AMPHIBOLIZATION OF SILLS AND DIKES IN THE LIBBY QUADRANGLE, MONTANA*

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ABSTRACT

Numerous mafic sills, a few dikes, and one stock intrusive in the Belt rocks in the Libby quadrangle, Montana, show widespread amphibolization similar to that observed in the pre-Cambrian Purcell sills of British Columbia and Northern Idaho. The Montana sills are the same age as the Purcell intrusives, whereas the dikes and the stock are regarded as late Mesozoic. The amphibolization of both groups of intrusives is believed to have been caused by hydrothermal solutions which were derived from and followed the quartz monzonite, granodiorite, and similar intrusives that invaded the Belt rocks of northern Idaho and northwestern Montana, probably in the late Mesozoic. The ore deposits in these areas also are gentically related to the granodiorite and quartz monzonite.

INTRODUCTION

A series of mafic sills, commonly called the Purcell sills, intrusive into the Belt sedimentary rocks of northern Idaho and southern British Columbia has been described by different workers[1] and assigned to the pre-Cambrian.

* Published with the permission of the Director, United States Geological Survey.

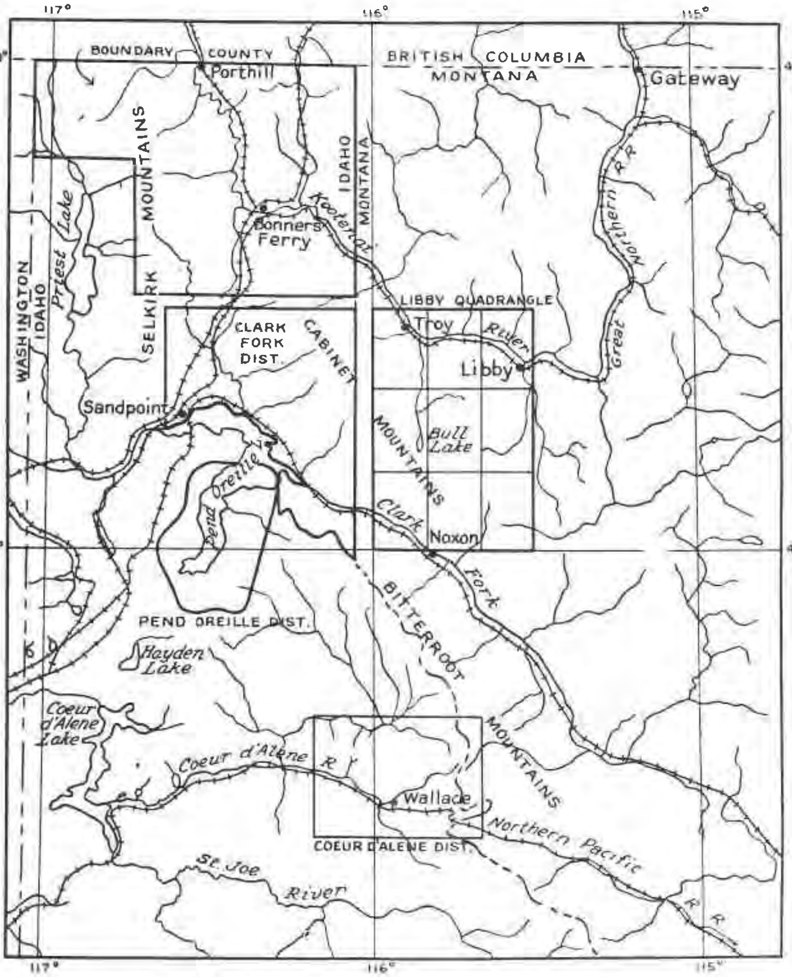
[1] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: *Mem.* **38,** *Part I, Canada Geol. Survey, Dept. of Mines,* pp. 209–255, 1912.

Schofield, S. J., The origin of granite (micropegmatite) in the Purcell sills: *Canada Geol. Survey, Mus. Bull.* **2,** pp. 1–32, 1914.

Schofield, S. J., Geology of the Cranbrook map-area, British Columbia: *Mem.* **76,** *Canada Geol. Survey, Dept. of Mines,* pp. 56–70, 1915.

Calkins, F. C., Geological reconnaissance in northern Idaho and northwestern Montana: *U. S. Geol. Survey, Bull.* **384,** pp. 48–50, 1909.

In the course of the mapping of the Libby quandrangle, Montana, (Fig. 1) for the United States Geological Survey, many similar sills in



INDEX MAP SHOWING LOCATION OF LIBBY QUADRANGLE, MONTANA

Scale

0 10 20 30 40 Miles

FIG. 1

Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County Idaho: *Ida. Bur. of Mines and Geology, Bull.* **10,** pp. 36–38, 1926.

Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: *Ida. Bur. of Mines and Geology, Bull.* **12,** pp. 24–25, 1930.

the Belt rocks of that quadrangle and adjacent areas north and south of the Libby quadrangle were mapped and examined. They are regarded as belonging to the same series of intrusives as the Purcell sills.

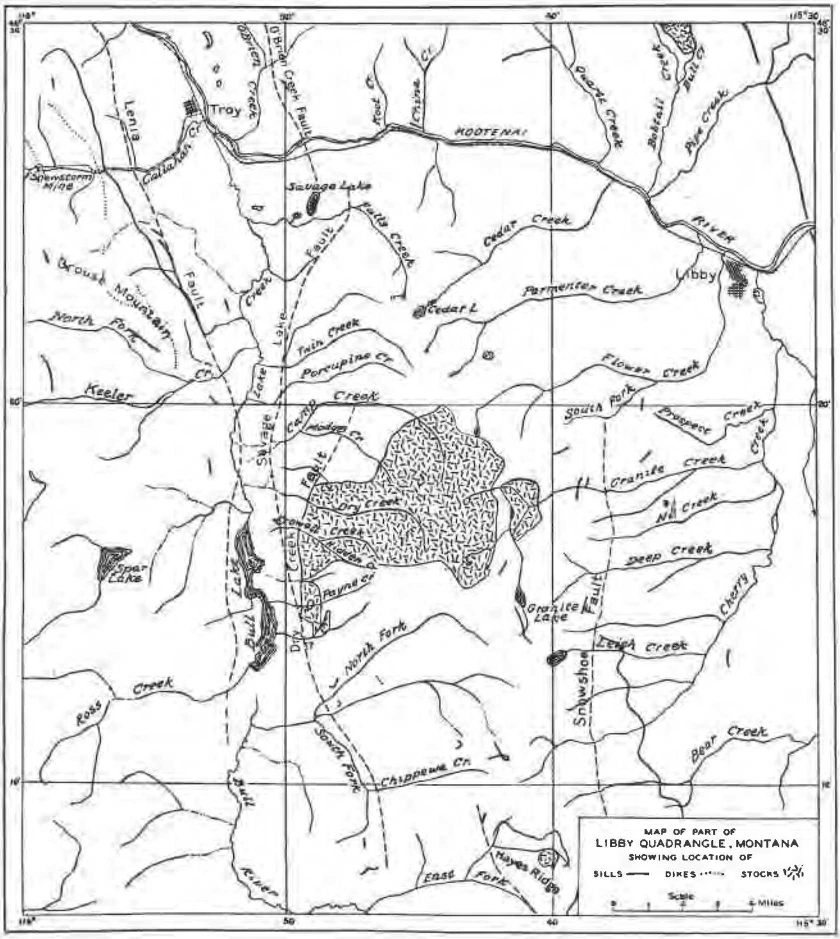


FIG. 2

A number of mafic dikes and a few felsic dikes accompanied, or succeeded, the quartz monzonite and granodiorite stocks[2] which invaded the

[2] Gibson, Russell, Campbell, Ian, and Jenks, W. F., Quartz monzonite and related rocks of the Libby Quadrangle, Montana, and the effects on them of deuteric processes (*in preparation*).

Belt rocks probably in the late Mesozoic. A few of the sills may possibly belong to this later period of intrusion.

The sills, the mafic dikes, and one of the stocks have been altered by amphibolization which appears to have been widespread. Superimposed on the amphibolization locally there has been further hydrothermal alteration to chlorite, sericite, carbonate and other minerals, and introduction of metalliferous deposits. Both sills and dikes have been extensively prospected.[3] (Fig. 2 shows the distribution of these intrusives.[3a])

The writers desire to acknowledge the helpful criticism of Messrs. C. S. Ross and G. F. Loughlin of the United States Geological Survey, and Professor E. S. Larsen, Jr. of Harvard University in the preparation of this paper.

GENERAL GEOLOGY OF THE AREA

The dominant rocks of the area are shale, argillite, sandstone, quartzite and dolomitic limestone of the Belt series. Four formations, the Prichard, Ravalli, Wallace, and Striped Peak are exposed within the area. These sedimentary rocks and the included sills have been folded into large open anticlines and synclines which in most places trend north-northwest and plunge at a low angle in the same direction. The axial planes of the folds are commonly inclined eastward. The beds have been faulted and many of the crosscutting faults are persistent, steeply dipping, and show great vertical displacement.

The folded rocks have been invaded by several small stocks that are probably of Mesozoic age, and which range in composition from diorite to quartz monzonite and syenite; the most abundant rock being quartz monzonite. The largest stock has a surface area of about 20 square miles.

SILLS

Size and Distribution of the Sills

The Prichard, Ravalli, and Wallace formations have been invaded by a succession of sills whose original composition was probably similar to that of a diorite. Because of their altered condition they have been called in this paper metadiorite. None was seen in the Striped Peak formation. About 40 sills were observed and nearly that many have been mapped. In some instances the same sill may possibly have been mapped on both limbs of a fold and regarded as two sills. Most of them are thin and

[3] Gibson, Russell, Geology and ore deposits of the Libby quadrangle, Montana: *U. S. Geol. Survey, report in preparation.*

[3a] The Dry Creek fault shown on the map is the Bull Lake fault of Calkins, *U. S. Geol. Survey*, Bull. **384,** pp. 67, 68, 1909.

discontinuous and cannot be traced far; and, as individual sills show very different degrees of alteration, correlation is difficult.

The longest and most conspicuous sills are in the northwestern part of the quadrangle between Keeler Creek and Preacher Mountain west of Troy; in the northeastern part on Mount Sheldon; and in the southeastern part east and west of the Snowshoe fault. Small sills were observed in many different places within the quadrangle. They decrease in number and thickness toward the south.

The sills range in thickness from 10 inches to 800 feet and in length from a few feet to 10 miles. Most of them are about 100 feet or less in thickness and only five have been traced for a distance greater than two miles. They weather easily and do not commonly form conspicuous features of the topography, and hence, their dimensions may commonly be greater than those recorded.

About 14 per cent of the total number of sills are in the Prichard, 16 per cent in the Ravalli, and 70 per cent in the Wallace formation, but the greatest thickness of sill material, roughly 1200 feet, is in the Prichard.

Petrography

Megascopic features

The most abundant type is a holocrystalline, medium-grained, dark-green metadiorite composed chiefly of hornblende and tabular plagioclase, with smaller amounts of biotite and accessory minerals. Quartz rarely exceeds 15 per cent and in a very few sills it is lacking. The average grain size of hornblende, the dominant mineral, is 1.4 millimeters; of the plagioclase 0.6 millimeter. These interlock in random orientation in a tight fabric.

A second type, which is of minor importance quantitatively, is a porphyritic rock in which phenocrysts of plagioclase, quartz, or mafic minerals are conspicuous in an abundant groundmass similar in grain-size and composition to the finer-grained facies of the metadiorite. These types grade into each other.

The metadiorite sills differ among themselves and in different parts of the same sill in grain size, in proportions of the essential minerals, and in degree of alteration. No stratification was observed according to mineral density nor were any pegmatite streaks seen.

Hornblende is completely, or almost completely, replaced in over half the sills. In some of these little or no plagioclase remains, and the rock is composed chiefly of minerals mentioned below which are the result of further hydrothernal alteration. This is true especially near prospects and mines where metalliferous veins have been opened up in the sills.

Modes of several sills are given in Table 1.

TABLE 1

	1	2	3	4	5	6	7	8	9	10
Hornblende	59.6	64.6	53.4	tr	18.3	18.4	11.4	—	—	—
Plagioclase	17.1	12.8	23.4	2.3	19.3	30.1	18.7	51.8	42.5	57.6
Quartz	14.0	5.8	5.8	14.3	2.3	2.1	3.4	0.4	9.8	—
Biotite	1.0	1.5	—	12.9	11.7	16.6	8.8	1.0	18.1	—
Chlorite	1.0	4.4	3.9	28.4	19.2	8.6	22.3	28.9	19.6	35.0
Carbonate	0.3	0.7	2.3	17.5	2.7	4.6	8.5	—	2.8	—
Sericite	tr	3.3	1.9	17.5	tr	3.2	4.8	tr	—	tr
Epidote and clinozoisite	3.6	3.6	6.0	tr	17.8	9.9	13.3	tr	tr	tr
Accessory	3.4	3.3	3.3	7.1	8.7	6.5	8.8	17.9	7.2	7.4
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1. Long sill between the Lenia fault and the Snowstorm mine.
2. Less altered part of sill at Liberty mine, south of Callahan Creek.
3. Sill at Paul ranch, south of the Liberty mine sill.
4. Sill at Silver King mine on North Fork of Keeler Creek.
5. Sill on Burnt Mountain on north side of Keeler Creek.
6. Sill at Martin's prospect, northwest of Hayes Ridge.
7. Long sill from Bear to Leigh Creeks.
8. Sill on Mt. Sheldon between Kootenai River and Pipe Creek.
9. Sill on North Fork of Bull River.
10. Sill on Horse Creek, north of Granite Creek.

Microscopic features

Several textures and great differences in grain size are seen under the microscope. The most common texture is controlled by long interlocking euhedrons of hornblende. Granular texture is seen only in the thoroughly altered specimens. Where foliation is present it is formed largely by reorientation of biotite and by chlorite. A porphyritic texture with a matrix that is coarse for a true porphyry is found in a few sills.

Next to hornblende and plagioclase the most abundant minerals are chlorite, carbonate, sericite, quartz and biotite, which are chiefly alteration minerals. Epidote, and clinozoisite are erratic in amount and distribution. Orthoclase, sphene, rutile, leucoxene, apatite, magnetite, ilmenite, tourmaline, and zircon are the accessory minerals.

Hornblende. Hornblende ranges in size from 0.02 to 18 millimeters and averages about 1.4 millimeters. It is strongly pleochroic, and forms euhedrons and subhedrons. In places the fabric of the rock is controlled by elongate interlocking hornblende grains which crystallized later than the smaller plagioclase grains and, consequently, enclose, penetrate, or wrap around the plagioclase (Fig. 3). According to Harker[4] this texture is markedly developed in rocks in which the hornblende is in great part

[4] Harker, Alfred, *Petrology for students*, pp. 67–68, Cambridge, **1923.**

derived from augite. Augite was observed in only one sill and here it was partly replaced by hornblende.

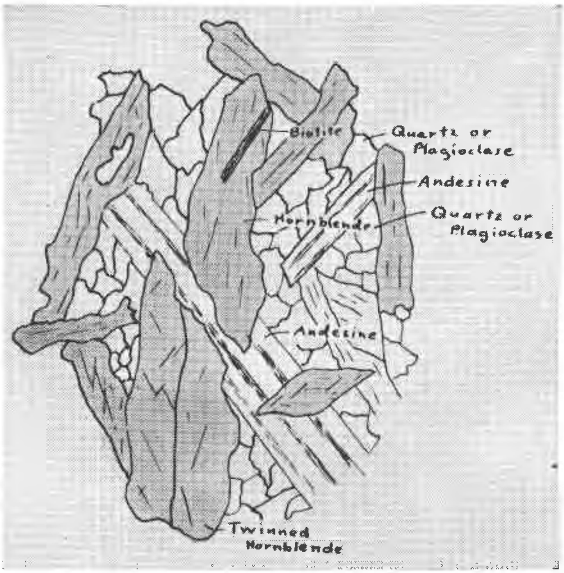


FIG. 3. Sketch of part of thin section showing crosscutting nature of hornblende. Magnification 30×.

Optical properties of hornblende from several sills are given in the accompanying Table 2. Hornblende with lower indices of refraction is found in intrusives in association with plagioclase of more calcic composition, whereas hornblende of higher indices is associated with more sodic plagioclase. Rice[5] found this same association in the Purcell sills of British Columbia. Optical properties of two hornblendes are quoted from Rice's paper for comparison. His analyses of these two hornblendes show that Type "A," which is associated with the more sodic plagioclase, has slightly more potash and soda than Type "B"; whereas Type "B," which is associated with more calcic plagioclase, has slightly more lime than Type "A."

TABLE 2

Intrusive	α	β	γ	$\gamma-\alpha$	$Z \wedge c$	2V	sign
1.	1.637	1.652	1.661	.024	18°	75°	Neg.
2.	1.638	1.654	1.658	.020	18°	53°	Neg.
3.	1.658	1.672	1.681	.023	19°	77°	Neg.
4.	1.669	1.681	1.691	.022	16°	85°	Neg.
5.	1.666	1.678	1.688	.022	18°	84°	Neg.

[5] Rice, H. M. A., Amphibole from the Purcell sills, British Columbia: *Am. Mineral.*, vol. **20**, pp. 307–309, 1935.

Pleochroism

	X	Y	Z
1.	Pale olive green	olive green	bluish green
2.	Pale yellow	olive green	greenish blue
3.	Pale yellowish blue	dark yellowish green	dark greenish blue
4.	Pale yellowish brown	pale olive green	deep bluish green
5.	Pale yellow	olive green	greenish blue

1. Dike at Togo prospect on Callahan Creek.
2. Purcell sill in British Columbia. Rice's type "B" hornblende.[a]
3. Large sill between Snowstorm Mine and Lenia Fault.
4. Sill at Martin's prospect northwest of Hayes Ridge.
5. Purcell sill in British Columbia. Rice's type "A" hornblende.[a]

[a] Rice, H. M. A., *op. cit.*

Hornblende shows all degrees of alteration and is the first mineral to be attacked locally by hydrothermal solutions which deposited the ores. In some specimens, however, it is fresh and constitutes 65 per cent of the rock. It is replaced chiefly by chlorite and to a less extent by carbonate, epidote, biotite, magnetite and albite.

Plagioclase. Most of the feldspar of the sills is plagioclase, ranging in composition from albite to calcic andesine, the most abundant being oligoclase or andesine. In some specimens there are two kinds of plagioclase, but zoning is of minor importance. Oligoclase and andesine have been replaced very extensively by more sodic felspar, albite or albite-oligoclase, accompanied by epidote and clinozoisite. The average grain size is 0.6 millimeter, but the common range is from about 0.1 to 2 millimeters. In exceptional cases the grains reach a length of 30 millimeters. Alteration of plagioclase to other minerals is not so widespread, so conspicuous, or so early as alteration of hornblende, and a rock in which the hornblende has been completely or almost completely replaced may contain 15 to 65 per cent albite and, less commonly, andesine. In the neighborhood of prospects, and to a minor extent elsewhere, the plagioclase is replaced by sericite, clinozoisite, epidote, and carbonate.

Quartz. Quartz is erratic in distribution and grain size but is commonly fine grained. Much of it has clearly been introduced during hydrothermal alteration of the sills containing metalliferous veins, but even in those sills which are still chiefly hornblende and plagioclase, and contain no metalliferous deposits, quartz commonly makes up 5 to 15 per cent. Anderson[6] also mentions the usual amounts of quartz present in the Purcell sills of northern Idaho and southern British Columbia.

[6] Anderson, A. L., Geology and ore deposits of the Clark Fork district: *Ida. Bureau of Mines and Geol., Bull.* **12**, pp. 26–27, 1930.

Contact Metamorphism

Contact metamorphism near the sills is commonly inconspicuous. The effects of recrystallization are seen everywhere in the Belt rocks and it is not always possible to determine how much metamorphism is attributable to the sills and how much is regional. It seems clear that, near some sills, small amounts of biotite (later altered to chlorite), feldspar, quartz, carbonate, pyrite, pyrrhotite, magnetite, tourmaline and sphene have been disseminated in the enclosing argillaceous sandstone. So much biotite has been introduced into the sandstone a few inches from a sill contact, in a few places, that it is difficult to determine the exact position of the contact. Near any metalliferous deposits in a sill, metamorphism is a little more conspicuous in the enclosing sedimentary rocks. Here, sulphides and carbonate, especially, are more abundant in disseminated grains.

DIKES

The dikes have been described elsewhere[7] and will be mentioned here only briefly.

Most of the large or persistent dikes in the Libby quadrangle are metadiorite and are in the northwestern part, north and south of Callahan Creek and west of the Lenia fault. About 10 dikes of this type were observed, two of which were more than 140 feet in thickness. The largest mine in the quadrangle, the Snowstorm, and many of the prospects in the Grouse Mountain area are in metadiorite dikes.

A few thin dikes which range in composition from granite to quartz diorite cut the quartz monzonite stocks and the sediments near the border of the stocks. All the dikes are distinctly crosscutting and are later than the folding.

The typical metadiorite dike is made up chiefly of hornblende and andesine. The plagioclase is less commonly sodic labradorite or oligoclase. From one to 10 per cent of quartz is present and the accessory minerals are apatite, zircon, tourmaline, sphene, magnetite and ilmenite. Where hornblende is fresh, little or no biotite is present. One of the dikes contains from 25 to 40 per cent of augite, but it is all partly altered to hornblende. In short, the metadiorite dikes are now roughly similar to the sills in composition and texture, though the range in grain size in the dikes is not so great as in the sills.

Many of the metadiorite dikes contain metalliferous deposits, and they are commonly more thoroughly altered than the petrographically similar sills, consequently some are now wholly or partly composed of chlorite, sericite, carbonate, quartz, and biotite, with smaller amounts

[7] Gibson, Russell, Campbell, Ian, and Jenks, W. F., *op. cit.*

of clinozoisite, epidote and other minerals. The plagioclase in the sills is much albitized, but this has not been observed to so great an extent in the dikes.

AMPHIBOLIZATION

The mafic sills and dikes have been called metadiorite because it is believed that, like the sills in British Columbia and in the Clark Fork and Boundary County districts of northern Idaho, they have undergone widespread metamorphism. As mentioned above, the hornblende is clearly later than the plagioclase and may have been derived from a pyroxene, but in only one sill and in one dike did the hornblende grains show cores of augite.

In the Clark Fork district west of the Libby quadrangle Anderson[8] found that hornblende, in similar sills believed to be pre-Cambrian, contains cores of hypersthene and augite, and suggests that hornblende in all these sills is a replacement of pyroxene. Kirkham and Ellis[9] are of the same opinion concerning the hornblende in the pre-Cambrian sills in Boundary County, Idaho, northwest of the Libby quadrangle. The sills in these three nearly contiguous areas are very similar in composition, occur in the same formations of the Belt series, and are almost certainly identical in age. It is believed, therefore, that they have had very similar subsequent histories.

Schofield[10] called attention to the great changes which have taken place in the pre-Cambrian Purcell sills of British Columbia, a part of the southern boundary of which is contiguous with Boundary County, Idaho. Here the augite and hypersthene of the original gabbro have been altered to hornblende so that the rock is now a hornblende gabbro. Schofield also mentions a quartz diorite phase of the sills in which the hornblende appears to be secondary. On the other hand, Daly,[11] who first described these sills, regards the rock as a primary hornblende gabbro, but he does not mention finding augite almost completely altered to hornblende, as do Schofield, Anderson, and Kirkham and Ellis.

Further evidence of widespread alteration of the sills in the Libby quadrangle is presented by the replacement of calcic plagioclase by albite, a process that is much more striking in the sills than in the dikes.

[8] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: *Ida. Bur. of Mines and Geol., Bull.* **12,** p. 27, 1930.

[9] Kirkham, V. R. D. and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: *Ida. Bur. of Mines and Geology, Bull.* **10,** p. 37, 1926.

[10] Schofield, S. J., Geology of Cranbrook map-area, British Columbia: *Canada Geol. Survey, Memoir* **76,** pp. 56–70, 1915.

[11] Daly, R. A., Geology of the North American Cordillera at the 49th Parallel: *Canada Geol. Survey, Memoir* **38,** pp. 222–223, 1912.

The metamorphism proceeded in stages of decreasing intensity. First the pyroxene was converted to amphibole. This was succeeded by albitization of plagioclase, in places accompanied by the formation of epidote and clinozoisite. Biotite begins to appear as hornblende diminishes in amount, though some biotite seems to be contemporaneous with hornblende. Later, both hornblende and biotite are replaced by chlorite and other minerals. Finally, plagioclase disappears and the rock is composed of sericite, clinozoistie, epidote, carbonate, chlorite and quartz. This complete alteration is conspicuous especially where metalliferous veins have been deposited in the intrusives.

As alteration proceeds, the texture of the rock changes. The hornblende-plagioclase rock is fine- to coarse-grained dioritic; the thoroughly altered rock is fine grained and shows little or no trace of its former texture. There are all gradations between these two textural types.

The writers believe that clues which account for the widespread amphibolization and albitization are found in the numerous prospects and mines in northern Idaho and northwestern Montana; and in the numerous, though in places, small intrusives of quartz monzonite and closely related rocks. These intrusives are less abundantly exposed in northwestern Montana than in northern Idaho, but the scattered small stocks in Montana are probably cupolas on larger intrusives not far below the present surface. If this be granted, it is not difficult to conceive of hydrothermal solutions from these intrusives which thoroughly permeated the rocks and brought about the amphibolization and albitization of the sills and dikes. To these same solutions may be ascribed other changes in the Belt rocks of the Libby quadrangle not discussed above, namely the albitization of certain limestones in the Wallace formation, the introduction of disseminated pyrite and pyrrhotite into many different beds of otherwise slightly altered Belt strata, and the filling of many small fissures with quartz veins. Some of these phenomena are seen in rocks remote from the outcrop of any known stock. Finally, these solutions deposited the ores seen in the prospects and mines of northwestern Montana and northern Idaho.

AGE OF THE SILLS AND DIKES

No definite evidence of the age of the sills and dikes is found within the Libby quadrangle. They are all in Belt rocks. No sills were seen in rocks younger than the Wallace, but dikes cut all of the Belt strata. Similar sills in the Clark Fork region[12] and in Boundary County, Idaho,[13] are

[12] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: *Ida. Bur. of Mines and Geology, Bull.* **12,** pp. 25–26, 1930.

[13] Kirkham, V. R. D., and Ellis, E. W., Geology and Ore Deposits of Boundary County, Idaho: *Ida. Bur. of Mines and Geology, Bull.* **10,** pp. 36–38, 1926.

regarded as Algonkian and have been correlated with the Purcell sills in Canada described by Daly[14] and Schofield.[15] The sills are more numerous in these areas in northern Idaho than they are in the Libby quadrangle and farther south. Only one sill was seen in the Trout Creek quadrangle immediately south of the Libby quadrangle, and none is reported from the Coeur d'Alene district. Thus, in the areas under discussion in northern Idaho and northwestern Montana the sills appear to decrease in number and thickness from northwest to southeast.

The area is invaded by dikes of late Mesozoic (?) age, some of which are very similar in composition and appearance to the sills; and it is entirely possible that some of the sills are the same age as the dikes. However, the long sills, which appear to have been folded and faulted with the Belt rocks and to have taken part in all the orogenic movements which affected these rocks, are certainly to be correlated with similar pre-Cambrian sills in northern Idaho. Only one of the sills in the Libby quadrangle regarded as pre-Cambrian exhibited a crosscutting apophysis. This was a small dike and was traced for only a few feet. The greater part of the intrusive in question is clearly a sill.

The stocks are regarded as late Mesozoic[16] because of their proximity to very similar stocks in Idaho, regarded as late Mesozoic. The dikes belong to the same period of intrusion as the stocks. The solutions responsible for the amphibolization and other related phenomena are believed to have soaked through the region shortly after the intrusion of the stocks and dikes. However, the sills are pre-Cambrian, and it is recognized that there may have been two periods of amphibolization, the earlier of which followed the intrusion of the sills but preceded the Mesozoic intrusives.

[14] Daly, R. A., Geology of the North American Cordillera at the 49th Parallel: *Mem.* **38,** Part I, *Canada Geol. Survey, Dept. of Mines,* pp. 207–255, 1912.

[15] Schofield, S. J., Geology of Cranbrook map-area, British Columbia, *Mem.* **76,** *Canada Geol. Survey, Dept. of Mines,* pp. 56–70, 1915.

[16] Gibson, Russell, Campbell, Ian, and Jenks, W. F., *op. cit.*