DIKE CONTACT REACTION ZONE IN LIMESTONE AT GROTTO, WASH.

by

PAUL HOWARD KNOWLES

A THESIS SUBMITTED FOR THE DEGREE OF BACHELOR OF SCIENCE

UNIVERSITY OF WASHINGTON

1938

CONTENTS

DIKE CONTACT REACTION ZONE IN LIMESTONE AT GROTTO, WASHINGTON.

Preface

During the summer of 1935 a field study was made of the dikes and their resultant reaction rims with limestone in the quarry of the Northwest Portland Cement Company, located at Grotto, Washington. Thin sections were made and subsequent investigations were accomplished in the Geology Laboratories of the University of Washington.

Attention was originally focused upon these numerous dikes because of the difficulty which they introduced in the grinding processes in the making of cement from the limestone. The machinery was adapted mainly for crushing the relatively softer limestone, and the grinding of the harder rock of the dike had to be accomplished at the same time. However, the economic aspects of this problem will not be undertaken in this paper, other than that the information gained herein may help in its potential solution, or to further geological investigations of the deposit or nearby deposits.

This article will endeavor to give a complete petrographic description of the dike, the limestone, and the related reaction rim with special emphasis on the minerals produced and their paragenesis.

The writer is deeply indebted to the Superintendent of the Northwest Portland Cement Company at Grotto for his permission to have access to the quarry; to the quarry Foreman for his guidance and assistance at the quarry; to the Chemist at the Grotto plant for the chemical analysis of the limestone; to

Prof. George E. Goodspeed, Professor of Geology at the University of Washington, for his criticism and suggestions; to Doctor Howard Coombs, Associate Professor of Geology at the University of Washington, for his assistance with the photographic work; and to Mr. C. W. T. Hollister of the Northwest Portland Cement Company for the map of the area in the vicinity of the quarry.

GEOGRAPHIC AND PHYSIOGRAPHIC FEATURES

The Skykomish Basin is located along the North and South Forks of the Skykomish River on the west side of the Cascade Mountains northwest of Seattle, Washington.

The North and South Forks of the Skykomish River, which have their junction about a mile below Index, comprise the main drainage of this region. This drainage is apparently intimately connected with Pleistocene Glaciation, the history of which yet remains to be developed. The topography is everywhere rugged, as a result of glacial action, and adolescent stream erosion. The peaks in the immediate region average 5500' in elevation; Grotto Mountain is 5333', Spire Mountain is 6065', and Crosby Mountain is 5533'.

The area is easily reached by an excellent paved highway, a distance of 85 miles from Seattle to Grotto (See Vicinity map, page 3). The Great Northern Railroad also has its main Eastern Line running through the valley of the South Fork of the Skykomish River. The Northwest Portland Cement Company has its cement plant located at Grotto, and a well kept trail

VICINITY MAP

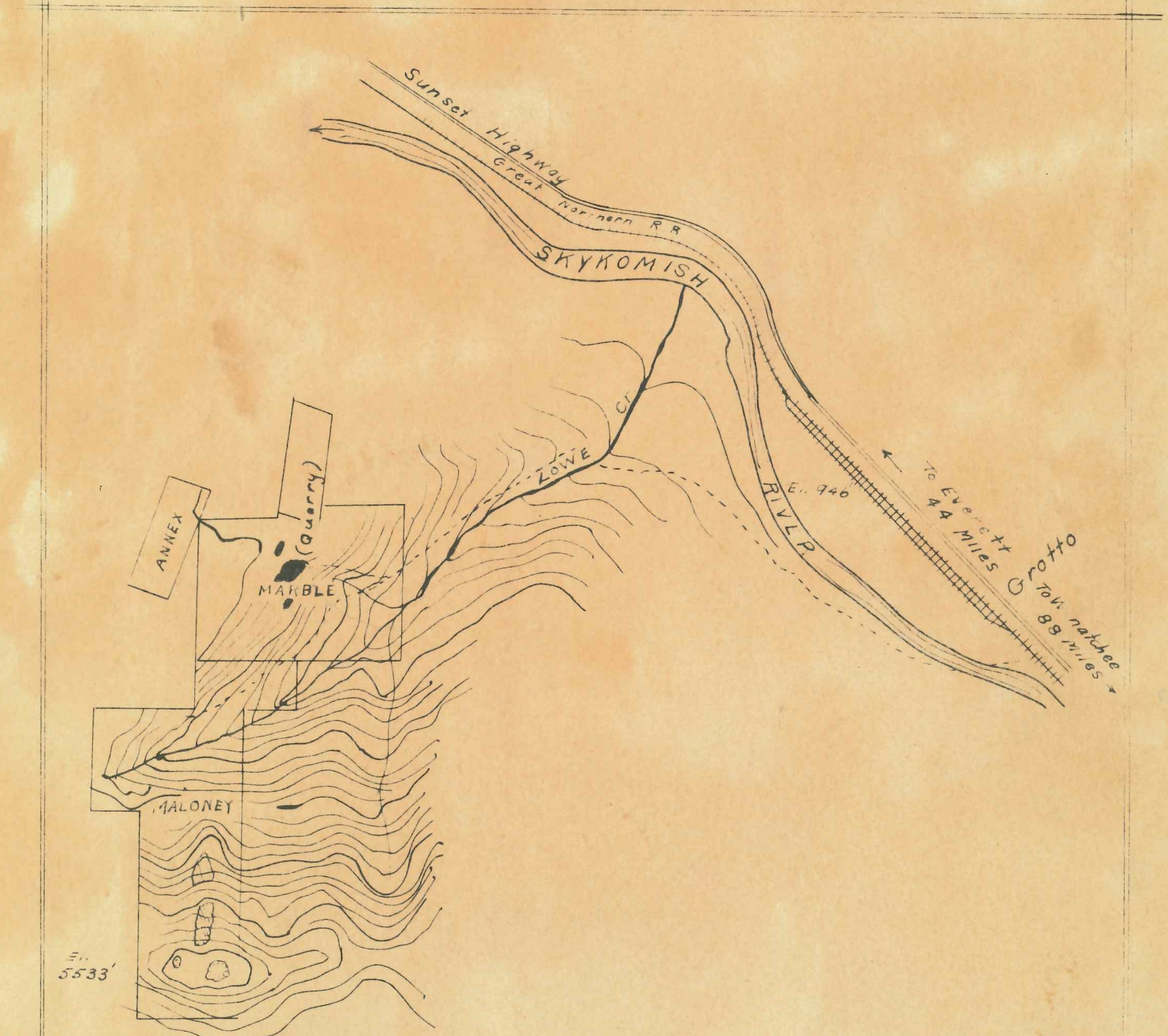


Figure 1

extends from their plant for three miles to the quarry, which is located on the Southeast side of Palmer Mountain above Lowe Creek, a tributary of the South Fork of the Skykomish River. The limestone is quarried by open face methods on the side of the mountain, and the mined material then transported to the Grotto cement plant by an aerial tram. All favorable outcrops of the limestone have either been staked out or acquired by the Northwest Portland Cement Company with a view towards prolonging their industry. These activities portray a growing concern, and represents the largest cement industry on the west side of the Cascades. No month passes without some form of Precipitation, but in the winter the snowfall is very heavy, and as a result quarrying operations are confined to the late spring, summer, and early fall months.

GENERAL GEOLOGY

Stratigraphically this region is divided into two groups: 1. Pre-Tertiary and 2. Tertiary, which are divided by a great unconformity.

According to W.S. Smith the geological history of the Skykomish area can be traced to the Ordovician Period in which marine limestone occurs along with a series of quartzites, schists, and associated greenstones. The remainder of Paleozoic and entire Triassic is completely missing. In the Jurassic, however deep-seated volcanic activity occured resulting the intrusion of the great Sierra Nevada-Cascade granodiorite batholith of which the Index Batholith is the local representative. The Cretaceous is absent. Following the Mesozoic intrusions came a positive orogenic movement, corresponding to the Laramie Revolution, resulting in the elevation of the Cascades high above sea level.

Continental deposition opened the Tertiary in which the Swauk Sandstone was deposited unconformably on the eroded edges of the earlier metamorphic rocks. Miocene andesite tuff beds succeed the Guye formation of the late Eocene and Oligocene of which there is no definite information. These beds are volcanic tuff ejectimenta cut by dikes and sheet-like intrusions of andesitic composition. The immediate source of these tuffs has as yet been unexplained, but their chemical resemblance to the Miocene granodiorite suggests forcibly that they have a common origin. In later Miocene a recurrence of deep-seated vulcanism occured resulting in the invasion of the Snoqualmie Granodiorite, the location of which is immediately to the south of the Skykomish area. In latest Miocene and early Pliocene the region was planned to a low relief; followed by a disturbance of isostatic equilibrium which resulted in the arching up of the area to a probable maximum height of 8000 feet. Since this uplift, canyons some of which are 5000 feet deep have been cut in the granodiorite; a fact bearing witness to the severity of erosion. The results of the vigorous erosion of the Pleistocene valley glaciers are seen today and the topography has remained about the same. The only discernable Post-Tertiary history is recorded in a thin layer of volcanic ash which probably drifted from Mt. Rainier by the prevailing southwest winds[1].

1. W. S. Smith, Stratigraphy of the Skykomish Basin, Wash., Jour. Geol. No. 24, (1916).

FIELD RELATIONS OF THE DIKE AND LIMESTONE

The coarsely recrystallized limestone in the vicinity of Grotto occurs probably as residual erosion remnants, with the best outcrops at the quarry and on top of Crosby Mountain, directly to the south of the quarry about one mile. No fossils have ever been found in either of these outcrops, however another outcrop in the same vicinity was dated Ordovician by evidence of fossils obtained from a cherty phase of the limestone[2]. Cutting the limestone in general high angle dips are a large number of basaltic dikes varying from mere stringers to a width of five feet. The dikes started in an original fissure and developed by replacement of the limestone a reaction zone composed of an array of contact metamorphic minerals[3]. This original fissure nature and subsequent replacement of the limestone relationship is generalized in Fig. 3 page 8 in which a former dike is intersected and offset by the present dike. This offset is seen to bear a direct dependence upon the actual width of the present dike rather than on the total width of the dike and the reaction zone. Also note in the sketch that the reaction zone diminishes at the intersection of the two dikes.

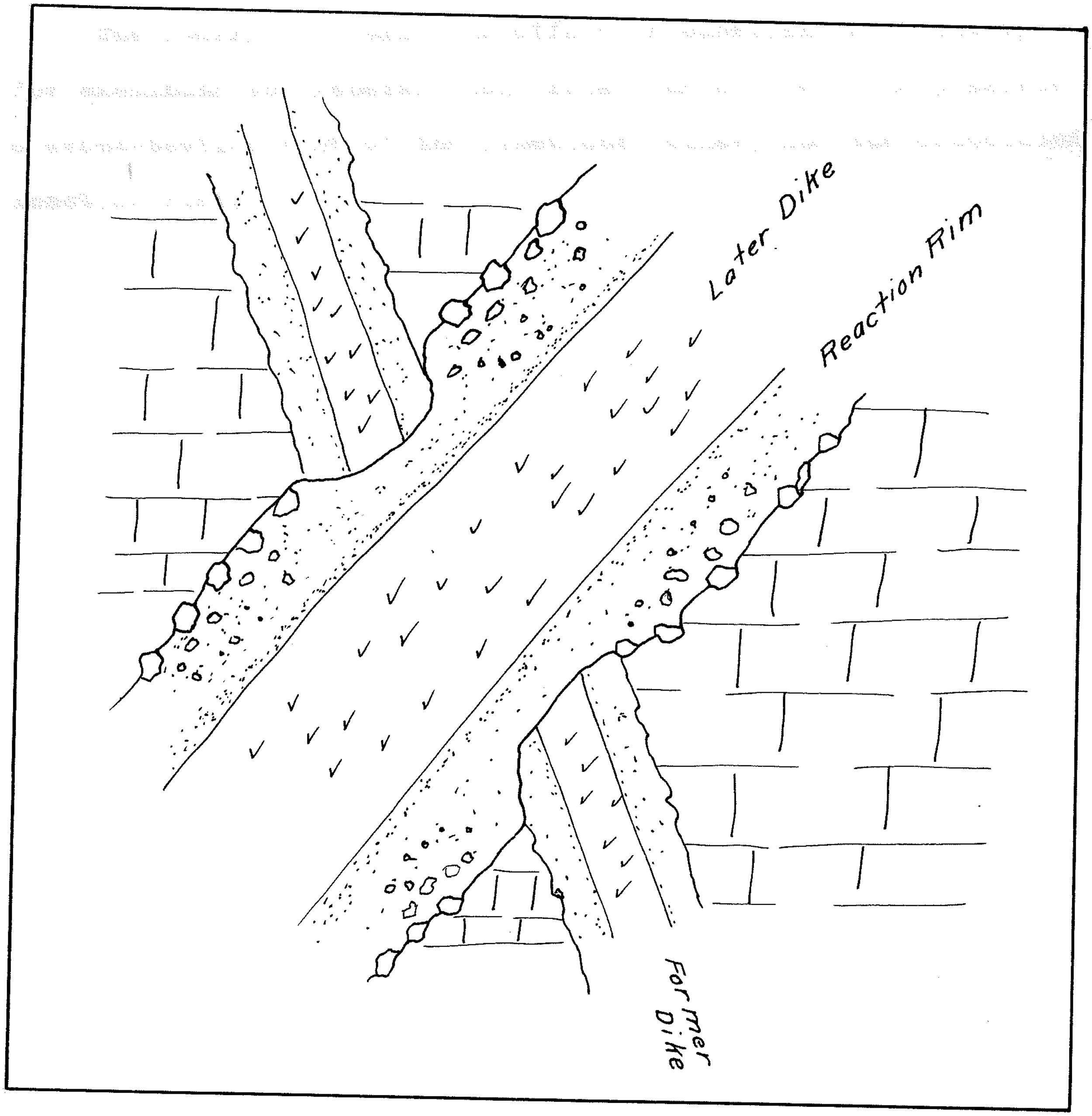
The width of the reaction zone is directly proportional to the variable width of the dike: a normal five inch dike would have a reaction area of about two inches on both sides of the dike. The garnet crystals which are ever-present in the contact area are more highly developed when associated with

2. W. S. Smith, op. cit.

3. Figure 2, Page 7.

Photograph of a hand specimen showing the dike (lower) and the reaction zone (upper). Note development of garnets.

Fig. 2



Sketch showing intersection of two dikes and subsequent offset.

Figure 3

the larger dikes. This is to be expected as there would be more intense metamorphic action if the dike were larger.

The quarrying operations afford an excellent opportunity for examining the general field relations as they make possible a cross-section view of the limestone, dikes, and the associated reaction rims.

PETROGRAPHY

THE BASALTIC DIKE

Megascopically the dikes are a grayish-green hard aphanatic basaltic appearing rock with very small porphyritic feldspar crystals visible. There is no visible alteration due to weathering on the specimens as they were taken well within the central part of the quarry. Although intrusive, the dike must be classed as volcanic as the rock is truly aphanatic and the only discernable crystals are the above mentioned porphyritic ones which are on a small scale. A narrow band of chilled selvage is apparent between the reaction zone and the dike itself.

Microscopically the dike shows a fine grained pilitic texture (See Figures 4 and 5, Page 13) with no hydrothermal alteration, although some deuteric effects are noted, which will be discussed later. The porphyritic crystals range from 1.40 mm. to 0.15 mm. in diameter. The groundmass which occupies, by far, the largest area consists of an intimate mixture of cryptocrystalline and microcrystalline material. The microcrystalline crystals can be determined mainly as feldspars and augite, and as the cryptocrystalline material has the same general appearance it is quite probably an incipient phase of feldspar and augite.

The major minerals present are excellent euhedral phenocrysts of bytownite, subhedral to anhedral augite ranking second, and rounded quartz anhedra ranking third. Orthoclase, magnetite, pyrite, biotite, and hornblende are also present as minor constituents. The plagioclase often shows well developed progressive zoning with a continual gradation outward from the calcic to the sodic phase. Although the outer bands due to their narrowness may superficially appear to consist of a smaller amount of material, in reality, after a close study are found to contain about the same amount as the inner bands. The outer bands are quite clear but the inner core contains many inclusions. The plagioclase crystals range from 1.40 mm. in length to 0.40 mm. in length with the average being about 1.00 mm.

Associated with the plagioclase are glomeroporphyrictic (See Figure 4, Page 13) aggregates of anhedral augite. This augite-plagioclase relationship, which is limited to the larger crystals of augite, is a common occurrence according to Tyrrell[4]. A very small amount of hornblende is present always associated with the augite.

Anhedral quartz is ever-present as irregular blebs either diseminated or adjacent to the glomeroporphyritic aggregates (Figure 5, Page 14). The crystals of quartz are very clear and exhibit the common wavy extinction.

Anhedral magnetite is scattered sparsely throughout the rock, and with a few exceptions is adjacent to the augite. Pyrite occurs independent of any relationship with any of the other constituents. Biotite also has a limited appearance in short to long irregular blades. The Paragenesis of the minerals is as follows: Plagioclase, orthoclase and augite formed early and centemporaneous with augite extending beyond the time limit of the formation of the plagioclase; the next

---

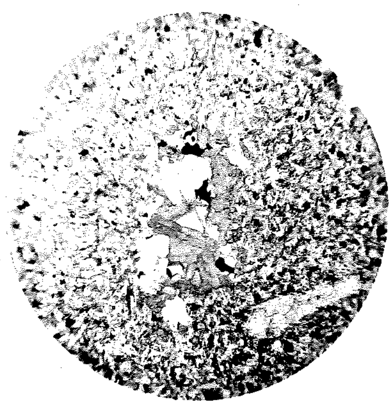
4. G. W. Tyrrell, Prin. of Geology, p. 95, (1926)

mineral to form is quartz which occurs as fillings in the inter-spaces (See Figure 5, Page 14) between the plagioclase and augite; the last minerals to form are hornblende, magnetite and pyrite. A small amount of seritization has occured with the formation of minute plates of muscovite, but the proof of its paragenesis is poor although it probably occured during the formation of the plagioclase as some muscovite can be seen within a few cores of zoned plagioclase which, however, is an exception.

From the foregoing data combined with the chemical and mineral analysis (Page 15) this dike is classified as a Quartz-Bearing Porphyritic Basalt Dike.

Photomicrograph showing glomeroporphyritic aggregates. Note pilitic texture of the groundmass of the dike.

Figure 4



Photomicrograph of the dike showing anhedral quartz filling interspaces. Note irregular particles of magnetite.

Figure 5

MINERAL PERCENTAGE OF THE DIKE:

Plagioclase	8.0 %
Orthoclase, Microcline	2.5
Quartz	1.0
Augite	7.0
Magnetite, Muscovite, Pyrite, Biotite, Hornblende	1.5
Groundmass	80.0
Total:	100.0 %

CHEMICAL PERCENTAGE OF THE DIKE: (Analysis by author).

SiO_2	56.80 %
Al_2O_3	13.30
Fe_2O_3	12.15
MgO	3.98
CaO	4.21
$Na_2O + K_2O$	4.20
Total:	94.64 %

THE LIMESTONE

The limestone has been uniformally dynamically metamorphosed to a fairly high degree. The entire mass is very coarsely recrystallized with all evidence of any possible fossils having been destroyed in the process. The faces of some of the larger crystals are nearly 2 cm. across, but the average is about 1 cm. Chemically the limestone is nearly pure $CaCO_3$ with varying amounts of magnesium irregularily distributed. Dark exotic coloring which occasionally occurs within the calcite is probably ferriginous and carbonaceous impurities.

Microscopically the calcite crystals show quite distinctly the three directions of cleavage, high birefringence, and a mosaic pattern. No visible minerals are present other than calcite; this readily agrees with the chemical analysis below. The impurities are too much in the minority to assert themselves in determinable crystal form, although some are probably present in cryptocrystalline form. The magnesium is too sparse and too unevenly distributed to even enroach upon the classification of a dolomite; although in small areas where a concentration of magnesium has been effected a hand specimen might be termed a dolomite.

Following is a chemical analysis of the average variety of limestone found in the quarry[5]:

---

5. Northwest Portland Cement Co's Chemist, Grotto, Wash.

SiO_2	0.18 %
Al_2O_3	0.24
Fe_2O_3	0.20
CaO	56.30
CO_2	42.15
MgO	0.63
Total:	99.70 %

Following is an analysis of a sample of the limestone with a fairly high percentage of magnesium[6]; this rock which this sample represents is much smaller in quantity than the above mentioned sample:

SiO_2	0.54 %
Fe_2O_3	0.28
Al_2O_3	0.38
CaO	43.35
MgO	15.00
CO_2	40.10
Total:	99.65 %

No difference in the size or crystal form either megascopically or microscopically could be observed in the rock with the higher percentage of magnesium as compared to the average limestone at the quarry; the only visible difference was that the material containing the higher percentage of magnesium had a slight blue color as compared to the lighter color of the average limestone. This difference can be noted megascopically.

6. Northwest Portland Cement Co's. Chemist, Grotto, Wash.

THE REACTION RIM

The reaction rim which formed as the result of the contact of the hot basalt being injected into the limestone occurs symmetrically on both sides of the dike. The porphyroblastic minerals and structures, both megascopic and microscopic, along with the adjacent rocks classify it definitely as a contact metamorphic zone of comparatively high temperatures. The contacts are quite definite and this criterea combined with the illustration on Page 8 presents evidence to the assumption that the dike started as a true injection with contact metamorphic minerals developed as a result of replacement.

Immediately adjacent to the dike the reaction zone begins having a brownish fine-grained maculose structure which grades into a granulose texture extending to the limestone contact. A description of this reaction zone naturally falls into three sub-zones which are determined by the megascopic size of the metacrysts and general appearance.

Inner Zone

The Inner Zone begins immediately at the contact of the dike and the subsequent reaction and is characterized megascopically by its very fine grained texture.

Microscopically the rock is a fine grained recrystallized area with the ground mass showing as an irregular mass of isotropic material which appears to be a combination of an incipient phase of the porphyroblasts and possibly deuteric alteration. This isotropic mass is particularily intense in a very narrow band just at the contact of the dike rock; this band probably represents a chilled phase and resulting tachylyte. Determinable minerals present are a few small anhedral crystals of tremolite and rounded blebs of anhedral clinozoisite, with the incipient phase of the garnetization clearly visible. The garnetization appears as an irregular mass of isotropic material, but under plain light it is easily recognizable as garnet due to its high index of refraction.

Intermediate Zone

With a gradual change the Inner Zone grades into the Intermediate Zone wherein the incipient nature of the garnetization becomes less predominant and these is a tendency of the material to assume crystal form. The visible crystals are more numerous and uniform in size: the average being about one tenth of a millimeter in diameter. A few subhedral garnets are seen however in general the tremolite and clinozoisite are still anhedral.

It is here, in the center of the reaction zone as a whole, that the loss of the maculose texture is observed with the gradual appearance of the granulose texture although the complete granulose texture is not fully achieved until the last zone is reached. This change can be noted both megascopically and microscopically.

Outer Zone

It is in this last zone wherein the garnets as porphyblasts assume their greatest beauty and form (Figure 6, Page 21). Some of the larger garnets are as large as two centimeters in diameter, but the average are about one half to one centimeter. The majority are perfect euhedral dodecahedral crystals. Megascopically the zone presents a more clearer brown color than the two preseding zones, as a result of the more complete crystallization of the contact minerals.

The garnets as determined by the microscope and blowpipe metnods are grossularite and andradite with the former predominating. In many instances the garnets show zonal structure with grossularite forming the core and andradite a narrow surrounding band. The grossularite is readily distinguished from the andradite by the slightly lower refringence. The most peculiar and persistant character of the grossularite is the anisotropic effect which after being once recongized was used for further determination of the mineral. This anisotropic effect is a characteristic limited to a variety of grossularite called pyreneite according to Winchell [7]. Other minerals in this outer zone are anhedral to subhedral tremolite, clinozoisite, and wollastonite. The tremolite and clinozoisite crystals are larger and more numerous than in the two previous zones, while the wollastonite is a newcomer in the present array of minerals. Small irregular

7. N. H. and A. N. Winchell, Elements of Optical Mineralogy, p. 242 (1909).

Photomicrograph of the outer zone of the reaction rim showing euhedral garnets. (Low power, crossed nicols)

Figure 6

inclusions of limestone are visible within a number of the metacrysts, especially in the garnets, thus illusrtating the replacement nature of the reaction.

Small specks of pyrite[8] are present, evidently representing the emanations connected with the last stages in the cooling processes of the basaltic dike. This pyrite is located at or near the contact of the reaction zone and the limestone, and is present only as small specks and not as stringers.

Microscopically this entire outer zone presents a mosiac pattern of distinctly metamorphic porphyroblasts of the contact type.

Following is a mineral percentage of the outer zone of the reaction rim:

Grossularite	-----	65 %
Andradite	-----	15
Tremolite	-----	4
Wollastonite	-----	4
Clinozoisite	-----	2
Pyrite	-----	±
L. S. (inclusions)-		±
Total:		100 %

The paragenesis of the metamorphic minerals in the entire reaction zone is as follows: grossularite formed first and andradite second in isolated areas, followed by tremolite and

8. The author assayed this pyrite material for gold and silver, but it was found to be barren of such elements.

then wollastonite. The paragenesis of the clinozoisite could not be readily determined, but it was probably intermediate in the order of formation, as it is anhedral to subhedral in form.

DISCUSSION

Petrogenesis Within the Dike

This quartz bearing porphyritic basalt dike conforms to Bowen's Reaction Principle[9] in petrogenesis, as both continuous and discontinuous series of minerals are in evidence.

Although the dike is classed as a basic type, olivine is decidedly absent. The answer to this is found in the presence of free quartz which is usually prohibitive to the formation of olivine. Instead the next mineral in Bowen's Reaction Series was formed, namely, the calcium-magnesium pyroxene, augite, which is present on a relatively large scale. Following this idea one step further and upon inspection of the thin section, minute beginnings of crystals of hornblende can be found, always adjacent to the mineral augite.

The zoning of the plagioclase is the next important example of Bowen's Reaction Series. In this case it is a plagioclase continuous series as contrasted to the augite-hornblende discontinuous series. In the original melt the calcic phase crystallized first and became the core around which the more sodic plagioclase continued to form. The melt finally solidifying when bytownite crystallized. It is to be here noted that the zoning from about Ab_4An_6 to Ab_2An_8 was progressive and not oscillating.

---

9. N. L. Bowen, The Reaction Relation in Petrogenesis, Jour. Geol., 30, (1922), pps. 177-198.

Fenner in his "Law of Mass Action"[10] gives an excellent reason for the cause of the above mentioned reactions: "If we imagine that in a solution of this nature in which equilibrium has been attained crystallization begins, it is seen that a disturbing factor is introduced; for the removal by crystallization of one or more compounds is constantly changing the relative proportions of the substances left in the mother-liquor which may have been present in small amounts in the original magma may reach a high degree of concentration in the residual dregs of the mother-liquor. As a result crystals first deposited become unstable and new reactions occur."

---

10. C. N. Fenner, "The Crystallization of a Basaltic Magma from the Standpoint of Physical Chemistry", Am. Jour. of Sci., 29 (1910).

The Metamorphic Minerals

The garnets in the reaction zone are the most predominant of the resultant metamorphic minerals and there are a number of phenomena connected with them that are worthy of discussion. The first thing that one notices upon examining the thin-section is that the garnets are not isotropic as usual, but on the contrary are anisotropic in character. There are a variety of opinions regarding the cause of an anisotropic garnet. Winchell[11] states that it is a variety of grossularite called pyreneite, and thus the anisotropic character is within the crystal make-up. Klein[12] attributes this characteristic to strain within the crystal rather than to the crystal itself. Mallard[13] agrees with Winchell in placing the emphasis for this phenomenum upon the crystal form, and gives an excellent reason for his belief. Mallard states: "Inherently the mineral is really orthorhombic with the external form due to twinning; the twinned unit being pyramids whose vertices meet at the center and whose bases form the external surface". In the case of the present mineral in question, I am inclined to agree with Mallard and Winchell in placing the anisotropic effects due to the internal crystal structure, because the extinction is quite definite and not wavy as would probably be in the case of strain within the crystal, such as is seen in many quartz crystals.

---

11. N. H. and A. N. Winchell, Elements of Optical Mineralogy, p. 242 (1909)
12. Ibend, pps 241-242.
13. Ibend, pps 241-242.

The next important feature noticeable in connection with the garnets is their zoning which, although, is not present in every garnet is nevertheless not rare. Whenever the zoning did occur, the central core was always grossularite with a narrow band of andradite on the periphery. I believe that the answer to this zoning lies in comparing the chemical composition of the dike with the chemical composition of the two types of garnets represented. There was evidently the right proportion of Fe_2O_3 and Al_2O_3 present in the dike so that when metamorphism and replacement occured with the limestone a predominance of grossularite was formed. In the formation of grossularite, whose composition is $Ca_3Al_2Si_3O_{12}$, depletion of Al_2O_3 occured leaving a concentration of Fe_2O_3, and whenever this concentration took place andradite formed, the chemical composition of which is $Ca_3Fe_2SiO_3O_{12}$; thus resulting in a zoned area. This procedure took place only in favored places and as a result the formation of andradite with consequently zoning was not general throughout the reaction area.

W. L. Uglow[14] has through investigations presented a series of lime-silicate minerals which he calls "true contact minerals". He lists the following minerals as such: Grossularite, Andradite, Epidote, Diopside, Tremolite, Actinolite, Wollastonite, Biotite, Calcite, and Quartz. It is to be noted that by comparison to this list, the mineral assemblage of the present reaction zone can all be classified as true contact minerals, and consequently the zone as contact metamorphic.

---

14. Ec. Geol. Vol. 84 (9), pps. 19 and 215-230, (1913).

TEMPERATURE OF THE REACTION AND METAMORPHIC RELATIONS

Pentti Eskola[15] has written and excellent discussion on the temperature of contact phenomena which is comparable to the present problem. He bases his geologic thermometer upon the general contact reaction:

$$RCO_3 + SiO_2 \rightarrow RSiO_3 + CO_2$$

as connected with V. M. Goldschmidt's Pressure - Temperature diagram.[16]

Eskola states: " ----- This assumption (Goldschmidt's diagram) has been very strongly supported by petrological investigations which I have carried out in the pre-cambrian limestone of Finland. In the southeastern part of the pre-cambrain area of Fennoscandia there are extensive formations all of whose character point toward metamorphism at low temperature. In the limestone of this area quartz occurs together with dolomite and fine scaly micaceous minerals (biotites rich in magnesia) are usually the only silicates. Sometimes epidote occurs, a fact indicating that this hydrated calcium aluminum silicate also belongs to the low temperature minerals.

Northwest of this low temperature area there is a broad zone within which the limestone contains, besides mica, amphiboles of the tremolite-actinolite series, but no other silicates. Going further northwest diopside-hedenbergite is added to the list of minerals of the metamorphic limestone, together with many others,

---

15. Gneiss and Limestone Contact Phenomena, J. of Geol., Vol. 30, pps. 265-294, (1922)

16. Die Gesetze der Gesteinsmetamorphose, Vid. selsk. Skr., Mat-naturv. Kl., No. 22 (1912).

such as scapolite, vesuvianite, and grossularite and andradite. Finally we find, as local developments near the contacts of the igneous masses, but never in regional distribution, wollastonite limestone and in this most of the other silicates may occur also. This mode of occurrence clearly indicates that wollastonite, among the lime-bearing silicates, requires the highest temperature to form.

We may thus discriminate the following paragenetic types of limestone:

1. Quartz Limestone, in which quartz is coexistent with the dolomite.
2. Tremolite Limestone. Tremolite is usually present; quartz occurs in calcite rock, but is not coexistent with dolomite.
3. Diopside Limestone. Diopside usually present, quartz occurs together with calcite but not with dolomite.
4. Wollastonite Limestone. Wollastonite is present provided the rock contains silica in excess of the amount needed to form the magnesium bearing silicates. Quartz and calcite do not occur in contact with each other."

Morey and Ingerson[17] have also recently compiled many noteworthy contributions to the determination of the temperature of formation of various minerals. From this data it is shown that Wollastonite could be produced at a maximum temperature of 425°

---

17. Morey and Ingerson, The Pneumatolytic and Hydrothermal Alteration and Synthesis of Silicates, pps. 750-760, Ec. Geol, No. 5, Aug. 1937.

and a minimum temperatue of 210°; and that tremolite could be produced at a minimum temperature of 400°; and that garnet was produced at a red heat. All experiments were in a wet system.

The reaction being discussed in the present paper certainly falls into the catagory of high temperature metamorphism when based upon Pentti Eskola's investigations. Quartz and limestone do not occur together in anyplace whatsoever, as well as the decided absence of any micaceous minerals. Tremolite does occur but only in a very small proportion. The presence of the large amounts of grossularite, andradite, and especially wollastonite clearly proves that the reaction must fall into Eskola's last two classifications, namely, high temperature; at least in the early stages of the contact action.

The work of Morey and Ingerson does not contradict the above statement after one studies carefully the paragenesis of the reaction minerals. Thus garnets which need the highest temperature of formation, crystallized first when the pyrometasomatic effects of the dike were the greatest. Upon the dropping of the temperature the wollastonite formed, followed by tremolite.

CONCLUSION

As there are several areas showing outcroppings of limestone with similar dike injections in the near vicinity of the deposit under discussion in the present paper, the problem may arise in which correlation of the deposits may be desired. Due to the absence of fossils, correlation must be accomplished by other means, namely, structural methods, by a comparison of the chemical analysis of the limestones, and by comparison of the reactions of the similar intrusions into the limestone. It is with the last statement in mind that the author stressed such itemps as petrographic and chemical analysis of the dike, temperature at time of injection , the intensity of contact metamorphism, and the resultant contact minerals.

BIBLIOGRAPHY

Bain, G. W. , Contact Metamorphism and Related Changes in Composition, Vermont State Geologist, 15th Rept. (1926)

Bowen, N. L., 1. Evolution of Igneous Rocks, Jour. Geol., Vol30 (1922)

2. The Reaction Relation in Petrogenesis, Jour. Geol., Vol 30, (1922).

Eskola, Pentti, Gneiss and Limestone Contact Phenomena, Jour. Geol., Vol 30, (1922)

Fenner, C. N., 1. The Crystallization of a Basaltic Magma from the Standpoint of Physical Chemistry., Am. Jour. Sci. Vol 29, (1910).

2. Stability Relations of Silicate Minerals., Am. Jour. Sci. Vol. 36, (1913).

Trueman, J. D., The Value of Certain Criteria For the Determination of the Origin of Foliated Crystalline Rocks., Jour. Geol., Vol 20, (1912).

Goldschmidt, V. M., DieGesetze der Gesteinsmetamorphose, Vid. selsk. Skr., Mat-naturv. Kl., No. 22 (1912).

Hunt, T. S., On Some Crystalline Limestone of North America., Am. Jour. Sci.,(2) 18, (1854)

Lindgren, W., 1. Contact Metamorphism at Bingham, Utah., Geol Soc. Am., Vol 35 No. 3 (1924).

2. The Nature of Replacement., Econ. Geol. Vol 7 (1912)

3. Volume Changes in Metapmorphism., Jour. Geol. Vol. 26, (1917).

4. The Origin of the Garnet Zones., Econ. Geol. Vol. 9, (1914).

Morey and Ingerson, The Pneumatolytic and Hydrothermal Alteration and Synthesis of Silicates, Econ. Geol., No. 5 Aug. 1937.

Myers, W. M. , Mineralogy of some Commercial Garnets., Am. Jour. Sci., 5th Ser. Vol 12, (1926).

Russell, I. C., Geology of the Cascade Mountains in Northern Washington. (20th Annual Report), U.S.G.S. Part 2 (1899).

Shedd, Solen, Coke and Limestone of Washington., Wash. Geol. Survey Bull No. 27, (1922).

Smith, W. S., 1. Stratigraphy of the Skykomish Basin, Wash., Jour. Geol. Vo, 24 (1916).

2. Physiography of the Skykomish Basin., N. Y. Ac. Sci. An. 37, (1917).

3. Petrology and Economic Geology of the Skykomish Basin, Wash., Wash. Sch. Mines Q. 36, (1915).

Tyrrell, G. W., Principles of Geology., (Dutton and Co.) (1926).

Uglow, W. L., A Review of the Existing Hypothesis on the Origin of the Secondary Silicates Zones at the Contacts of Intrusives with Limestone. Econ. Geol., Vol 84, (1913).

Van Hise C. R., Metamorphism, Mon. 47, U.S.G.S. (1904).

Winchell, N. H. and A. N., Elements of Optical Mineralogy., (1909).