A CONTACT METAMORPHIC ZONE FROM THE LITTLE BELT MOUNTAINS, MONTANA

James H. Taylor, *Harvard University.*

Contents

1. Introduction and Acknowledgments

The contact zone described in this paper is situated some 10 miles south of the town of Neihart in the Little Belt Mountains of central Montana. The material examined was collected during the summer of 1933 by Professor E. S. Larsen, Jr., from a cutting on the new White Sulphur Springs-Neihart automobile road. From Weed and Pirsson's account of the area (1)[1] it seems almost certain that the intruded limestone of the contact zone is a member of the Cambrian Barker formation while the igneous rock is probably one of the small bodies mapped as "diabase, basalt, minette, vogesite or kersantite."

The present account is limited by the material available and is not intended to be anything more than a preliminary description of an area which appears likely to repay more detailed study. The author's thanks are due to Professor Larsen for affording him the opportunity of carrying out the work and for much kind assistance and criticism. He is also indebted to Professor L. C. Graton for allowing him to have polished surfaces of opaque minerals made by his special process, and to Dr. K. C. Dunham for help in the identification of the opaque minerals.

2. The Igneous Rock and Endomorphic Contact Zone

The igneous rock is a calc-alkaline gabbro whose essential constituents are abundant pyroxene, biotite and labradorite together with serpentine and talc pseudomorphs after olivine.

[1] See list of references at end.

The pyroxene is a colourless augite occurring in rather irregular fragments. In many cases the smaller grains are disposed in typical reaction relation round the margins of the olivine pseudomorphs. The latter have the unmistakable form of olivine prisms capped by steep bipyramids, but it is rarely that any of the original mineral is left in the centre of the replacing talc and serpentine. Brown biotite is plentiful in long fibrous laths, giving a lamprophyric appearance to the rock in the hand specimen, and there are smaller amounts of a green chlorite approximating to delessite. These minerals are set in a groundmass of irregular and often somewhat cloudy plagioclase, with a composition—as determined by measurement of the indices—of $Ab_{35}An_{65}$.

Among the accessory minerals are blebs of calcite, abundant needles of apatite, commonly with a central core of inclusions, epidote, blue to colourless anatase, magnetite and pyrrhotite often partially altered to limonite.

Micrometric analysis gave the proportions of the various constituents as:

Labradorite	35.5%
Biotite	25.1
Serpentine and talc (after olivine)	19.7
Augite	13.1
Calcite	3.5
Other constituents	3.1

which according to Johannsen's new classification (2) determines the rock as a melagabbro with the symbol 3312 P.

Where the igneous rock near the contact has itself undergone metamorphism the most striking change is in the composition of the feldspar which is entirely orthoclase. Pyroxene is considerably more abundant than in the unaltered rock and biotite much scarcer. Any traces of the original olivine have completely disappeared and there has developed in considerable quantity a green, faintly pleochroic mineral with moderate birefringence and a poorly developed spheralitic structure which is referred to antigorite.

The replacement of the labradorite by orthoclase can only be regarded as due to the action of the same hydrothermal solutions that effected the metamorphism of the surrounding sediments. If we accept B. S. Butler's suggestion (3) that hydrothermal solutions are essentially controlled by the principles of Bowen's reaction series and that hydrothermal processes are in fact the logical

extension of such a series, the replacement of labradorite by ortho-
clase becomes readily explicable. According to Butler, "In the
formation of orthoclase . . . the composition of both the rock and
the altering solutions would seem to be controlling factors." If
K_2O was present in sufficient quantities, orthoclase would tend
to form; while if potash was scarce, sericite with the lower
$K_2O: Al_2O_3$ ratio would result. Apart from the normal concentration
of K_2O in the residual liquid, the abundant biotite in the unaltered
igneous rock provides a potential source. Biotite being low in the
reaction series would be one of the first minerals to react with or
dissolve in the hydrothermal solutions: and that this has actually
happened is suggested by the relative scarcity of biotite in the
endomorphic contact zone. Possibly the supply of CaO (and to a
less extent Na_2O) liberated from the plagioclase was partly re-
sponsible for the increase in the amount of pyroxene.

3. The Zone of Dark Silicates

Petrography.

The altered igneous rock of the endomorphic contact zone passes
out gradually into what Larsen (4) has called the zone of dark
silicates. In the hand specimen the rock from this zone often re-
sembles the gabbro, but its texture is very variable and in some
cases porphyritic pyroxene can be seen with the unaided eye. The
following is a list of the minerals recorded in approximate order
of abundance:

Pyroxene	Sphene	Thomsonite
Prehnite	Ripidolite	Pyrrhotite
Calcite	Sericite	Pyrite
Orthoclase	Phlogopite	Limonite
Garnet	Biotite	Magnetite
Epidote	Actinolite	Sphalerite
Gehlenite	Apatite	Chalcopyrite
Merwinite	Vesuvianite	Hematite
	Chrysotile	

The typical mineral assemblage is a pyroxene-prehnite-calcite
one (illustrated in Fig. 1). Pyroxene is generally the dominant
mineral, almost colourless except for a narrow green border, in
large hemihedral crystals up to 3 mm. in length. It is frequently
zoned and shows the strong dispersion ($r > v$), which is usually
associated with titaniferous augite—a feature which serves to dis-

tinguish it from the pyroxene of the igneous rock. Locally it is altered to a green chloritic mineral optically negative with very small 2V, almost zero birefringence and mean index 1.625[2], agreeing with the data for ripidolite. In other cases it is replaced by a fibrous uralitic hornblende.

The abundance of prehnite is one of the chief characteristics of this suite of rocks. Its optical properties are extremely variable and anomalous characteristics such as abnormal interference
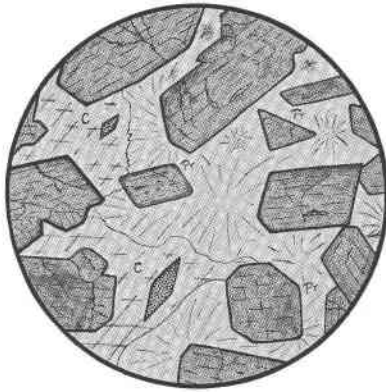

FIG. 1. Zone of dark silicates: pyroxene (stippled) and little sphene set in a groundmass of prehnite (Pr) and calcite (c).×12.

colours, incomplete extinction and lamellar twinning were commonly observed. Two specimens gave the following data:

(a)	(b)
Biaxial positive	Biaxial positive
disp. $r>v$ strong	disp. absent or very weak
$2V=40°$	$2V=65°$
$\alpha=1.627$	$\alpha=1.614$
$\beta=1.629$	$\beta=1.621$
$\gamma=1.648$	$\gamma=1.641$

Prehnite was clearly one of the latest minerals to form and occurs commonly in radiating aggregates in an interstitial relation to the pyroxene, replacing the other constituents of the rock. In some cases the replacement is complete and nothing but prehnite is left, in others orthoclase and calcite in various stages of alteration

[2] All indices quoted are ±.003.

remain. More rarely the pyroxene has also been attacked and consists of a hollow shell surrounding a radiating mass of prehnite. Less commonly thomsonite is associated with the prehnite in similar aggregates.

Some sections show a considerable amount of still unaltered feldspar, optically negative with $\beta = 1.521$ and a small optic axial angle. The habit varies from irregular masses interstitial to the pyroxene, through broad laths, to an imperfect radiating structure.

A colourless to pale brown birefracting garnet with sectorial twinning is commonly associated with the pyroxene. Optically it is biaxial positive with large 2V, varying from about 75° to nearly 90°, and dispersion $r > v$ strong. Perhaps on account of its pronounced zoning the indices are very variable: the maximum and minimum limits of β were determined as 1.784 and 1.756. Birefringence is of the order of .012.

Among the minor constituents sphene, apatite and a yellow-green epidote are conspicuous. Study of polished sections shows that a variety of ore minerals are present though never in any great quantity. They are chiefly sulphides apparently of late formation and include chalcopyrite surrounded and replaced by sphalerite, and pyrite and pyrrhotite altering to limonite. The pyrite has been most susceptible to secondary attack and is everywhere seen as cores and imbedded in banded limonite, in which thin hematite layers can be distinguished. The chalcopyrite appears to have been protected from alteration by its enveloping sphalerite. The primary minerals occur in discrete grains scattered through the rock so that the relations between them are not evident.

A distinct facies of the rock consists essentially of merwinite and melilite with small amounts of prehnite, calcite and vesuvianite: in the hand specimen it is rather lighter in colour than the typical dark silicate rock and in some ways appears intermediate between the light and dark zones. The merwinite shows the typical polysynthetic twinning, is optically positive with $\alpha = 1.710$, $\beta = 1.712$, $\gamma = 1.718$ and 2V (calculated from the indices) $= 70°$. It occurs in irregular grains set in a matrix of melilite (gehlenite) with low birefringence, negative sign and indices $\epsilon = 1.660$, $\omega = 1.665$. Locally both these minerals are cut by thin veins of merwinite with a little calcite and vesuvianite, suggesting that the latter had a relatively long period of formation, an earlier generation crystallizing before the gehlenite while a later generation succeeded it.
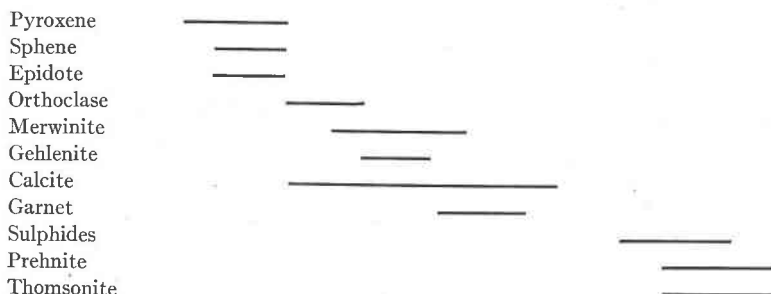
Paragenesis.

The order of deposition of the principle minerals, so far as could be determined from the sections examined is summarized in Table 1. Lack of knowledge of the exact nature of the unaltered country rock renders it impossible to judge to what extent fresh material was introduced across the contact during metamorphism. It appears, however, that two well-marked stages must be recognized:

(1) Formation of orthoclase and pyroxene by the agency of hydrothermal solutions.

(2) Replacement of orthoclase, calcite and to some extent pyroxene by prehnite with a little thomsonite.

TABLE 1. MINERAL SEQUENCE IN DARK SILICATE ZONE.

Mineral	Sequence
Pyroxene	————
Sphene	———
Epidote	———
Orthoclase	———
Merwinite	————
Gehlenite	———
Calcite	———————
Garnet	————
Sulphides	————
Prehnite	————
Thomsonite	————

4. THE ZONE OF LIGHT SILICATES

Petrography.

Specimens from this zone are much more uniform in appearance and texture than those from the zone of dark silicates and show less variety in the suite of minerals present. These minerals may be conveniently tabulated together:

Calcite	Gehlenite	Limonite
Vesuvianite	Sericite	Magnetite
Garnet	Epidote	Scawtite
Wollastonite	Pyrrhotite	Okenite?

Vesuvianite, calcite and garnet are the commonest constituents and much of the rock consists entirely of these three minerals. Frequently vesuvianite and calcite show a graphic texture, irregular angular fragments of calcite being surrounded by vesuvianite. The calcite extinguishes simultaneously over wide areas, and there seems little doubt that it has been replaced by the vesuvianite: locally it has a fibrous character. Vesuvianite and garnet are often

closely associated and, as much of the garnet is not completely isotropic, the two may be difficult to distinguish in thin section though the garnet has usually a distinctly higher index. The vesuvianite is optically positive with $\omega = 1.718$ and $\epsilon = 1.723$: the garnet has approximately $n = 1.765$ which agrees more closely with the index for hessonite than for grossularite.

Where wollastonite occurs it is in the form of irregular laths usually imbedded in and completely surrounded by vesuvianite: in some cases it has been partially replaced along the cleavages by calcite. In addition there are small amounts of a finely fibrous pale brown mineral with very low birefringence and mean index about 1.513 which is tentatively referred to okenite.

A distinctive variety of the rock is characterized by gehlenite and scawtite. The former occurs in large square or rectangular sections of weak birefringence, set in an apparently isotropic groundmass so discoloured and altered that its original composition is quite undistinguishable. The scawtite forms small laths optically positive, $\alpha = 1.603$, $\beta = 1.609$, $\gamma = 1.618$, $2V = 78°$, presumably monoclinic with $Y = b$ and $Z \wedge c = 30°$. The data thus agrees fairly satisfactorily with that recorded by Tilley (5) though the birefringence is somewhat weaker. There is no direct confirmation of Tilley's observation that it results from the alteration of gehlenite, but all the sections yielding scawtite also contained gehlenite. A thin 2 mm. dark-coloured vein cutting the gehlenite-scawtite-vesuvianite-calcite rock is illustrated in Fig. 2. On either side the vein is bordered by a solid mass of garnet some 0.2 mm. thick: the center of the vein consists of calcite, garnet, pyrrhotite altering to limonite and a light brown fibrous mineral including small laths of scawtite. The fibrous mineral would not yield any evidence as to sign or even its uniaxial or biaxial character. The individual fibres extinguish straight and have positive elongation, the mean index is approximately 1.580 and birefringence of the order of .010. Possibly it may be xonotlite but in the absence of better data, judgment is suspended and it will for the present be described as mineral x.

The junction between the zones of light and dark silicates is in many cases surprisingly sharp. In one thin section of the contact it can be seen that the large pyroxene crystals of the dark zone have been partially replaced by the vesuvianite and calcite of the light zone. The line of junction passes quite impartially through pyroxene and groundmass alike, and there can be no doubt that the dark silicates are the earlier and have been replaced by the

light. In other cases the contact is more gradual and the pyroxenes become progressively more irregular in form and more corroded round the margins as the light silicate zone is approached.

Paragenesis.

Table 2 gives the observed mineral sequence in this zone. With the exception of the oxides and sulphides of iron the minerals of this zone are almost exclusively alumino-silicates of calcium with only minor amounts of magnesium, iron, potash, etc. Again one can only speculate as to the amount of material introduced by

FIG. 2 Vein in zone of light silicates: garnet (stippled), calcite (c) and pyrrhotite (black) with ?xonotlite (x) enclosing laths of scawtite (s). ×27.

hydrothermal solutions and the general conditions at the time of formation. Merwin (6) as a result of laboratory experiments on birefracting garnets from the Kassan Peninsula, Alaska, has found that these become isotropic when heated to 800°C., and do not readily resume their original nature on cooling. Wright has put this forward as evidence of the contact deposits containing the garnet having been formed at a temperature below 800°C., but in the present state of our knowledge regarding the mineral it is doubtful if much importance can be attached to its presence.

TABLE 2. MINERAL SEQUENCE IN LIGHT SILICATE ZONE.

Gehlenite   ———
Wollastonite   ———
Scawtite   —————
Calcite   ——————————
Garnet   ————
Vesuvianite   —————
Pyrrhotite   ————
Limonite   ————

5. Comparison with Other Areas

As has been already inferred, the contact zone resembles in many essential details those described by Larsen and Hess in connection with the tungsten deposits of the United States (4). The most notable difference in the mineral assemblage of the Little Belt rocks is the abundance of prehnite. Harker (7) mentions "prehnitisation" as a common feature of hydrothermal contact zones, and figures somewhat similar rocks, in which prehnite has replaced the earlier minerals, from the Braemar district of Scotland.

The mineral scawtite has hitherto only been recorded from the contact zone at Scawt Hill, Northern Ireland (5), which has some points of resemblance to the Little Belt zone. The mineral assemblage of the latter, however, appears to be intermediate between the (high temperature) spurrite-larnite-merwinite-gehlenite assemblage of Scawt Hill and what Tilley refers to as the more normal (low temperature) diopside-wollastonite-grossular-calcite suite (8). Presumably the temperature of formation was intermediate between these two extremes.

Merwinite has been previously recorded from Scawt Hill (8), Crestmore, California (9), and Velardeña, Mexico (10). In each case it is associated with gehlenite and spurrite: the latter a mineral not so far recorded from the Little Belt but which may possibly be revealed by a further study.

6. References

1. Weed, W. H. and Pirsson, L. V., Geology of the Little Belt Mountains, Montana: *20th Ann. Rept. U.S.G.S.*, pt. **3**, 1899.
2. Johannsen, A., *Petrography*, vol. **1**, University of Chicago Press, 1931, ch. XIV.
3. Butler, B. S., Influence of the replaced rock on replacement minerals associated with ore deposits: *Econ. Geology*, vol. **xxvii**, 1932, pp. 1–24.
4. Hess, F. L. and Larsen, E. S., Contact metamorphic tungsten deposits of the United States: *U.S.G.S. Bull.* **725-D**, 1921, pp. 248–257.
5. Tilley, C. E., Scawtite, a new mineral from Scawt Hill, Co. Antrim: *Mineral. Mag.*, vol. **xxii**, 1930, pp. 222–224.
6. Wright, C. W., Geology and ore deposits of Kasaan Peninsular, Alaska: *U.S.G.S. Prof. Paper* **87**, 1915, p. 108.
7. Harker, A., *Metamorphism*, London, **1932**, p. 134.
8. Tilley, C. E., On larnite and its associated minerals from the limestone contact-zone of Scawt Hill, Co. Antrim: *Mineral. Mag.*, vol. **xxii**, 1931, pp. 77–86.
9. Larsen, E. S. and Foshag, W. F., Merwinite, a new calcium magnesium orthosilicate from Crestmore, California: *Am. Mineral.*, vol. **vi**, 1921, pp. 143–148.
10. Tilley, C. E., On a custerite-bearing contact rock from California: *Geol. Mag.*, vol. **lxv**, 1928, pp. 371–372.