Contact Metamorphism in the Highlands

Frank Trask Jr.

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CONTACT METAMORPHISM IN THE HIGHLANDS

by

FARRA TRASK, JR.

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA

May 4, 1926
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INTRODUCTION

On the southern margin of the Boulder Batholith about twenty miles south of Butte in the Highland Mountains there are many miles of contact between the igneous and sedimentary rocks. As two kinds of igneous rocks and many different kinds of sedimentary rock are present it is an excellent place for the study of contact metamorphism. This thesis will present the common views held on contact metamorphism by the leading authorities, and will describe the facts observed in the Highlands and their relation to the common views.

FIELD WORK

The field work was done in August and September of 1935. It consisted of collecting specimens of the unaltered sedimentary rock, fresh igneous rock, and as many specimens of the contact rock as was thought advisable. The width of the contact areas, and the different zones of metamorphism were noted. It was not possible to determine an exact width for many zones because the batholith extends under the sediments at different depths, and the whole roof has been more or less affected.

THE PROCESSES OF CONTACT METAMORPHISM

When a body of molten igneous material comes in contact with the pre-existing rocks the rocks are commonly
altered or metamorphosed. These changes may be brought about by several agencies; heat, pressure, pneumatolitic and hydrothermal action, and assimilation are important. In the past it has been rather common for some geologists to assign all contact metamorphism to one or the other of the processes mentioned but it is believed at present that all have their affects and that a combination of all brought about the changes that we observe.

By heat alone it is possible to form new minerals from their constituents. For example if limestone and quartz are fused together to form a glass that has a composition of CaSiO₃, and that glass is heated to 800 degrees Centigrade, wollastonite will be formed. A logical natural comparison to this process is the formation of wollastonite from beds of arenaceous limestone. However a difficulty is immediately encountered as the heating would cause carbon dioxide to be driven off and thus result in a shrinkage in volume. As no shrinkage of such beds has been proven to the satisfaction of a majority of workers in the field it seems imperative that some material must have been added from the outside to take the place of the carbon dioxide. The temperature attained is also very important. The lavas in Hawaii have been observed to flow at temperatures as low as 600 degrees Centigrade and to have reached a temperature of 1200 degrees Centigrade. Acidic magmas are believed to begin crystallizing at about 800 degrees Centigrade and continue to about 400 degrees Centigrade. These temperatures would not greatly affect a limestone as the carbon dioxide pressure necessary
to halt the calcining of calcium carbonate at 879 degrees Centigrade is only one atmosphere. From this line of argument it follows that heat alone may hasten a process or cause physical changes such as size of grains but that it cannot bring about all the chemical changes observed in contact metamorphism.

Pressure alone causes rock to flow as though it were a viscous solid and also brings about changes in mineralogy. These changes uniformly trend toward minerals of higher specific gravity than the parent material and are of considerable consequence in deeply buried rocks. But of the material studied none was deeply buried at the time of metamorphism and the pressure exerted by the intruding magma was probably small so that pressure did not have any salient effect on the changes.

The passage of solids in solution in fluids from the magma into the surrounding rocks is undoubtedly of great importance. When the fluid is a gas the process is known as pneumatolitic and when it is water the process is known as hydrothermal. These processes will supply practically all that is necessary to bring about the changes believed to result from contact metamorphism and are probably dominate. The source of the fluid is the magma which has much dissolved gas and water. That water is an important constituent of magmas has been proven from analysis of the emanations of volcanoes. Above the critical temperature and pressure for water (365 degrees Centigrade and 200 atmospheres pressure) the action must be pneumatolitic. Below the critical point it may be either pneumatolitic or hydrothermal. The only
prerequisite for these processes is that some kind of channel be provided for their passage. Interstices in the rock, incipient cracks or well defined fractures may all serve as passage ways.

It may be postulated that in the magma the liquid or gas takes various substances such as silica and alumina into solution and then makes its way toward the borders as the magma cools. When they come in contact with material that will react with the dissolved matter the solution loses the solute and a new mineral or minerals is formed. If the reaction causes a loss of some gaseous constituent of the host rock, its space will be taken up by the introduced substance.

It is seen then that introduction of solutions derived from magmas satisfy practically all conditions necessary in the formation of a contact zone. Briefly they supply foreign materials to be used in making new minerals, transport those materials and furnish some of the heat necessary to bring about the changes.

**GENERAL STATEMENT ON THE HIGHLANDS**

The sedimentary rocks in the Highlands range from pre-Cambrian to Mesozoic in age, and are composed of quartzites, argillites, shales, and limestones. The argillites and quartzites of the Belt Series (pre-Cambrian) had been metamorphosed by dynamic processes prior to the intrusion. The shales, limestones and quartzites of Paleozoic age had been moderately indurated and folded, but not markedly metamor-
Figure 1. Photomicrograph showing calcite twins in thin section. Polarized light.
phased before intrusion.

The main mass of the igneous rock is quartz monzonite of early Tertiary (Eocene) age and comprises part of the Boulder Batholith. In some places a border phase of diorite is found at the edge in contact with the sedimentary rocks. Many dikes, sills, and cupolas cut the sediments.

**DIORITE LIMESTONE CONTACTS**

On the northern end of Lime Kiln Hill an excellent exposure of limestone-diorite contact can be seen. The contact zone is approximately 200 feet wide and is made up of several "zones". These zones do not have sharp lines of demarkation but do show gradual changes so that a specimen collected 50 feet farther from the contact than some other specimen shows distinct differences.

The limestone is a pure white rock that does not contain over 5 per cent impurities. On approaching the contact the limestone is seen to have been recrystallized and stained slightly with limonite. Under the microscope it is seen that much of the calcite has recrystallized in twins. (Fig. No. 1, Plate 1) The calcite twins formed have 0112 as a twinning plane and a characteristic of two sets of parallel bands that cross each other. Under crossed nicols these bands show wavy lines within them that show lower order colors in contrast with the higher order dull gray of the main part of the calcite.

Nearer the contact incipient epidotization begins and the calcite crystals increase in size. Also a slight
amount of free quartz, making up less than 5 percent of the mass, has been introduced. Epidotization and chloritization then become more important with epidote making up the bulk of the rock. The bits of remaining calcite stand out markedly, and give the rock a mottled appearance. Chlorite and diopside become increasingly predominate and within 25 feet of the igneous rock they make up over half of the rock. Epidote and calcite continue as important constituents while all of the rock is stained brown by limonite. Although the limonite may be altered from pyrite it does not occur as a pseudomorph in the isometric system but is scattered through the rock as a film between mineral particles.

Directly adjacent to the diorite the contact rock becomes hard and light colored. Epidote, diopside, and plagioclase feldspar in a matrix of quartz form this highest stage of metamorphism. The line between this rock and the diorite is quite sharp and can readily be recognized in a hand specimen.

On a high hill to the south-east of Lime Kiln Hill a large stock of diorite intrudes the limestone. Here as before crystalline calcite, chlorite, epidote, diopside, and quartz are present but the dominant mineral is andradite garnet. The contact zone appears to be over 1000 feet wide but this may be in error because the underground position of the diorite is not known. Thus that which is 1000 feet from the igneous rock on the surface may be but a short distance from it vertically.

In many places the rock appears to be composed of
about 80 per cent massive garnet and minor amounts of the other minerals, especially epidote. Actually the "massive" garnet is crystalline and shows its crystal faces when a piece is fractured with a hammer. The common form is the dodecahedron and occasionally a perfect crystal can be broken free.

**DIORITE ARGILLITE CONTACTS**

On Red Mountain at an altitude of about 9,500 feet above sea level a stock of diorite has been intruded into the Belt argillite. The contact zone is rather narrow, extending about 30 feet laterally. The argillite adjoining the zone of mineral alteration is bleached white but not otherwise affected. As the color of the rock is due mainly to iron oxides either the iron was leached or reducing conditions prevailed to change the iron to a ferrous form.

The contact rock itself is an exceedingly hard and resistant body. It is composed of andradite garnet, epidote hornblende, and hedenbergite. Earthy hematite is present in spots and gives a brilliant red dotted pattern to the rock.

**QUARTZ MONZONITE LIMESTONE CONTACTS**

By far the most common type of contact to be found in the Highlands is the quartz monzonite limestone contact. In general the many miles of such contacts are similar but a few specific examples that show striking differences can be found.

One of the best exposures is on the southern end of Lime Kiln Hill where the quartz monzonite has stoped through
Figure 2.

Photomicrograph of thin section of actinolite (dark) in a matrix of quartz and diopside. Plain light.

Plate 2.
the border of diorite and into the limestone. The contact is characterized by its narrow zone of metamorphism and the many changes in type of rock that occur within the zone.

The limestone is a fine grained pure white rock that has been recrystallized near the contact zone. At a distance from the contact they become large, often measuring one-half an inch across, and show the typical rhombohedral cleavage most handsomely. When this coarsely crystalline limestone is broken open it emits a peculiar fetid odor that is suggestive of hydrogen sulphide.

Quartz and fine grained garnet are the first minerals to appear as one goes from the limestone into the contact zone. The rock is light brown in color, very hard, and heavy but not at all striking in appearance. A second stage contains finely disseminated pyrite, actinolite, epidote, quartz, diopside, and garnet all mixed together in a rock that contains but very little free calcite. Yet the bedding of the limestone has been preserved so perfectly that it is evident that the present minerals replaced the original rock molecule for molecule.

Epidote in large columnar crystals, chlorite, diopside, and quartz make up the bulk of the next zone. Actinolite and mica are also present. One specimen that was examined in thin section consisted largely of quartz, diopside, and actinolite. Figure 2, Plate 2, shows a microphotograph of this section in plain light. The actinolite shows up as the dark mineral. It is not in well defined crystals but is scattered through the matrix in small fibers, many of which have an arboreal form.
Figure 3.
Photomicrograph showing fractured contact minerals.
Plain light.
Adjacent to the quartz monzonite, quartz becomes the dominant mineral while epidote, chlorite, talc, and actinolite make up smaller portions. Here feldspars may be noted for the first time, but they do not make up over 10 per cent of the specimens examined. The rock shows a rough schistosity that indicates some pressure during metamorphism.

The first definitely igneous rock at the gradational contact is a chlorite-epidote quartz monzonite. The chlorite is clearly an alteration product from the hornblende of the original rock but the epidote occurs in crystals and was probably formed in the magma prior to complete crystallization. It is probable that its formation was due to the presence of some assimilated material from the walls. The agency that altered the hornblende did not affect the feldspar in any way so that the crystals of this mineral stand out on weathered surfaces.

From this place the igneous rock grades evenly and quickly into normal quartz monzonite through a zone that contains many cognate inclusions of diorite. These inclusions are well rounded from the corroding effects of the quartz monzonite magma but in the center of them little or no change appears to have taken place. In a few it was thought, but not definitely proved, that they contained a little more biotite than the normal diorite.

It was noted in several thin sections from this contact and from other contacts that one of the characteristics of contact deposits is the fractured minerals. Figure 3, Plate 3 is a photomicrograph of typical fractured contact rock.
As this feature is so common and also of some significance, it is proper that it be discussed here. During the cooling of a magma and the heated wall rocks around, it is to be expected that shrinkage would set up tensional forces. That these forces should be accentuated at the contact and bring about the development of cracks is readily explainable. First it is the meeting place of two substances with different coefficients of expansion, different coefficients of conductivity, and in different phases. Also the material beyond the contact on the host rock side is cold while that in the innerpart of the magma is hot. All of these differences would act to produce a zone of movement at the contact.

One quartz monzonite limestone contact notably different from that just described was found on the north side of Nevin Hill. Here the zone of metamorphism is practically lacking, but a large mass of quartz having the appearance of a quartz vein and containing very small amounts of finely disseminated galena is found between the igneous and sedimentary rock.

At other contacts, and especially those of Gallatin limestone (middle Cambrian) tremolite was quite abundant. In the Gallatin formation small needles of fiberous tremolite were found as much as a mile, horizontally, from the contact. They were so characteristic of this formation that they were useful in identifying the beds.

ORE DEPOSITS

Small pockets of gold ore, and very localized de-
posits of copper minerals are found in the quartz monzonite limestone contact zone, but none of those in the Highlands are as yet known to be of commercial value, except the gold deposits on Nevin Hill. The copper deposits appear to be of fair grade at the surface but the active condition caused by the carbonates of the limestone does not favor leaching and so there is a relative concentration of the oxide minerals.

The Butte-Highland Gold Mine on Nevin Hill is mining the only commercial contact deposit in the Highlands that has been discovered to date. The phenomena of "chimneys" of ore is well illustrated here. These deposits were formed at the intersections of cleavage planes in the limestone by ascending hydrothermal solutions and consist of limonite, gold, and soft altered limestone. The three ore shoots are in the form of chimneys or pipes that vary from a few inches to sixteen feet in width and extend downward for over 500 feet. At present a tunnel 2300 feet long, driven into the hill, has encountered a typical irregular shaped contact deposit. The tunnel starts in limestone near the contact but cuts both diorite and quartz monzonite thus proving that the distance from the ore deposit to igneous rock is much less than it appears to be on the surface. The deposit is a typical contact replacement deposit of irregular shape. Besides gold the ore contains limonite quartz, a little sericite, and calcite. It has been postulated that the solutions that formed this deposit moved upward along the zone of weakness between the folded limestone and interbedded argillite. But the contact between the limestone and argillite is sharp and
Figure 4.

Photomicrograph of Belt argillite, Polarized light.

Plate 4.
shows no evidence of having been affected by hydrothermal solutions so the path of migration was probably along shear cracks in the limestone itself.

QUARTZ MONZONITE-ARGILLITE CONTACTS

Gold Hill in the Highlands is a chonolith of quartz monzonite that has intruded Belt argillite. The contact zone is about 200 feet wide where it is best exposed on the south side of the hill, and consists of at least two definite zones.

The argillite (Fig. 4, Plate 4.) is an exceedingly fine grained rock composed of sericite, quartz, calcite, siderite, and limonite. The average grain diameter is 0.04 millimeters which makes it rather difficult to study under the microscope. Several counts of the quartz grains showed that they constituted 40 percent of the rock thus making it a quartz argillite. The surface weathers red with small pits.

The first contact rock to be found as one goes from the sedimentary towards the igneous side is a black, jointed rock. It consists of long needles of actinolite in a fine grained matrix of calcite, sericite, and diopside. The second zone is found adjacent to the igneous rock and is composed of a very hard and resistant rock. It consists of large crystals of calcite, light green and light pink pyroxenes and small garnets. A very little actinolite is present. Microscopically the calcite is seen to be twinned (Fig. 5, Plate 5.) and also to make up the largest crystals. The pyroxenes are badly fractured, but have been cemented by the same minerals with different orientation. The most notable features of this rock are the beautiful colors caused by the green and
Figure 5.

Photomicrograph of calcite twin in a matrix of fine grained pyroxenes. Polarized light.
pink pyroxenes and the complete absence of epidote.

On lower Fish Creek the main body of the batholith has invaded Belt argillite. At one place a huge block of the sedimentary rock has been stopped off, and had floundered but a few feet when the magma became too viscous to allow further settling. The contact between the quartz monzonite and the argillite is very sharp and there is little or no metamorphism other than the recrystallizing of the mica of the argillite into slightly larger plates within an inch of the contact.

**QUARTZ MONZONITE-QUARTZITE CONTACTS**

To the west of the Butte-Highland Gold Mine a long ridge, which is capped by Quadrant (Pennsylvanian) quartzite, is contacted on all sides and below by quartz monzonite. This association should give ideal conditions for the development of a contact zone because of the intimate association of the igneous and sedimentary rocks.

Normally the Quadrant formation is composed of a massive, fine-grained, light colored quartzite interbedded with thin bands of shale and calcareous shale. At one place the contact zone was not over 10 feet wide. The quartzite has been recrystallized slightly and also stained a light brown by limonite. The limonite is scattered as a stain over the quartz crystals and does not make up any appreciable part of the rock. The very narrow contact zone is composed mainly of quartz but also contains small amounts of epidote and garnet. On the igneous side of the contact the rock is a dense, fine-grained, white rock that contains over 50 percent of
free quartz. The remainder is made up of orthoclase, albite and a little muscovite. Amphiboles, biotite, and pyroxenes were not observed. The formation of this rock, no doubt, was due to the assimilation of quartzite by the magma and the solidifying of the magma before diffusion of the acid-rich material could take place. In the same zone a lenticular deposit of opal approximately 10 feet long and 2 feet wide has been formed. Examinations show that the opal contains no impurities except dendrites of psilomelane along cracks but that the milky-white color makes it non-commercial.

Another cross section from the same contact shows a zone of metamorphism over 300 feet wide. On the quartzite side of it the rock is fine-grained, approaching chaledony in some specimens, and is criss-crossed by a multitude of veinlets filled with either quartz or chaledony. Epidote, garnet, chlorite, diopside, ziosite, and quartz make up the contact rock. Quartz, diopside, and epidote are the most important minerals. The quartz monzonite at the contact has not been notably altered. A bed of shale in the quartzite that outcrops 200 feet from the beginning of the contact zone has been metamorphosed to a phyllite. The phyllite is a dense black rock with a conchoidal fracture and is essentially recrystallized shale.

A third position of the quartz monzonite-quartzite contact was studied because of the large width of the metamorphosed zone. At this point the sediments have been changed markedly for 1000 feet from the igneous rock. The first hint of contact action was found in quartzite that was entirely
normal except for a little pyrite that was finely disseminated and looked fresh and unaltered. The next zone was composed of quartzite that was interfingered with many small quartz veinlets which carried small amounts of pyrolusite. The veinlets are fracture fillings and were deposited by hydrothermal solutions that did not alter the country rock.

As one progresses toward the intrusion a zone of andradite garnet, quartz, sericite, tremolite, and limonite is encountered. The garnet occurs in small crystals and is the dominate mineral. The limonite is not a thin film as has been described in connection with other contacts but occurs in spongy masses. From this it would seem logical to conclude that the limonite was a residue after the decomposition and leaching of some iron-bearing mineral, possibly actinolite. The quartz is fine-grained as it is in the quartzite but is quite cellular, doubtlessly due to the leaching of some relatively soluble substance. From this zone onward toward the igneous rock the free quartz of the contact rock decreases to not over 5 percent of the total. Hornblende begins to appear in large crystals in a matrix of actinolite, sericite, and diopside. The rock is compact, hard and resistant to weathering.

The zone nearest the quartz monzonite is nearly 600 feet wide and remarkably uniform for the entire width. The rock is made up of orthoclase and diassage. The former mineral occurs in large irregular masses, often three-quarters of an inch in diameter. Rarely a cross section through a piece of orthoclase shows a crystal outline. But commonly the
boundaries are irregular with no relationship to crystal faces or cleavage. The diallage is gray-green in color and on a cleavage face has a pearly luster. On surfaces that have been exposed to weathering the luster is rather dull. The rock is hard and forms a prominent ridge that rises above the general level of the quartzite ridge.

At various places along the several miles of quartz monzonite-quartzite contact jasper was found. It did not occur in a large body but rather, was in small masses. Most of the pieces were not of uniform color but showed streaks of various shades of red through them.

CONCLUSIONS

In the conclusion it is the writer's purpose to correlate the processes of contact metamorphism which were discussed earlier in the thesis with the facts as described.

The first process to be considered is that of heat alone. Although it is probably of great importance in speeding chemical action heat, by itself, does not bring about the changes observed in contact metamorphism. This was amply shown by the lack of metamorphism in the stopped block of argillite mentioned on page 13, and by the many variations along the quartzite contact where the temperature must have been the same and the amount of heat quite uniform. If heat alone could bring about the changes the contact zone of metamorphism would tend to be more uniform.

Assimilation of sedimentary rock by the magma and crystallization of the resulting melt before dissemination would change the composition of the igneous rock near the
contact as was described on pages 13 and 14. But this does not account for the intense metamorphism found in rock that was not molten at any time during the change.

This leaves the alternative that of the known processes the passage of solutions from the magma to the country rock and the subsequent chemical reactions is the most important. The channels or passageways for these solutions are the many fractures that were observed in practically all contact rocks (Fig. 3, Plate 3). The solutions themselves are hot when they leave the magma and furnish an appreciable amount of heat to help the chemical reactions. Whether the action is pneumatolitic or hydrothermal is not easily determined. In theory the so-called "high temperature" minerals would be considered pneumatolitic in origin while the "low temperature" minerals would be hydrothermal. But as a good geothermal thermometer has yet to be proven no attempt was made to estimate the temperatures or agents of formation. It is, however, well known that both gases and liquids act as solvents for solids. Therefore it can be safely stated that solids dissolved in a fluid are the sources of new materials introduced into the contact zone. The fact that metamorphism is much more intense in some places than in others when the conditions seemed to be the same is accounted for by the possibility that fracturing was more intense at those points.

Briefly the process outlined accounts for; material to be used in forming new minerals; a means of transporting them from their source to the zone of metamorphism; and supplies at least part of the heat used in bringing about the chemical reactions.