoic age or underlain by granitic rocks of the batholith.

Glacial deposits, river and terrace gravels, and other sediments or volcanics of Cenozoic age do not enter into the subject matter of this paper and are therefore disregarded herein.

G. Distribution and Manner of Emplacement of Granitic Rocks

As previously implied, the eugeosyncline has through large areas suffered complex deformation, high grade metamorphism and granitization. According to Misch (29), "The eugeosyncline is the workshop of granitization. There is absolutely no doubt that the higher grades of regional metamorphism are combined with the production of granitic rocks". Also, "Strong regional

metamorphism and the production of assorted granitic rocks are so closely related that they are part of one and the same process." The eugeosyncline, therefore, is the home of the great batholiths and these have formed through processes of granitization of previously existing geosynclinal sediments. The granites are the product of exaggerated metamorphism or ultrametamorphism, but smaller granitic bodies satellitic to the large batholiths frequently are of a truly igneous origin.

Although high grade synkinematic regional metamorphism is almost always confined to the eugeosyncline, there are places where such metamorphism has overlapped the boundary and affected small parts of the miogeosyncline (29). One such area is in the Idaho panhandle where a mass of granitic rock forms the core of the Selkirk range. These granites have been considered a part of the Loon Lake batholith by some writers. Others have considered them as a southerly extension of the Nelson batholith. When writing of the area in 1930, Anderson considered these to be intrusive igneous granites (2). However, in 1940 he considered them banded gneisses containing some bodies of massive igneous rock and some bodies of quartzite. The gneiss greatly resembles igneous rock although it retains sedimentary structures and grades into quartzite. In other places the gneissic foliation which is generally prominent becomes faint only in the rock that shades into massive igneous rock (3). Kirkham considered four granitic cupolas in the Purcell trench east of the main granitic mass to be of magmatic intrusive origin (21). Sampson also considered the cupolas near Lake Pend Oreille to be bodies which had forcefully intruded Belt sedimentary rocks (32). Thus, there seems to be some evidence that the main mass of Loon Lake batholith has formed by granitization of sedimentary rock, but that the stocks and offshoots located in the Purcell Trench east of the main mass have formed by crystallization of granitic magma.

The granitized rocks in Loon Lake batholith are Precambrian Belt for-

mations of the eastern facies although the dashed line on Fig. 1 was arbitrarily drawn so as to include these granitized sediments and batholithic rocks with the western or eugeosynclinal facies. This, therefore, is one of those rare localities where regional metamorphism and granitization has transgressed the boundary between eugeosyncline and miogeosyncline.

If the Cordilleran geosyncline is mapped so as to show the eugeosyncline on the west, the miogeosyncline in the center, and the continental platform (or shelf areas of the craton) on the east it will be seen that the boundary between eugeosyncline and miogeosyncline is a sinuous one with numerous embayments and re-entrants. If the granitic areas are then mapped, with the granites of metasomatic origin shown as stippled areas and the igneous granites shown as black areas, it will be seen that most of the igneous plutons occur as stocks which find their home principally in the miogeosyncline not far from the eugeosyncline boundary (29). Some igneous granites are found in the eugeosyncline but these are in the minority. Misch calls the granites of metasomatic origin "autochthonous" granites, i.e., "formed in place as the result of a transformation of the geosynclinal material itself in the inner and deeper parts of the geosyncline". The igneous granites are "allochthonous". They are "strangers where they occur, showing no genetic relationships to the inclosing wallrocks" (29). The magma of the allochthonous stocks represents palingenetic material that has moved from ultrametamorphosed areas in the eugeosyncline into the relatively unconsolidated and unmetamorphosed miogeosyncline. Field observations actually show this. The nature of the metasomatic Loon Lake batholith in northern Idaho and its igneous offshoots in the Purcell trench have already been described. In addition, Hedley and Fyles have found in the Jurassic-Cretaceous Nelson batholith of southeastern British Columbia that, "The eastern part (at the miogeosyncline boundary)seems plainly to be intrusive, but the western part grades into a large area of complex granitization that

occupies much of south central British Columbia" (14). As for the Idaho batholith, numerous students have found this to be partly igneous and partly metamorphic-metasomatic (39) (16) (31) (33). It lies in the apex of the Columbia River arc, in the eugeosyncline but close to the miogeosyncline boundary. Numerous granitic stocks lying in the miogeosyncline east of the batholith are all igneous.

Many geologists traditionally assume that adjacent igneous intrusions must gradually merge downward into a larger igneous parent body lying at some unknown but great depth below. This writer does not concur with that supposition. If a new plane of erosion were to reveal the igneous-metamorphic complex some thousands of feet below the present surface it is likely that the outcrop pattern at the new plane of erosion would be rather similar to the outcrop pattern seen today at the present plane of erosion. Hot emanations rising from the depths of the eugeosyncline during synkinematic and late-kinematic metamorphism will tend to move into areas of maximum deformation according to the principles outlined in 1925 by W.J. Mead (28). When the rocks have become impregnated with a certain amount of moisture, close to the critical temperature, a sudden release of pressure due to faulting could cause a volume of rock to go into the condition of a melt. Especially since, as Mead says, a comparatively small change in the water content of a mass will change it from a comparatively rigid condition to a relatively fluid condition. Given a sudden release of pressure due to faulting there will occur an additional influx of hot fluids from surrounding areas. There could thereby be created a pocket of palingenetic magma. This need not necessarily be connected to any hypothetical huge magma chamber located at greater depths.

Misch has remarked that a pocket of new magma need not intrude. It may remain in place, and eventually cool and crystallize, but it is very likely to move if differential stresses are present (29). In the kinematic situation

the magma will probably move, and will do so in the direction of least resistance. If the melting occurs deep within the eugeosyncline the possibilities for direction of movement of the magma will be limited. The body will become elongated approximately parallel to the direction of regional trend, and will no doubt move upward into higher rocks into regions of relatively lessened pressure. It does not seem likely that the magma could move any great distance, because through assimilation of high grade metamorphic wallrock it would be quickly cooled to the point of crystallization. But if the melting occurs near the miogeosyncline boundary the magma will have more freedom of movement. In this transitional border zone there must be a great "potential difference" between the two structural units: chemically, thermally, electronically, structurally, mineralogically, hydrostatically, and kinematically. The magma would not intrude deeper into the eugeosyncline against isoclinally folded, complex structures, in which it would have to assimilate previously existing high temperature minerals that would cause it to quickly cool and solidify. It would be more likely to intrude into the relatively simple structures of the miogeosyncline where bedding attitudes, and faults with great persistence and regularity would make intrusion easy. It would then assimilate low temperature minerals rich in water and oxygen. This assimilation would be of an exothermic nature thereby preserving the heat and prolonging the activity of the magma. A thesis of the present paper, therefore, is that there will be a movement of palingenetic magma out of the eugeosyncline and into the migeosyncline, following the direction of least resistance, aided by bedding attitudes and pre-existing faults, into rocks of a decreasing degree of consolidation.

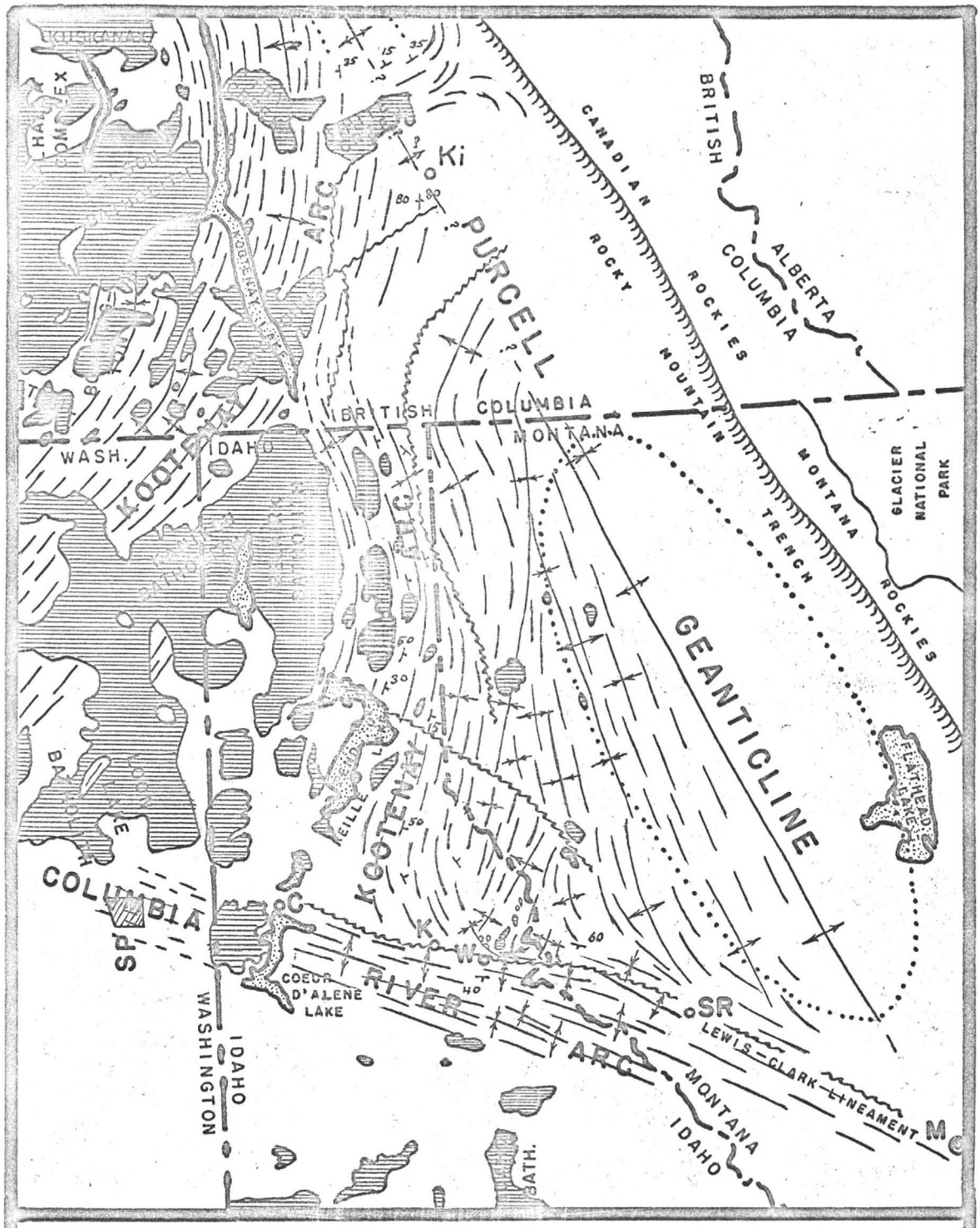

Fig. 2

Geologic Structure of North Idaho, Northeastern Washington, Southeastern British Columbia, and Northwestern Montana (subject to revision)

0 20 40 60 MILES

1" = 30½ miles (approx.)

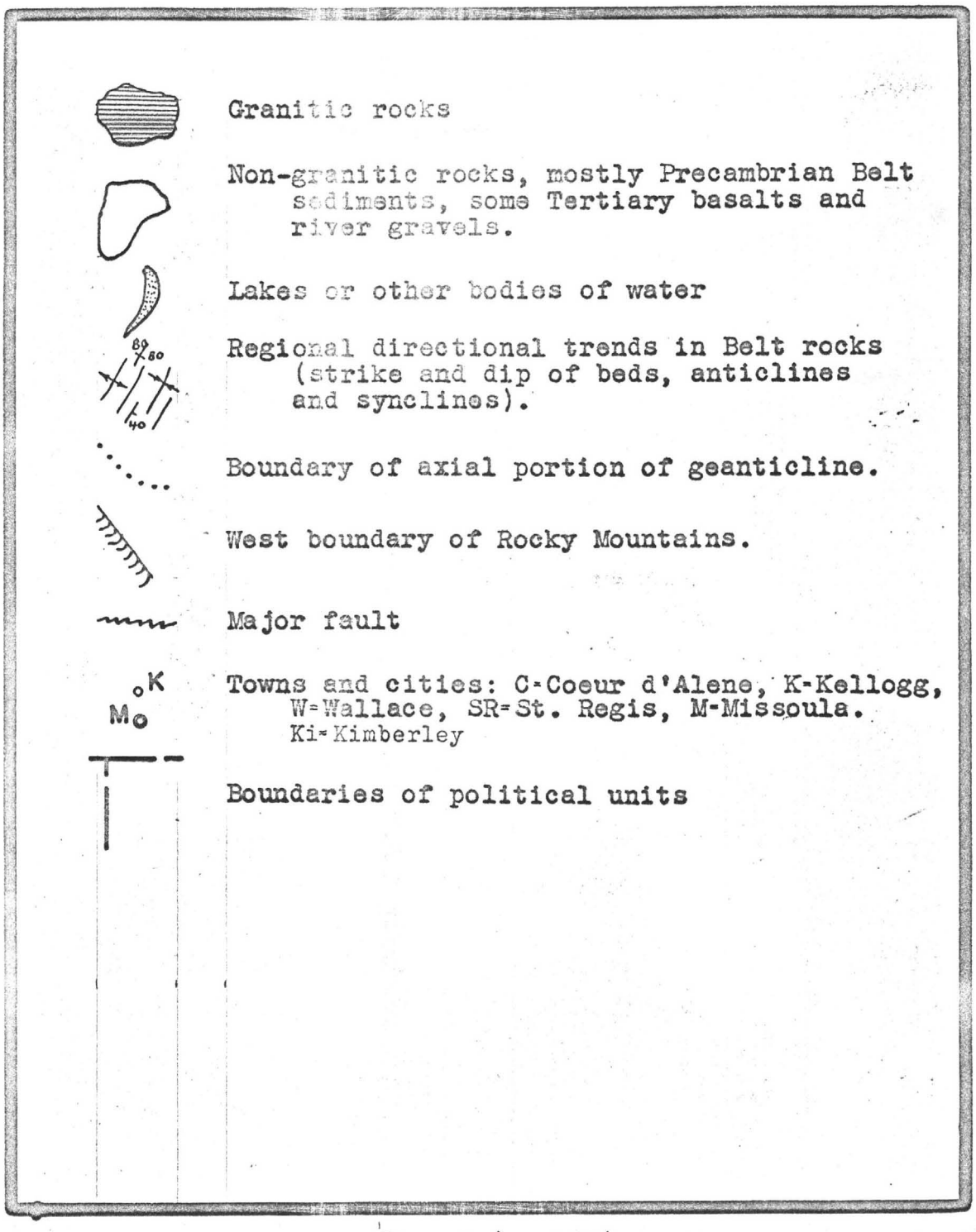

Fig. 2 (cont'd)

Legend

REGIONAL TECTONIC FRAMEWORK

Some factors which appear to be of significance regarding the location of the Coeur d'Alene mining district are: 1. It is situated in a miogeosynclinal re-entrant, 2. It lies at the junction of arc systems, and 3. It is at the most deeply sheared portion of the Coeur d'Alene-Missoula-Red Lodge lineament.

Country rock in major re-entrants or embayments of deformed geosynclines is frequently exceptionally disturbed. Arc systems are loci for the concentration of ore solutions. Junctions of arc systems may be strongly disturbed, and are characterized by sharp changes in the directional trends of regional structures. Exceptionally deep shear zones provide throughgoing faults which penetrate deeply into the geosyncline.

A. The Miogeosynclinal Re-Entrant

The Coeur d'Alene district is located in a re-entrant of the miogeosyncline as shown on Fig. 1. The relationship of the district to the re-entrant is more intimate than is apparent on the map because the district is part of a mineralized belt 95 miles in length which begins at the city of Coeur d'Alene and extends toward St. Regis.

B. Junction of Arc Systems

Fig. 2 consists of a map showing the distribution of rock types in northern Idaho and surrounding areas. The map also illustrates the structural trends present in Precambrian sedimentary rocks. These trends are defined by fold axes, the strike of bedding in folded rocks, and of axial cleavage, and foliation trends of fine grained platy minerals.

The structural trends show that the Coeur d'Alene district is located in a triangular area bounded on the south by the north limb of the Columbia River arc, on the northwest by the Kootenay arc, and on the northeast by the Purcell geanticline.

1. Columbia River Arc

The term "Columbia River" arc has been used by a number of writers including Badgley (4). It is not a good designation because the river flows across only a small part of the arc. Billingsley (5) (6) is credited with the term "Columbia" arc but the designation is vague because it does not immediately suggest to the reader the exact location of the structure. Misch calls it the "West Pacific" arc, or "Arc of the Pacific Northwest" (29). The former brings to mind the western part of the Pacific ocean near the coast of Asia. The latter would be acceptable to Americans, but to Canadians the Pacific Northwest presumably indicates the Yukon area. Smedes credits King (1959) with the term "arc of the Nevadan orogenic belt" (36) which is a cumbersom term. Therefore, although "Columbia River" arc is not a good term it seems to the writer to be the best available.

The Columbia River arc is the largest arc in western United States. The north limb begins in the coast ranges of British Columbia and Vancouver Island. It trends southeasterly across Washington State and northern Idaho. Idaho batholith lies in the apex of the arc. The Butte mining district, and Boulder, Philipsburg and other batholiths and stocks seem also to be related to the apex. Even the Belt embayment, where the miogeosyncline protrudes into the foreland southeast of Helena, called the Central Montana trough by Smedes (36), seems to be related to the apex of the arc. From the Butte-Philipsburg region the south limb of the arc trends southwesterly across Idaho and southern Oregon into northern California.

Although the fold structures, lineation, foliation, and other directional trends in the rocks of the arc were produced principally during the Nevadan orogeny the arc itself dates to a much earlier age. The location of the arc was determined by factors of sedimentation and vulcanism existing during late Precambrian and early Paleozoic time. Eardley's tectonic map of the Cambrian, Ordovician, and Silurian (8, plate 2) shows the presence of a sharply bowed volcanic orogenic belt in western British Columbia, Washington and Oregon. The belt was convex toward the east, being especially strongly bowed toward the east during the Devonian and Permian periods. A conformable arc of sedimentation lay on the east side of the volcanic belt, in the area of interest of this paper. These statements are based on the assumption that Eardley's tectonic maps are reasonably accurate. The volcanic arc and the arc of sedimentation formed the tectonic framework from which was produced the Columbia River arc of principally Nevadan orogenic structures.

The Idaho batholith is younger than the fold structures and lineation in the Columbia River arc since it is well known that granites form during late-synkinematic and post-kinematic stages of orogeny. Metamorphic processes do not reach a sufficiently high degree of intensity to produce granites until the later stages of orogeny. Therefore, the present location of the

batholith had nothing to do with the development of the arc. Rather, the presence of an important arc apex impressed upon eugeosynclinal sediments and volcanics determined the location of the Idaho batholith. The northern limit of the batholith was determined by the eugeosyncline-miogeosyncline boundary, although the intensely sheared Coeur d'Alene-Missoula-Red Lodge lineament may have been a factor of lesser importance.

2. Kootenay Arc

Hedley and Fyles (14) define the Kootenay arc of southeastern British Columbia as "a great belt of heterogeneous sedimentary rocks which trend southeast in the Lardeau region, south along Kootenay Lake, and southwest on the Pend d'Oreille River". Like the Columbia River arc, the Kootenay arc came into existence primarily through vulcanism and sedimentation. As shown on Fig. 1, the boundary of the eugeosyncline passes through West Arm of Kootenay Lake a few miles east of Nelson, B.C. It then passes northerly along the west shore of the lake. On the west side of this boundary the rocks are of the volcanogenic-sedimentary facies, and granitic rocks of the Nelson and Kuskanax batholiths and their outliers. Somewhat deeper into the eugeosyncline are found high grade metamorphic rocks of the Shuswap terrain in intimate relationship with the westernmost rocks of the Nelson batholith. On the east side of the boundary are found relatively unmetamorphosed miogeosynclinal rocks of the Windermere and Purcell series. These are strongly metamorphosed only close to the eugeosyncline boundary, and in a few apparently small (?) Precambrian metamorphic areas which are associated with Precambrian granitic intrusions, and in metamorphic haloes near Mesozoic granitic stocks. In the miogeosyncline are found the Bayonne, White Creek,

Fry Creek, and Horsethief Creek stocks, also the Precambrian Hellroaring Creek stock and small outliers related to it.

If it is permissible to make tentative interpretations on the basis of Eardley's tectonic maps (8) it could be said that faint expressions of the Kootenay arc began to take form during the early part of the Pennsylvanian period. A trough of sedimentation lay on the east side of the volcanic orogenic belt. The eastern edge of the trough lay at the approximate longitude of the present eugeosyncline boundary. According to Eardley's map the east edge of the trough had the form of an arc which was convex easterly, conformable to the present location of the Kootenay arc. The arc of sedimentation persisted through Permian time. Permian and Triassic volcanics were then deposited in the arc, and these were followed by intense folding during the late Jurassic Nevadan orogeny.

The writer feels it imperative to state that, as in the case of the Columbia River arc which is older than the Idaho batholith, the Kootenay arc is older than the Nelson batholith. Hedley confirms this with the following statement, "Although the Nelson batholith occupies the central bow in the Kootenay arc, and the sedimentary structures are affected by it, the arc is not solely the result of intrusion. Structures attributable to intrusive forces along the north batholithic margin are superimposed upon earlier regional structure of northwest trend --. The arcing of the sedimentary formations appears to be a structure of great intiquity that perhaps localized intrusion and certainly was modified by it"(14).

In that portion of the triangular area bounded by arc systems, in which is located the Coeur d'Alene, Pend Oreille, and Clark Fork mining districts, the directional trends in Belt formations seem to be transitional between

those of the Kootenay arc and the Purcell geanticline. Superficially the trends in north Idaho appear to branch off from those of the Kootenay arc as though the two trends had been forced apart by intrusion of the Loon Lake batholith. Actually they have not been forced apart, because the batholith has formed principally by in-place granitization of pre-existing sedimentary and volcanic rocks. During the Nevadan orogeny the triangular area was subjected to a combination of stresses which may have caused some rotation of the area, and possibly some eastward extrusion of that portion which lies between the Osburn and Hope faults (37) (4). These unusual stresses may explain why high grade metamorphism and granitization was able to invade the miogeosyncline in northernmost Idaho.

Since the directional trends in the triangular area seem to the writer to be more closely related to those of the Kootenay arc than to those of the Purcell geanticline they are in this study classed as Kootenay arc structures. The northeast trending folds in the Coeur d'Alene district and adjacent portions of Montana then represent the easternmost expressions of the Kootenay arc.

3. Purcell Geanticline

Lying between Kootenay arc and the Rocky Mountains of British Columbia and Montana is a broad northwesterly trending upwarp or welt known as the Purcell geanticline. It extends approximately from Missoula, Montana northward into British Columbia at least as far as the big bend of the Columbia River, and conceivably as far north as the big bend of the Fraser River. Rocks outcropping in the geanticline are of the Precambrian Belt (Purcell) series. In British Columbia the flanks of the geanticline, especially on the west, are overlain by the late Precambrian Windermere series. Immediately south

of the big bend of the Columbia all of the exposed rocks are Windermere. The geanticline as a whole plunges very gently north and northwest (23). Between the International border and Kimberley, B.C. the geanticline is interrupted by a number of northeasterly trending faults and folds which appear to have had some influence on the emplacement and direction of elongation of the White Creek and Fry Creek stocks.

Evidence indicates that the geanticline originated during Precambrian time (43) and supplied sediments for the Windermere deposition (24). It may be that during the Nevadan orogeny this ancient welt formed a bullwark partly against which the Kootenay arc was compressed. However, the major deformation in the geanticline, as in the arc, occurred during the Nevadan orogeny. According to Leech, the trends in the Precambrian folds apparently were similar to the Nevadan trends. This similarity of structural trends increases the probability that many folds owe part of their development to each period of deformation, which indicates the difficulty of recognizing those that were initially Precambrian (24).

C. Coeur d'Alene-Missoula-Red Ridge Lineament

The Lewis and Clark lineament, also called the Montana lineament, was named by Billingsley (6) and has been discussed by many writers (7) (5) (6) (36) (4). As originally defined it was composed of at least three separate parts. These were the two echeloned members: the Absaroka line extending along the Yellowstone horsts, i.e., along the north front of Yellowstone Park; and the Helena-Missoula line. The third part extended from Missoula toward Spokane. These three parts were not of the same age and origin, and did not have the same direction sense, although this may not have been known at the time Billingsley named the lineament.

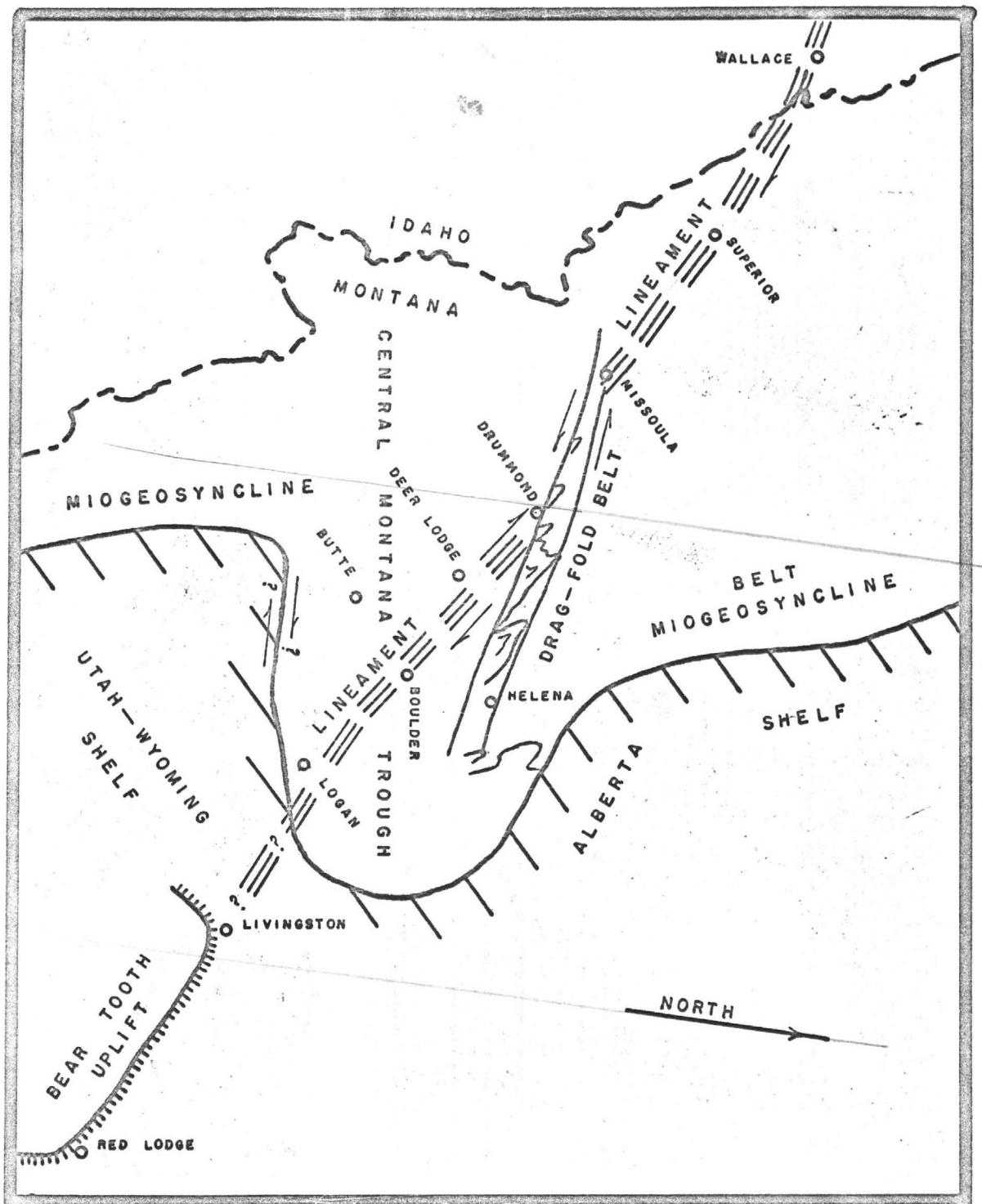

Fig. 3
CENTRAL MONTANA TROUGH and
COEUR d'ALENE-MISSOULA-RED LODGE LINEAMENT

0 20 40 60 80 MILES

1" = 42½ miles(approx)

Long prior to the work of Billingsley and Locke (6), Calkins and Jones had noted the existence of a depression which follows, with comparatively slight deviations, a straight line extending east-southeastward from Spokane, Washington, to Deer Lodge, Montana, a distance of 300 miles. This they referred to as the "old valley" or "Coeur d'Alene trench" (7). They recognized that it was underlain by a major fault zone. Beginning at Spokane, or even west of Spokane, and as far as Coeur d'Alene Lake the zone underlies the valley of the Spokane River. It can then be traced up the valley of Cedar Creek to Fourth of July Pass and east-southeasterly through the vicinity of Kellogg, Wallace, Mullan, and Mullan Pass. In Idaho the structure coincides with the north limb of the Columbia River arc in which flows the South Fork of the Coeur d'Alene River. It appears as a zone of intensely sheared rock containing numerous more or less parallel faults striking roughly east-southeast. This is without a doubt the most strongly sheared and faulted area in the State of Idaho. The Osburn fault is the dominant fault in the shear zone, but the Placer Creek, Burnt Cabin, Silver Creek and some others are also large faults. In Montana the zone can be traced along the old valley which passes north of Saltese, Deborgia, and St. Regis. East of St. Regis the zone is less distinct but can be traced by means of faults, depressions, aligned river valleys, and occasional diorite intrusions through Missoula, Drummond, and Deer Lodge.

The Lewis and Clark line was said by Billingsley to comprise a northwesterly-trending tear fault zone of continental scale. The area between the two echeloned lines was described as an area with north by east fold trends forming a diagonal link in the Cordilleran Lewis-Lombard thrust zone. The area is defined in more detail by Harry Smedes who follows previous usage in referring to this diagonal link as the "Central Montana trough" (36).

Smedes also referred to the possible presence of a NNW-SSE trending

tear of Precambrian age passing diagonally across the Central Montana trough. Such a tear would extend from Missoula through Livingston and on toward the southeast. The present writer came independently to this viewpoint. In this study the term "Coeur d'Alene-Missoula-Red Lodge lineament" is proposed to describe this structure. It is one single, apparently continuous lineament whose origins date back to Precambrian time. Principal movement on the lineament, however, was in places Mesozoic and in places Tertiary. Strike slip movement was right lateral throughout, but vertical movements were more important. Rather than veering easterly from Missoula to Helena, as does the Lewis and Clark line, the Coeur d'Alene-Missoula-Red Lodge line continues in its southeasterly trend across the Montana trough through the vicinity of Logan and Livingston to Red Lodge. It apparently passes through the Boulder Batholith along a line of weakness marked by North Boulder River. This need not imply that the lineament is younger than Boulder batholith which was emplaced during early Tertiary time. The lineament is a master fault zone of great age. Boulder batholith was intruded with cross-cutting relations to the lineament, but the lineament remained a zone of weakness (11).

The Central Montana Trough as described by Smedes is bounded on the north and east by the Alberta shelf which is covered by a veneer of Precambrian Belt rocks. He considered the Helena-Missoula line as marking the north boundary of the trough. On the south and east the trough is bounded by the Wyoming-Montana-Utah shelf. This shelf outcrops as crystalline rocks forming the Beartooth and Tobacco Root Mountains, and the Camp Creek metamorphic area south of Boulder batholith. The boundary between the shelf and the south edge of the trough is marked by a fault zone said to have been an important tectonic boundary through Belt, Paleozoic, and Recent time. Congolomerates and wedge arkoses shed from the fault scarp occur throughout this zone. These include the North Boulder group of Precambrian sediments. A principal tenet of

Smedes' paper (36) is that the trough, the Alberta shelf, the Wyoming shelf, and the Cordilleran geosyncline which bounds the trough on the west mark major blocks of the earth's crust. The trough, he says, has exhibited predominantly negative tendencies through geologic time. Thus, Smedes developed "a concept of a crustal block system of four units bounded by important major rifts which, once established in pre-Beltian time, persisted throughout long periods of geologic time and exerted a principal control over all subsequent periods of deposition and of orogeny". Thrust faults, high angle reverse faults, and en echelon folds mark the north edge of the graben-like trough block. Smedes interpreted this as a left-lateral tear zone developed during the Laramide orogeny when the supracrustal rocks of the trough moved eastward. The tear zone corresponds to the Helena-Missoula line of Billingsley. Right lateral faults, according to the interpretation of Smedes, branched from this tear zone near Missoula to form a composite wedge that moved relatively westward, as though pinched between the trough rocks and those to the north, like a watermellon seed pinched between thumb and finger. Hietanen described the westward movement of a wedgeshaped block north of the Idaho batholith, i.e., between the batholith and the Osburn fault (16). This is perhaps the wedge referred to by Smedes.

The Helena-Missoula line, which Smedes considers a major tear zone, appears to be superimposed upon or across the Coeur d'Alene-Missoula-Red Lodge lineament. It is younger than the latter and developed independently of it. Therefore, it is no longer necessary to ask the question posed by Badgley and others (4) (36), "Why is strike slip action of a right lateral nature in the Coeur d'Alene district, and of a left lateral nature at the east end of the Lewis and Clark line (i.e., the Helena-Missoula line)"? The answer is that the over-all direction sense is probably the same all along the Coeur d'Alene Missoula-Red Lodge lineament. The Helena-Missoula line is a separate and

distinct structure with a direction sense of its own.

That there may be a line of weakness diagonally across the Central Montana trough seems indicated not only by North Boulder River flowing across Boulder batholith, but by other streams flowing in the same lineament. For example that portion of the Clarks Fork of Columbia River which flows between Deer Lodge and Drummond. This part of the lineament appears to have been offset to the east with respect to the Coeur d'Alene-Missoula portion of the lineament. The alignment of streams, and some faults and dioritic intrusions, with the Stillwater Complex and the northwesterly-trending edge of the Wyoming shelf (as represented by the northeastern front of the Beartooth uplift) is almost too perfect to be accidental.(11).

If shifting movements in a zone of weakness between the Wyoming and Alberta shelves have influenced Precambrian Belt sedimentation, and perhaps to some extent are responsible for the easterly inbowing of the Cordilleran geosyncline, then continued weakness during late Precambrian time along the northeast edge of the Beartooth uplift could have influenced development of the Coeur d'Alene-Missoula-Red Lodge lineament and the extreme shearing of the north limb of Columbia River arc. Although most of the visible faults along the mountain front are Laramide the fault trends are inherited from Precambrian structures in the basement (20).

The amount of relative movement, and the age of movement, in the Coeur d'Alene-Missoula-Red Lodge lineament has not been the same all along the structure. There is little concrete evidence of large scale strike-slip movement in the lineament even in the Coeur d'Alene district.

The Stillwater complex was intruded into the zone prior to 1500 m.y. ago. Diabase dikes were intruded during later Precambrian time into faults

with westerly, northwesterly, northerly and northeasterly trends. But little if any deformation took place during the long interval between Cambrian and Late Cretaceous times. The principal faulting and uplift of the Beartooth Range occurred during the Laramide orogeny. Fault movements were mainly vertical (20).

Eastward movement of supracrustal rocks in the Central Montana trough took place during the Laramide orogeny (36). The Helena-Missoula line cuts the lineament and appears to have produced left-lateral offset of the latter by a number of miles. If so, then the lineament is pre-Laramide, or at least early Laramide, in this area.

North of the Central Montana trough there is little evidence of strike-slip movement. Belt rocks on the north side of the lineament are in general older than are those on the south side. This is mainly due to vertical movements, and upwarping of the Purcell geanticline. However, a number of faults in the lineament cut Cambrian rocks, thereby proving that much movement in the lineament has been post-Cambrian. It is also younger than the fold structures.

In the Coeur d'Alene district are faults which show evidence of strike slip movement, but it is rarely possible to quantify the data. Arguments have been advanced in favor of strike-slip movement of 12 to 16 miles on the Osburn fault (15) (41). Little if any of the "evidence" can stand critical examination. Vertical movement on some of the faults has been large. Information regarding age of the lineament can be obtained through observation of the relations between ore deposits and the monzonite stocks at Gem. The stocks have been geochemically dated as late Lower Cretaceous, i.e., between 94 and 116 millions of years old (22). Evidence, in the nature of shapes and limits of orebodies, metamorphic mineralogy, sulfide mineral zoning, and other ore-monzonite relations, has lead the writer to conclude that the ore deposits

were emplaced following intrusion of early monzonite dikes but prior to stock intrusion. Ore mineralization and monzonite intrusion were closely related in time. The ore deposits are therefore quite definitely associated with the Nevadan orogeny. There is little doubt that most of the faults are older than the ore veins, therefore the faults comprising the lineament in the Coeur d'Alene mining district were formed during the Jurassic to Lower Cretaceous Nevadan orogeny or earlier. However, some movement occurred on many of the faults after the ore veins had been deposited. This movement could have taken place during the late Nevadan or Laramide orogeny or later in the Cenozoic. The faults are younger than the folds. Although some of the folds may have been initiated during Precambrian time the principal deformation was almost undoubtedly Nevadan as will be described in detail in a succeeding part of this study.

In Kootenai County, Idaho, the lineament is represented by numerous westerly-trending folds and faults. Strike-slip movement has not been pronounced, but vertical displacement amounts to several thousands of feet (3). The age of folding in that area is said to be early Tertiary because younger hypabyssal intrusive rocks are associated with them. This, however, is not a valid criteria because dikes can be injected into folded structures at any time after the deformation. There is little doubt that the fold structures formed during the Nevadan orogeny as did other Columbia River arc structures.

SUMMARY

A study of many major ore districts has lead the writer to infer that the presence of a volcanic geosyncline is essential to the formation of

economically important primary sulfide deposits related to mobile belts.

Maps of the Cordilleran geosyncline show that its borders are sinuous and irregular. The borders are marked by embayments of eugeosyncline into miogeosyncline, and re-entrants of the miogeosyncline into eugeosyncline. There are also embayments of miogeosyncline into foreland, and re-entrants of foreland into miogeosyncline.

Embayments and re-entrants frequently are loci for nodes, arcuate structures, intersecting fracture systems and lineaments. Therefore they often form important geologic crossroads in which are located major mining districts.

Breaks, fracture systems, lineaments and arcuate structures are related to ore deposits in a structural sense in that they influence the concentration and movement of ore solutions and are favorable loci for ore deposition, or provide entry ways into favorable loci. Orogenic belts and their intersections, and chains of granitoid batholiths are related to ore deposits in a genetic sense in that they play a part in the generation of the deposits. However, the ultimate origin of the metals probably lies in the mantle.

The Cordilleran geosyncline in the area of this study consists of a western volcanic facies and an eastern non-volcanic facies. The western facies is Paleozoic and Mesozoic, but the eastern facies are composed of Precambrian Belt rocks.

Indirect physical evidence in the form of Precambrian volcanic flows which thicken toward the west, supported by the evidence from lead and sulfur isotopic analysis of mining district ores, indicate that at least a prototype volcanic eugeosyncline must have existed during the Proterozoic era. Areas underlain by Belt and Purcell formations are therefore referred to as the miogeosyncline.

The boundary between eugeosyncline and miogeosyncline is herein drawn so as to include with the former all areas containing Mesozoic volcanics and the great crystalline complexes of metamorphic and granitic rocks. Areas containing little or no volcanic rocks and no granitic complexes are included with the latter. Numerous smaller granitic bodies are included with the miogeosyncline, but these are post-tectonic igneous intrusions.

The Coeur d'Alene mining district is located in a triangular area bounded by the north limb of the Columbia River arc, the Kootenay arc, and the Purcell geanticline.

Significant factors regarding the location of the Coeur d'Alene mining district are that it is situated in a miogeosynclinal re-entrant; it lies at the junction of arc systems; and it is at the most deeply sheared portion of the Coeur d'Alene-Missoula-Red Lodge lineament. Country rock in major re-entrants is usually strongly disturbed. Arc systems are loci for concentration of ore solutions, and junctions of arc systems provide rapid changes in directional trends. Exceptionally deep shearing provides throughgoing faults which penetrate deep into the geosyncline.

The Lewis and Clark lineament, as defined by Billingsley, was composed of three separate parts which were not of the same origin and age, viz., the Coeur d'Alene-Missoula line (right lateral strike slip); the Missoula-Helena line (left lateral strike slip); and the Absaroka line along the Yellowstone horsts (right lateral strike slip along the north front of Yellowstone Park).

The term "Coeur d'Alene-Missoula-Red Lodge lineament" is proposed and used herein to describe an apparently continuous lineament. It passes diagonally through the Central Montana trough, and through the Boulder batholith along a line of weakness marked by North Boulder River. The lineament dates to Precambrain time, was intruded by Boulder batholith, but has remained a line of weakness.

Central Montana trough cuts across the Coeur d'Alene-Missoula-Red Lodge lineament, and has produced offset of the lineament by some miles.

CONCLUSIONS

1. The presence of a volcanic geosyncline is essential to the formation of economically important primary sulfide ore deposits related to mobile belts.

2. Some indirect physical evidence, supported by recently acquired isotopic evidence from the Mining district, indicates that a eugeosyncline, at least in ancestral or prototype form, existed on the west of the miogeosyncline at the time that the Belt (Purcell) sediments were being deposited. The Belt rocks may correctly be said to represent the miogeosyncline. During the Proterozoic era the eugeosyncline probably lay near what is today called central or eastern Washington and south-central British Columbia west of Kootenay Lake.

3. The Coeur d'Alene district is situated in a miogeosynclinal re-entrant. It lies at the junction of arc systems, in the most deeply sheared portion of the Coeur d'Alene-Missoula-Red Lodge lineament. It is in a triangular area bounded on the south by the north limb of the Columbia River arc, on the northwest by the Kootenay arc, and on the northeast by the Purcell geanticline.

4. Directional trends in the triangular area are transitional between Kootenay arc trends and those of the Purcell geanticline. Since they seem to be more closely related to trends in the arc than to those in the geanticline they are here classed as Kootenay arc structures. The northeasterly-trending folds in the Coeur d'Alene district and adjacent parts of Montana therefore represent the easternmost expressions of the Kootenay arc.

5. An apparently continuous lineament passes from Coeur d'Alene through Missoula, Deer Lodge, Boulder, Logan, Livingston, to Red Lodge. The term "Coeur d'Alene-Missoula-Red Lodge lineament" is herein proposed and used to

describe the lineament. The Central Montana trough cuts across the lineament, and has produced offset of the structure.

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December 1[illegible], 1963

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42. The miogeosyncline is to a large extent underlain by crysalline rocks of the foreland, but the eugeosyncline is not. Therefore, the location of the miogeosyncline is in a general way fixed by the configuration of the submerged foreland. The "Eu-Mio" boundary is real and controlled. Nevertheless, there was bound to have been some interfingering of facies during sedimentary deposition at the "Eu-Mio" boundary.

43. That an ancient trough flanked on the east by a welt, which later became the Purcell geanticline, existed in S.E. British Columbia and N.W. Montana as early as the Lower Proterozoic seems indicated by the fact that the Precambrian formations flanking the geanticline on its west side are of unusual thickness. This is especially true of the Prichard and Wallace formations. The thickest and most complete sections of Belt rocks ever measured in Montana are located along , and west of this flank. (See Part II of this study.)

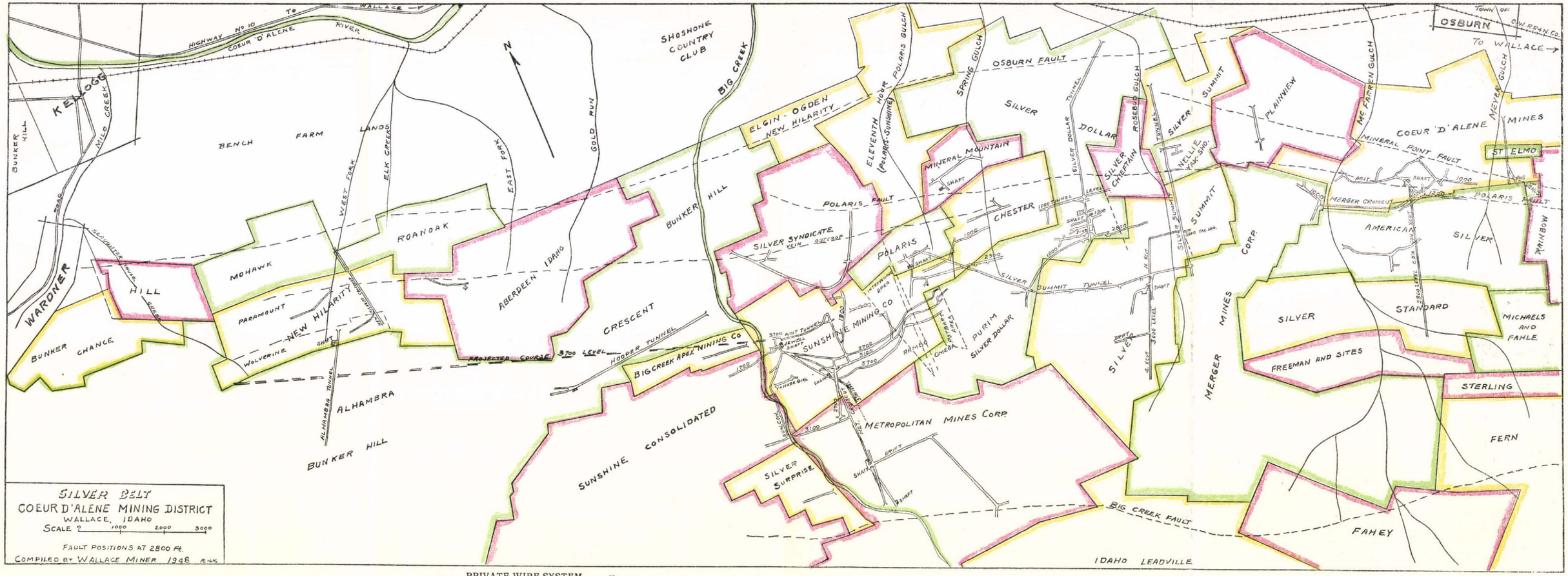
AGI Program, 40th Ann. Mtg.
May 4-7, 1959. P. 39

SECTION OF VOLCANOLOGY, GEOCHEMISTRY, AND PETROLOGY

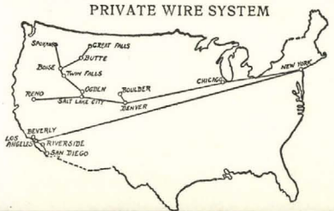
(1) AUSTIN LONG, ARNOLD SILVERMAN, and J. LAURENCE KULP (Lamont Geological Observatory, Columbia University, Palisades, N.Y.) Precambrian Mineralization of the Coeur d'Alene District, Idaho--The Coeur d'Alene district in northern Idaho is the chief Pb-Zn-Ag mining area in the Cordillerian region. Until recent isotopic studies, mineralization was assumed to have occurred in late Cretaceous or early Tertiary time during or subsequent to the Laramide disturbance. Fifteen galena samples from widely distributed mines in the area and at various levels in some of the mines were analyzed for lead isotope composition and did not vary beyond the experimental error. The average value and the standard deviation are:

	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}
Average of 15 Coeur d'Alene galenas	16.44 ± 0.06	15.58 ± 0.07	36.52 ± 0.22

This average gives a common lead model age of 1250 million years which agrees with the estimated age of pitchblende from the Sunshine Mine as derived from U-Pb isotopic ratios. The isotopic composition of the Coeur d'Alene lead is essentially the same as that in the Sullivan Mine and related ones in Southeastern British Columbia and suggests a common source for the ore during a single Precambrian mineralizing epoch. Precambrian lead was also found in veinlets cutting alleged Cretaceous dikes and may indicate remobilization of sulfides during the Laramide orogeny.



PRIVATE WIRE SYSTEM



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