THE GEOLOGY OF THE MONTE CRISTO DISTRICT WITH SPECIAL REFERENCE TO ORE DEPOSITS

by

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INTRODUCTION

In the heart of the Northern Cascades, about forty miles due east of Everett, Washington, lies the former mining town of Monte Cristo. Today it is almost a ghost town; mining has long since ceased. The town itself is more accessible than in 1900 when the mines were at the peak of their operation, for a road completed in 1942 leads up the North Fork of the Stillaguamish River over Barlow Pass into the basin of the South Fork of the Sauk River, in which the town is located. Formerly the Monte Cristo and Everett Railroad came along the same route, but the railroad had frequent washouts and was unable to keep open; the long stretches that it was closed caused it to eventually become scrapped. There is no other feasible method of getting to the town, although there are trails from the south over Poodle Dog Pass and Wilmon Pass and a trail from the north from Goat Lake over Ida Pass. None of these would allow for large scale transportation.

The town itself lies where the Sauk River divides into Glacier Creek, Seventy-six Creek, and Sunday Creek and it is in the basins of Glacier Creek and Seventy-six Creek that the major ore deposits are found. The elevations in the valleys vary between 2,000 feet and 3,000 feet, while the peaks rise sharply from 4,500 feet to 7,000 feet. This great change in topography has made some of the mining claims inaccessible and lends great beauty to the area.

Historically, the first claims were made in 1889 when, on the Fourth of July, Mr. Peabody sighted, gleaming in the sunlight, the Seventy-six vein. Rumor has it that the area was named then and there, as he shouted "It's as rich as Monte Cristo". Shortly thereafter, most of the other promising veins were claimed and, when the Pride and Mystery mines were purchased by certain well-known capitalists, the district seemed off to a good start. A smelter was built in Everett and a railroad completed to the mining camp. However, the comparatively short season of good weather, the frequent washouts of the railroad, and the onrush of prospectors to Alaska caused the capitalists to withdraw; without financial support the district was a failure.

The author spent over two months in the field in order to obtain the geological data used in this report but much of the information is sketchy. Necessarily, the more complex and variable local conditions have been fitted into the general picture and anyone using this information with regards to a specific ore deposit would be advised to make a separate study of the immediate vicinity of that deposit rather than accepting it as fitting exactly the general outline of the area.

The conclusions reached are the author's own and others may reach entirely different conclusions from the data herein presented.

Acknowledgment is made to Professor Goodspeed of the University of Washington and Professor Larsen of Harvard University under whose tutelage the author acquired his knowledge of Petrography, Metamorphism, and Ore Deposits. Due to this knowledge the many hours in the laboratory, working with thin sections, were well spent. Thanks are due to Miss Katherine Knowlton of Monte Cristo and Edmonds, Washington and Mr. F. H. Carlsen of

Seattle, Washington for their invaluable assistance while working at Monte Cristo. Appreciation is also expressed to the many others who helped the author while he was working in this area.

GENERAL GEOLOGY

The area seems to have had much the same history as that referred to the whole of the Northern Cascades. The oldest rocks are a sedimentary series which are almost exclusively non-marine. In theory they may have been derived from an older granitic rock or from some earlier members of the series of andesite flows which follow and flow over these sediments: probably both rock types were present in the Eocene. Overlying the sedimentary series and older andesites, and at places seemingly intruding, on the east side of Weden Creek, are the remains of a basalt flow. This flow is probably Miocene in age and later andesite flows seem to overlie.

In the late Miocene, the area was intruded by a granitic rock which in this district is a tonalite. Along with the intrusion there was probably uplift and folding. A result of this was the formation of large areas of schists from the andesites and sedimentary rocks. Large bands of schists are found in many places running along between the andesites and the tonalite.

By Pliocene time, the area was somewhat leveled off and the last of the andesite flows were probably widespread. In the Pleistocene, uplift must have occurred and the resulting forces caused tensional joints to develop in all of the rocks of the region. Subsequent glaciation, aided by the pre-existing drainage system, carved out deep gulches and left the region with its present day topography.

With reference to the ore deposits it seems likely that they followed the granitic intrusions and continued to develop through the Pliocene, the Pleistocene and the Recent. Hydrothermal in nature, they are closely allied with the processes of granitization. While the glaciers may have removed some of the ore, they also exposed much that might otherwise be concealed. It is possible that there are large, undiscovered, rich ore bodies underneath parts of the region.

GEOLOGIC MAP

The geologic map included in this report takes in the area of the basin of the South Fork of the Sauk River. In the south, the limit is the divide between the drainage basins of the Sauk River and of Silver Creek. On the north, the boundary is limited by the divide between the drainage basins of the Sauk River and of Goat Lake. On the east, it is limited by Cadet Peaks. The contour lines were obtained by making enlargements of the Glacier Peak, Sultan, Stillaguamish, and Silverton Quadrangles plus the individual variations observed by the author and the geologic sketch map by J. E. Spurr in Volume II of the Twenty-Second Annual Report of the U. S. Geological Survey. Some of the geologic data was also acquired from this last named map and some from the field work done by the author himself. Certain areas are found to have radically different types of rock than had previously been shown.

STRUCTURE

General Structural Relationships

The structure of this region is similar to that of the whole Northern Cascades. The oldest rocks, sedimentary in origin, have been folded, uplifted, peneplained, intruded and covered by later andesite flows. These andesite flows in turn have been eroded, intruded and weathered. Over the top of this weathering surface, the last of the lava flows made their appearance. The sedimentary rocks today have a uniform strike of N. 10° W. and a dip of 65° W. Many of them show pronounced schistosity, across which there is a series of parallel cleavage planes. The cleavage planes strike N. 65° E. and dip nearly vertically; they are found in the sedimentary rocks of Lewis Peak, Del Campo Peak, and Weden Creek Basin. On the east side of Weden Creek the sedimentary rocks are overlain by the earliest andesite flows which contain a large number of breccias, are almost parallel to the present land surface. In many places they have weathered pronouncedly and covered over, unconformably, by later andesite flows. On the west side of Weden Creek the sedimentary rocks have been intruded by a large tonalite dike. Here the contact zone is sharp and, while the tonalite displays all variations from a fine-grained to a coarse-grained igneous rock, there is a possibility that this dike was formed through replacement action rather than by intrusion. Some of the feldspar crystals are zoned with the high temperature variety on the outside and the low temperature on the inside; this strongly indicates granitization by replacement. In several other places, similar dikes have been observed intruding the sedimentary formations. On Coney Peak there are certain beds, conformable in dip and strike with the other sedimentary rocks, which seem to grade into low temperature metamorphic rocks. It is probable that during the Miocene intrusion these rocks were uplifted, warped, and metamorphosed into schists. However, there are andesites also closely allied with these schists, and it may be that they are derived from the andesites rather than the sedimentary rocks.

The andesites, the earliest of which are probably Eocene in age, seem to be fairly conformable over the whole area. While there are distinct breaks between flows, many have been almost parallel to the present land surface. Flow structure has been found in both early and late andesites. Sediments are found interbedded and a group of palagonites and breccias are situated uniformly near the middle of the andesite series; this would seem to indicate a fairly flat surface covered with lakes at one time. The last of the andesite flows, which must have come in late Pliocene or Pleistocene, was upon a well-eroded surface; the contact zone is clearly marked. These are particularly noticeable on the higher peaks such as Wilmon Peak, Silver Tip Peak, Monte Cristo Peak, Cadet Peaks, and Columbia Peak, all of which possess an andesite that shows little weathering and uniform character.

The basic mass on the east side of Weden Creek is structurally unconformable with the underlying andesite and seems to have come up through a dike in the sedimentary rocks. This dike, along which Weden Creek Mine is located, is composed of sheared ultrabasic rock. The basic igneous body was probably in a basin similar to that which exists today and, as far as could be determined from thin section, no flow structure was apparent; however, there are strongly orientated crystals of biotite about half-way up the mass. The thickness of this basic mass is at least 75 feet and it may have extended over a much larger area. Scattered fragments of basic rocks are found in other sections, but some of these might be from basalt flows. This mass is probably Miocene in age and perhaps similar to that of the Yakima Basalt.

The schists of the area have no uniform dip nor strike; they have no uniform thickness nor any uniform composition; stmucturally, they are quite interesting because they2seem to come between the intrusive tonalite and the pre-existing country rock. On the south edge of Seventy-six Gulch, there is a thin band of metamorphic rocks striking east-west and dipping nearly vertically between the tonalite on the south and the andesite on the north: the structure here has apparently been formed by the intrusion. High on Coney Peak, schists seem to have been formed through dynamic metamorphism. Some of these were formed by metamorphism of sedimentary rocks rather than andesitic flows, for many display quartz grains identical with those found in the arkosic rocks. On the lower slopes, as one comes up from up from the basin of the Sauk River, there are also schistose bands and, as these come between intrusive igneous dikes and andesitic rocks, they are almost certainly formed by Metamorphism of the andesites. Since the intrusions are believed to have occurred in early Miocene, it is probable that the schists were formed from the older rocks that were Eocene to

Miocene in age.

The structural relationships of the tonalite are the most interesting in the whole area. In certain places, they are typical of intrusive igneous bodies, and at other places they show no features of intrusive activity. It is the author's belief that some of the tonalite dikes intruded along zones of earlier weakness, while other large areas of the tonalite formed regular intrusive stocks. It is around these latter zones that the schists formed through dynamo-thermal metamorphism. Certain other contact zones indicate that the tonalite has been formed through a slow process of replacement granitization. Instead of a hot magma working upon the country rocks, there were hot rising solutions which slowly but surely replaced the andesites, forming the younger tonalite. This is perhaps best exemplified by the contact between the tonalite and the andesite near the Pride and Mystery veins on the north side of Glacier Creek Basin. There is a sharp contact zone, yet certain stringers of andesite may be found within the tonalite and spots of tonalite appear in the andesite. The effect of the granitic rock upon the structure seems to have been uplifting: in certain areas it has also caused the formation of schistose bands.

Jointing

The most striking structural feature of the Monte Cristo district is the pronounced jointing found in all types of rocks and in rocks of all ages. While there are over a dozen separate and distinct sets of joints, there are three major sets. One strikes N. 65° E. and dips 65-70° N.W., a second has the same strike but dips at an angle of 30 to the N.W., and the third strikes N. 10 W. and dips 65 to the N.E. The effect of this jointing is to leave large planes available to streamlets which expand when frozen. Wilmon Peak and the Needles show it clearly; the one is separated from the other by a major joint plane of this type. While the area on the east side of Seventy-six Gulch probably shows the jointing somewhat better than other sections, the sedimentary rocks of Weden Creek Basin, the andesites of Silver Tip Peak, and the rocks on the south side of Coney Peak all show the effects. On the south side of Silver Lake a high, almost vertical wall of andesite has about twenty glacial streams running down the side along jointing planes and presents a most striking view from the north side of the lake. On Coney Peak one finds principally sheet jointing. Large masses of tonalite and andesite can be seen sheeting off the sides of the mountain showing both the principal joint planes, along which the massive rock sheets break off, and the cross joints.

Insofar as the ore deposits are concerned, this jointing seems to play a major role, for many of the major veins follow along planes conformable with that of the jointing. It also seems to make for enrichment, where minor joints break across the major vein.

<u>Geologic Age</u>. The jointing is to be found in all the rocks of the district. Even the youngest andesitic flows show this jointing. While it is possible that there have been a series of orogenic movements such as to produce these joints, at least one of them must have come later than these final lavas. If the lavas are considered Pleistocene in age, then the final jointing

Structure-Jointing

Plate II

This photograph was taken in upper Glacier Basin looking from east to west. It shows the pronounced joint plane between the Needles Peaks on the right and Wilmon Peak on the left. The rock is andesite and jointing may be seen on the wall of Wilmon Peak parallel to the major jointing.

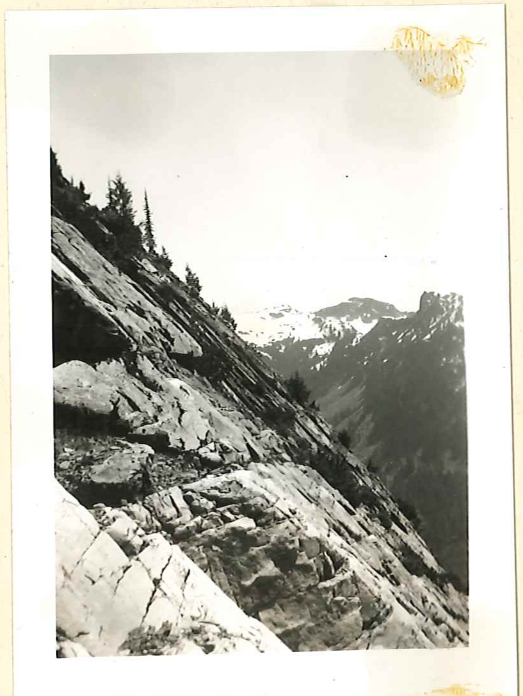
must also be of that age. It is the opinion of the author that much of the jointing took place during the uplift of the Cascades in Miocene time. This was probably a slow process and different planes of weakness developed. However, the final uplift of the Cascades, which took place in Pliocene-Pleistocene time, undoubtedly produced some new sets of joints and fractured the youngest lava flows. The intense erosion during the glacial age accounts for the sharp features that the joint planes made possible; in many cases, small alpine glaciers must have seized upon these zones of weakness as a passageway. Hence the development of the deep gorges on the sides of many of the peaks. Today these joint planes serve as excellent passageways for water and on almost all the peaks water may be seen cascading down the waterfalls in these marked zones. It is probable that the present rate of erosion will wear the sharp features away in a short geologic time, but, as it is, the jointing lends much scenic beauty to the district.

PETROLOGY

The rocks of the area include all major types: sedimentary formations, extrusive and intrusive igneous rocks, and metamorphic rocks. The sedimentary formations seem to be the oldest rocks, the extrusive andesites are a series of different rock types, the tonalite intrudes both of the preceding formations, and the metamorphic rocks are found along the intrusive contacts.

Structure-Jointing

Plate III



This picture shows some of the prominent sheet jointing of the district. It is taken on the side of Coney Peak looking east towards Monte Cristo Peak. The rock surface strikes N. 65° E. and is dipping about 65° to the S. E. A minor joint plane may be seen with the same strike but dipping at about 10° to the N. W. A third series of joints cuts off the slabs of rock. It may be seen in the background striking N. 10° W. and dipping almost vertically. The rock in the foreground is tonalite.

Sedimentary Series

One of the important rock formations in the Monte Cristo district is this series of sedimentary formations. They consist of arkoses, - Swauk ? shales, sandstones, and conglomerates. In places there are a few limy beds. This series seems to have been formed by the breakdown of some pre-existing granitic rock. It is assumed that these older granitic rocks underlie much of the area; at no place are they exposed and recognized. These granitic rocks would be comparable to the Mt. Stuart Granodiorite.

Composition. The rocks are composed of angulate quartz fragments, feldspathic material, and some carbonaceous matter. In the older conglomerates, pebbles of a granitic rock are found, as well as some that seem to be andesitic in nature. The arkoses which compose a large part of the series, are composed of quartz, feldspar, and biotite which seem to interlock forming a good granitic texture. In these rocks many traces of sedimentation have been eliminated and in the thin section they often appear to be an igneous rock. However, the biotite is fresh, and in certain places the quartz crystals have clearly grown since deposition. Often the feldspars have been regenerated and it is possible that with a slight amount of metamorphism these rocks would become indistinguishable from granitic intrusives. The conglomerates have a ground mass of quartz fragments with some amount of feldspathic material and are largely composed of pebbles of a granitic rock which resembles a typical granodiorite. The shales are composed of a large quantity of small angulate quartz fragments, feldspathic material, and fair amounts of carbonaceous matter. In places, small crystals of mica may be observed. The sandstones, which are almost quartzites in many places, are composed almost entirely of angulate quartz fragments and, as the fragments grow finer, they grade into the shales. The few limy formations also have large quantities of quartz fragments but, instead of feldspathic material, calcium carbonate is the cementing agent.

Location. The rocks are located on Lewis Peak, Del Campo Peak, in Weden Creek Basin, and on the westernmost part of Coney Peak. They are also found to the south of the district in the basin of Silver Creek. These formations strike N. 10° W. and have a dip of approximately 65° W. in general, but there are many local variations. The arkoses and conglomerates are best exposed on Del Campo Peak, the shales and sandstones in Weden Creek Basin.

Geologic Age. If the granitic rock from which these sediments were obtained is comparable in age to the Mt. Stuart Granodiorite, then the sedimentary rocks would be Eocene or younger in age, as the Mt. Stuart Granodiorite is generally considered to be late Mesozoic. In addition, these rocks resemble strongly the land sediments of the Swauk formation which was derived from the Mt. Stuart Granodiorite and is considered to be Eocene. On the basis of a single fossil found in the area, the sedimentary rocks have been correlated to the Puget group. This group is also Eocene in age. The author found a single leaf fossil in the area but was unable to correlate it with any known age. In this report the sedimentary series will be considered Eocene.

<u>Petrography</u>. The study of the sedimentary rocks in the thin section is most interesting. They are composed of angulate quartz fragments which show clearly that the particles have moved but a short distance. While some of the beds seem to be composed of fragments from andesitic extrusives, most of the materials are apparently formed by the breakdown of some granitic rock. The shales, which are the finest-grained rocks of this series, show many tiny quartz fragments cemented together in a feldspathic and carbonaceous matrix. As one progresses towards the more coarse-grained rocks, the chief differences are the increase in size of the quartz fragments and the decrease in the amounts of feldspathic and carbonaceous material. In the arkoses many of the quartz fragments have grown so as to be indistinguishable from primary crystals; there are also many striated feldspars, and fresh, unaltered biotite crystals. The arkoses as a whole seem to have been rejuvenated. In the conglomerates there is a high percentage of arkosic material which, combined with the large numbers of granitic pebbles, often leads to the formation of a granitic appearing rock. Indeed, it is quite possible that some of the so-called intrusives of the area are merely altered arkoses. Thin section analysis of the conglomeratic rocks shows that the granitic pebbles contain quartz, orthoclase, oligoclase, hornblende and biotite. As accessory minerals there are magnatite and apatite. Other pebbles are composed of fairly pure quartz, jasper, fine-grained volcanic material, and, in a few cases, older sedimentary pebbles. The matrix often shows good feldspar crystals which evidently could not have been formed while the rock was being deposited but must have grown around

some core of kaolinitic matter. Thin section analysis of the limy formations shows the large numbers of quartz fragments held together by calcium carbonate. Except for the limy nature of the matrix, these are indistinguishable from the other shales and sandstones of the series. All of the different types of rocks in the sedimentary series show unmistakable signs of being land sediments.

Andesite Series

Overlying the sedimentary series around Weden Creek Basin, on Lewis Peak and south of this district in the Silver Creek Basin, are a series of andesitic rocks. They overlie the sediments unconformably and cover large areas completely. There seems to be a distinct late stage of this series.

Composition. The different rocks making up this series are: andesites, andesitic breccias, dacites, ryholites, porphyries, and many thin, interbedded sediments. In many places the rocks are weathered so as to present a uniform green surface. However, most of the lavas themselves are dark in color.

Location. The andesites are to be found over all the Monte Cristo district with good exposures on Wilmon Peak, Columbia Peak, Coney Peak and Lewis Peak. Along both sides of Seventy-six Gulch there are excellent exposures of the andesite: while most of the beds are weathered, many of the different types of rocks can be identified here. In particular, the lava breccias are apparent for they weather to a light green rock that distinctly shows its brecciated nature. On Silvertip Mountain, Columbia Peak and Wilmon Peak there is an andesite, uniform in nature, that is much younger than the other members of the series. There is a fairly well defined contact zone, but, inasmuch as the composition is similar to that of the underlying beds, no distinction has been drawn between this and the earlier members of the series. In Pearsall Gulch there are also many fine exposures of the series. Here may be seen good examples of the dacites, ryholites and porphyries found in the area.

Geologic Age. Exact geologic age of the series is probably quite indefinite. As they overlie the sediments they are younger, but since some andesite pebbles have been found in the sediments, it is quite possible that the two were contemporaneous in age. Thus, it would not be implausible to say that the series began in the Eocene. The great thickness, at least 4,000 feet, indicates a large number of flows. Some are to be found on the highest peaks, and since these flows are comparatively unweathered, one may assume that they are Pliocene or Pleistocene in age. The great continuity of the beds suggests that at no time was there too long an interval without some volcanic activity. The series probably ranges in age from Eocene at the base to Pleistocene at the top and in this respect it might easily be correlated to certain andesite series farther south in the Cascades.

Petrography. Thin section analysis of these rocks yields quite varied results. Most of the specimens have been weathered so as to possess quite a different composition than that with which they were originally endowed. The andesites, in general, possess oligoclase and andesine feldspars, pyroxenes and hornblende as the dark material and a small amount of quartz and mica. When weathered large quantities of epidote and calcite are to be found. Also chlorite, pyrite, quartz, biotite and some actinolite are seen under the microscope. The actinolite is found particularly in certain breccias while the pyroxenes, chiefly hypersthene, are found in the youngest of the andesite flows. Many of the flows possess an extremely fine groundmass that is microscopically unidentifiable except for the many tiny laths of feldspar. Some of the rocks are glassy in nature and others show signs of once having been so; in particular, certain dacites and ryholites of Pearsall Gulch show fragments of volcanic glass in an extremely fine-grained, crystalline matrix. When the rocks are porphyritic they show phenocrysts of feldspar and pyroxene in a fine-grained matrix. Interbedded with these andesites are many thin sedimentary beds which show angulate fragments both of the mineral grains and of the andesites themselves. In certain cases they have been so altered as to be unrecognizable.

Probably the most interesting thin section made of the andesite flows was one made from a specimen taken from the north side of Lewis Peak. A section was made of the contact between the weathered surface rock and the unweathered lava. In both cases the most striking feature was the flow structure disclosed by the labradorite feldspar crystals. This showed that the rock is flat-lying as it lies; probably it was one of the most recent lava flows. In the weathered zone, the rock, which appeared green, showed large quantities of epidote, chlorite, biotite, labradorite, and some free quartz. In the unweathered zone, which appeared black, the specimen showed biotite, hornblende, and labradorite. The contact zone between them was composed almost exclusively of a layer of calcite.

Basic Rocks

Distribution. The basic rocks are found on the east side of Weden Creek Basin and extend towards Silver Tip Gulch. There are also small fragments of basaltic material found on the north flanks of Del Campo Peak and some in Glacier Gulch. These basic rocks are probably the remnants of a flow or of a sill; they lie over the older andesites and the sedimentary rocks.

Geologic Age. The basic rock overlies the older andesites, therefore it must be younger in age. As most of the basaltic flows of the Northern Cascades are Miocene and as the older andesites are probably Eocene or Oligocene, it is quite probable that these basic rocks are also Miocene. They seem to be fed by a dike on the east side of Weden Creek which cuts through the older Eocene sedimentary series.

Petrography. The basalts and basic rocks are dark appearing, but the surface weathers to a beautiful red color. They are limited in extent, but seem to be fairly uniform in composition. In the thin section augite, olivine, labradorite, biotite, and some hypersthene have been observed. When weathered these materials alter to yield serpentine, talc, actinolite, and chlorite minerals. The top part of the body seems to be fairly uniform in composition, but near the bottom one finds concentrations of sulphides; thin sections show olivine, augite, biotite, pyrite, chalcopyrite, and some pentlandite. It is along this lower contact that potential ores have been concentrated. Sulphides are probably due to concentration by meteoric waters, while the mafic materials may have been concentrated by magmatic differentiation.

Feeding the flow is a dike, striking N. 20° W. and dipping nearly vertically, which cuts through the sedimentary formations almost parallel to the eastern branch of Weden Creek. Material of the dike is almost exclusively serpentine. Thin sections show clearly that much of this is an alteration product from bronsite, but there are also some relics of olivine. It is of particular importance because the Weden Creek Mine lies on this vein. The materials mined are sulphides, particularly the chalcopyrite which is chiefly valuable for the copper and gold. Probably at one time this was an ultrabasic olivine-pyroxene dike, but exposure to weathering and shearing have caused the rock to alter.

Granitic Rocks

Granitic rocks of the area have a fairly uniform composition and vary in width from a few feet to several miles. They are found intruding the sedimentary series, the andesite series and in contact with the schists.

Composition. Composition of the granitic rocks seems to be largely that of a tonalite, grading at times to a granodiorite; in some places it varies in grain size enough to be called a porphyry, but nowhere does it vary too much from the general composition of quartz, oligoclase, biotite, and hornblende. Occasionally hypersthene is found and the common accessories are magnatite and apatite. Where the material has weathered, kaolin, epidote, pyrite, chlorite, and calcite have formed and this rock often appears to be identical with some of the weathered andesites, the main difference being the presence of some older crystals of quartz.

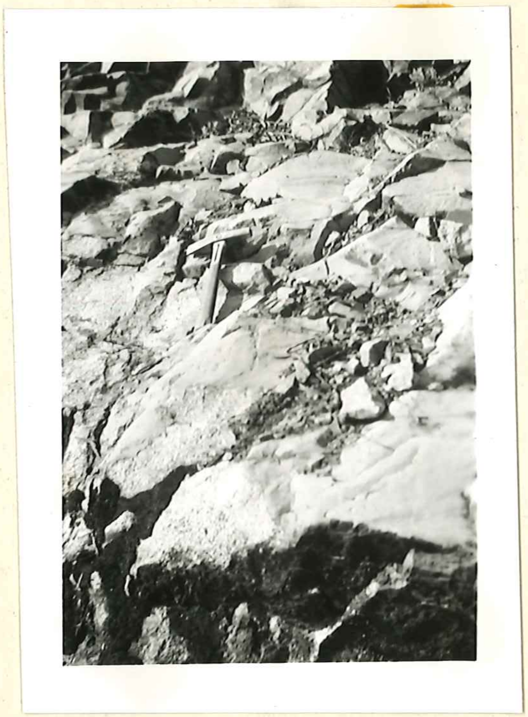
Location. The tonalite is to be found in widely scattered places, the best of which are those at the head of Glacier Creek Basin where the tonalites seem to be a massive dike cutting through the older andesite flows. Farther north, offshoots can be traced back to this large intrusive body; on Coney Peak three large east-west dikes are seen to come from this central core. To the south large bodies are observed to grade into the sedimentary rocks of Silver Creek Basin. Other notable exposures are the dike near the N. W. Consolidated Mine (in the sedimentary formations), the dikes along the flanks of Silver Tip Mountain, and the small dikes found in Pearsall Gulch and near the Rainy vein. In the underground workings of the veins tonalite may be found almost anywhere.

Geologic Age. The tonalite intrudes the sedimentary formations, it intrudes the older andesitic beds, and it is itself overlain by younger andesitic beds. Therefore it is some place between the Eocene and Pleistocene in age; it is probable that it correlates with the granitic rocks of the Snoqualmie Quadrangle and it would therefore be Miocene in age. However, since there are certain indications that this is granitization by replacement processes rather than by active magmatic intrusion, it might be considered as a continuous development from the Eocene to the early Pleistocene.

Petrography. Thin section analysis of the tonalite seems to indicate a typical granitic rock. It is composed of quartz, plagioclase feldspars, hornblende, biotite, and occasionally orthoclase. In a few cases augite and hyperstheme are found. As accessory minerals magnatite, apatite, sphene, zircon, and tourmaline are present. The textural relationship is typical of a granitic rock: large crystals, good boundaries, and a low percentage of mafic materials. It varies from fine-grained to coarse-grained.

Certain thin sections indicate that this is not a normal granitic rock. The large dike on the west side of Weden Creek shows excellent plagioclase feldspars. These feldspars are zoned with the high temperature mineral on the outside of low temperature; labradorite zoned around oligoclase. This would be an unusual occurrence in igneous rocks, for it indicates that the temperature, instead of dropping, has progressively gone upwards, a characteristic to be found only in metamorphic rocks. There is also to be found a certain amount of relic structure; running through feldspar and quartz crystals, alignments of fine inclusions may be seen. To the author this indicates that this dike has been formed not by intrusion but by a metamorphism of the arkosic rocks by solution. Since this dike does not strike exactly as do the sediments it is probable that replacement took place along some zone of structural weakness. One fact that would seem to contradict a replacement hypothesis is the development of good contact zones between the dike and the country rock. The dike is fine-grained at the edges, coarse-grained in the center; in composition it is much

Petrology, Tonalite-Andesite Contact　　　　　　Plate IV



Taken in upper Glacier Basin, this photograph shows the contact between the crystalline tonalite on the left and the finer grained andesite on the right. The contact is clearly marked and quite irregular.

closer to a granodiorite than to any other type of igneous rock. Also in favor of a replacement theory of granitization are the contact zones in Glacier Creek Basin. Here there is no zone of schistose rocks between the andesites and the intrusive, rather there is a conformable contact which shows the darker andesites grading in to the lighter tonalite. Megascopically this contact appears to be quite sharp, but thin section analysis contradicts this appearance. Small porphyroblasts of quartz and feldspar may be observed in the andesite. These seem to use some pre-existing crystal of the andesite as a core and build around it; some show good relic structures. In the tonalite there are skialiths of andesite, relics of the older rock which are left within the younger rock. This indicates that the contact between the two rock types is due to slow replacement rather than hot intrusive action. It is probable that this whole area has been subjected to a process of granitization by replacement.

Schists

The schists seem to be present at many places between the tonalite and the andesites. In many places they form a thin band of metamorphosed rocks, in other places a wide band and in some places they are entirely lacking. Some of these formations show signs of having metamorphosed from sedimentary rocks rather than andesite. It is possible that these were formed from sediments in the andesite series.

Composition. The rocks are composed of metamorphosed andesites and sediments, mineralogically consisting of epidote, actinolite, biotite, quartz, chlorite, and some feldspars. In many places they show good alignment, in others none at all. Some of the rocks show large 'Augen'. This is probably due to the presence of a conglomeratic bed rather than to cataclasis. Garnets have been observed in some of the rocks, seemingly indicating high temperatures; as a rule, these rocks are typical low temperature schists.

Location. The schists are to be found at the head of Seventy-six Gulch in the basin of Glacier Creek by Glacier Falls, and in three large bands on Coney Peak. In all cases they lie between the tonalite and the andesite series. They vary in strike and dip but the general trend is about N. 65° E. and the dip 70° N. W.

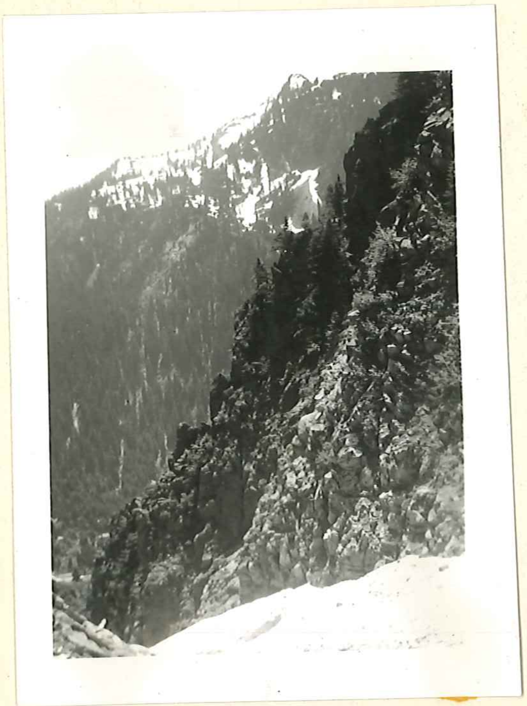
Geologic Age. There is every indication that these rocks are metamorphosed members of the andesite series; the fact that they always lie between the tonalite and the andesites would seem conclusive. As the tonalite is probably Miocene in age, so then would the schists be Miocene. In any event they are later than the andesites from which they were formed.

In an area undergoing granitization by replacement these schists might be accounted for as an early, high temperature phase of the hot ascending hydrothermal solutions. On the other hand, it is probable that these schists represent the contact zone between the first hot intrusive rocks of the area and the overlying andesites. The age may be taken as Miocene.

Petrography. In the thin section the schists are interesting. There is everything from a low temperature green schist to a high temperature, silicious, garnetiferous member. Perhaps

Petrology, Tonalite-Schist Contact

Plate V



(a)

(b)

Both of these pictures show the contact between the schist and the tonalite on Coney Peak. Photograph (a) shows the contact zone from a distance; the schist is the dark rock on the left and the tonalite the light rock on the right. The schist has apparently been permeated by iron sulphides and later weathered as it bears a bright red surface.

Photograph (b) shows a different contact; the schist is on the left and the intrusive tonalite on the right. There is a clearly defined contact zone between the two rock types.

the best study is that series of rocks cut across by the creek at Glacier Falls. A series of schistose rocks strikes N. 10° E. and dips nearly vertically. Across them a number of aplite dikes seem to run. The rocks vary in color from a pale green to a dark black; all have been metamorphosed. The light, green rocks contain epidote, silica, and garnet and they appear to have formed from a silicious sediment rather than from any pre-existing volcanic rock. Certainly there seems to be some definite alignment, a relic structure, in the rocks. The grains of quartz appear to be enlarged fragments; the alignment does not seem to be due to the metamorphic nature of the rock. The dark members contain silica, biotite, hornblende, actinolite, and chlorite. These seem to have metamorphosed from the andesitic lavas. They contain relics of feldspars and show the rejuvenated nature of some of the mafic materials. Thin sections of the aplite dikes, which are approximately 8 inches in width, indicate that they are replacement dikes rather than true igneous bands.

Thin sections of the schistose rocks on Coney Peak indicate both high and low temperature rocks. The closer one comes to the contact with the tonalite dike, the more the rocks seem to be metamorphosed. At a distance of about 50 feet they begin to grade in to the andesites. Some of the andesites not far away also show signs of porphyroblastic development which may well be due to the hot emanations coming from an intrusive body. Composition of these schists is oligoclase, actinolite, biotite, chlorite, silica, and the ever-present epidote. Schists at the head of Seventy-six Gulch are much the same, but they show less metamorphism than the other rocks. In many cases they seem to be formed from sediments rather than from andesitic rocks and are probably the results of a lower temperature contact than those on Coney Peak. As a whole, the metamorphic rocks of this area were formed from pre-existing andesitic rocks by localized high temperatures and active solutions.

METAMORPHISM

The metamorphic processes in this region are quite varied. Of greatest interest is the slow replacement of the country rock by solutions. Even schists of the area seem to have been formed in this way. In sharp contrast with the ordinary run of metamorphic rocks is the tonalite that appears to be paramagmatic in origin. In fact, all of the granitic rocks of the area may be of this type. Certainly some of the rock bodies are, in actuality, replacement dikes. Feldspar crystals in these rocks will show good zones with the alkali feldspars on the inside and the calcic feldspars on the outside of the crystals; at times they also show relic structure. Thin sections from the dike near the Northwest Consolidated Mine show both of these features. The rock is composed of quartz, feldspar, hornblende, and biotite. The zoning of the plagioclase feldspars shows inner zones of oligoclase and outer zones of labradorite. Between the crystals of orthoclase and of quartz there may be seen relic structures; tiny bits of feldspathic material show a sharp alignment running across and through the crystals. There are two arguments against the theory that these rocks were formed by replacement solutions. First, the contacts between the tonalite and the sedimentary rocks are marked by a fine-grained facies in the dike. The crystals are smaller and seem to be less well consolidated. Thin sections were made of this zone but none was actually obtained with the igneous rock and the sedimentary rock in the same slide. However, slides of the sedimentary rock showed porphyroblastic development of feldspar crystals. The second feature that appears contrary to the hypothesis of replacement granitization is the quantity of high temperature accessory minerals to be found in this rock. There are apatite, tourmaline, zircon, and magnetite; all are included in the quartz crystals as well as in the feldspars. In a paramagmatic rock it might be expected that the accessory minerals would be lower temperature minerals. Only the slight inclusions of feldspathic material, probably sericite, would seem to back up a paramagmatic origin. Although no flow structure was observed, it may be that these features are indicative of rheomorphism and that the rock was formed from a neomagma. The author believes that the evidence is in favor of granitization by replacement processes. In the basin of Silver Creek, arkosic rocks were observed that displayed features similar to this granitic rock while still showing their sedimentary nature. It is thought that if metamorphic processes had continued these rocks would have acquired the same igneous appearance as the dike rock studied.

The large tonalite mass stretching from Glacier Basin to Goat Lake shows interesting features. The contact between it and the andesite is typical of a replacement contact; borders are fairly will defined but there is no fine-grained contact

Metamorphism, Tonalite-Andesite Contact

Plate VI

The photograph is taken above Glacier Falls where the intrusive tonalite and the andesite contact one another. The tonalite is the light, coarse-grained appearing material which is intruding in veinlets and in isolated centers rather than along a smooth contact zone. The andesite is the darker, finer-grained rock in which the light zones of tonalite may be clearly observed.

zone. Thin sections made on both sides of the contact and through the contact show a gradual replacement of the andesite by the tonalite. The usual minerals of the andesite are hornblende, oligoclase, biotite, and orthoclase. These have been weathered on the surface to form epidote, quartz, kaolin, and sericite. The minerals of the tonalite are quartz, oligoclase, andesine, hornblende, and some biotite. The replacement phenomena entails a complete porhpyroblastic growth of quartz and enlargment of pre-existing feldspar crystals. That the replacement has occurred slowly is shown by the large-grained texture of the tonalite. There are several places in which large fragments or relics of the andesite may be seen in the tonalite. These andesitic inclusions give clear evidence of their nature and may be called skialiths, or "shadow rocks", as they are not foreign to the rock but shadows of what it once was. The overall picture is that of replacement of the andesite by ascending magmatic waters.

An excellent study is that of the rocks in the lower Glacier Basin. Glacier Creek descends in a series of waterfalls from the upper basin down to the lower basin where it later joins Seventysix Creek at Monte Cristo. The exposures are good. Thin sections made of the various rocks show actinolite, garnet, epidote, pyrite, diopside, and many other metamorphic minerals. The rocks around the falls are definitely metamorphic in nature. However, many do not seem to correlate exactly to the andesite rocks that are found nearby, rather they seem to be metamorphosed sediments. Under the microscope, distinct bedding planes can be seen.

The aplite dikes which cut across the other rocks in Glacier Basin are also interesting. These dikelets, which at first glance appear to be high temperature intrusive dikes, show a tendency to fade into the country rock. Indeed, several pronounced veinlets can be seen coming off of the six-inch dikelets at various points in their crossing. This might merely be magmatic stoping, but there seems to be also relic structures within the dikes themselves. Thin section analysis of these aplite dikes show garnet and diopside, a typical metamorphic occurrence in the Cascades. The conclusion drawn from these dikes is that they are formed by replacement rather than by intrusion.

In considering the larger metamorphic features of the region, one must mention the numerous large areas of schistose rocks. While most of these can conclusively be shown to have been derived from the andesites, certain ones show conglomeratic structures, quartzitic bands and other unusual features that one would expect only in metamorphic rocks of sedimentary origin. These rocks may have been formed from lenses of sediments within the andesitic lava flows. On the south side of Poodle Dog Pass, the schists are clearly sedimentary in origin.

On the west side of Coney Peak there is a large area that shows signs of cataclasis. There are some metamorphic mylonites and breccias in this region. These cataclastic rocks seem to have been formed from both sediments and andesites. They are quite different from the other metamorphic rocks of the region and very localized. The massive zone of serpentine, along which the Weden Creek Mine is located, might also be

Metamorphism, Aplite Dikes

Plate VII

This photograph was taken just below Glacier Falls and it shows one of the six-inch aplite dikes cutting across the schistose rocks in the basin. For about 80 feet, this dike has perfectly straight contacts, but in the center of the picture it may be seen that small veinlets are breaking off the main dike and some of the country rock is being enclosed by the dike material. The dike is a rock of fine-grained quartz crystals while the country rock is a schist apparently formed by the metamorphism of sedimentary rocks.

considered metamorphic. It is probably a weathered ultrabasic rock, but much of the altered material may be due to movement in the shear zone. Since replacement by solution is considered to be metamorphism, metamorphic rocks cover a very large part of the district.

SUMMARY OF GENERAL GEOLOGY

The geology of the area is quite varied; all four major types of rocks are represented here. The structure is comparatively simple, apparently being that of flat-lying beds intruded, folded, and covered over by lava flows. The jointing is probably the most striking structural feature for it cuts all types and all ages of rocks, leaving its many fracture planes to be seen at almost any place in the district. The feature of greatest interest is the metamorphism found in the area, specifically that process of granitization of the country rock. It is quite probable that this is more widespread than had previously been realized.

The rocks of the area may be correlated with those of nearby areas in the Northern Cascades. The land sediments, the arkosic rocks, are oldest and correspond to the Swauk Formation, the Guye Formation, and possibly to those marine sediments which are located slightly to the south, in the Index area, known as the Gunn Peak Series. The andesite series probably corresponds to the Keechelus Series of the Snoqualmie area. There, the andesites seem to have formed a continuous series from Eocene through Pleistocene, just as they seem to have done in the Monte

Cristo district. The basic rocks correlate well with the many common Miocene basalts of the Northern Cascades. The intrusive tonalite probably corresponds with the granitic rocks of the Snoqualmie area. It is the author's belief that it also corresponds with the granitic rocks of the Index area, although these rocks are commonly accepted as being different in age. The Index district lies a slight distance to the south of the Monte Cristo area and it is possible that the geology of the two districts is quite similar. In thin section, the granitic rocks near Index show a marked similarity to the tonalite of Monte Cristo. In particular the assemblage of accessory minerals indicates a relationship.

Altogether, the picture is that of an area of sedimentary rocks covered by lavas and later granitized. It is the author's belief that this igneous rock was formed by a replacement process rather than from a hot intrusive melt. This would indicate that the district is near the periphery of an intrusive mass rather than near its core. The igneous rocks in the heart of the batholith in this area show definite evidence of orthomagmatic origin, but most of the local tonalite shows signs of being metamorphic in origin.

ORE DEPOSITS

General Geology

The ore deposits of this district are almost exclusively in sulphide veins. These veins may be along joint planes, along bedding planes, or along the contact between the intrusive igneous rock and the country rock. As a rule, they weather to give a very pronounced red surface, presenting an appearance that not even an unskilled prospector could miss. The ore minerals are pyrite, arsenopyrite, chalcopyrite, with quartz and calcite as gangue minerals. The majority of the veins, which apparently are not fissure veins, vary in strike between N. 10° W. and N. 70° E.; as a rule, they follow the jointing in the area, while the dip ranges between 65° and vertical. The veins are frequently enriched where other joint planes, or fractures, cross them. Some of the richer veins are 8 feet in width. They were mined for their values in gold and silver. The gold is carried in solution by the arsenopyrite and the silver is carried in all of the sulphides, although probably most of it is in the arsenopyrite. Wherever the veins weather, they leave a zone comparatively richer in gold and considerably richer in silver; there is no apparent zone of secondary enrichment. The major mines are: the Monte Cristo Mine, the Justice, the Rainy, the Northwest Consolidated, the Seventy-six, the O. and B., and the Weden Creek Mines. Almost all of these are accessible directly from the town of Monte Cristo. At one time, there were railroad spurs which led to all the major mines; today these have washed away or deteriorated until they are no longer usable and, if

jt. control?

development work is going to be done, transportation facilities are the first items in need of improvement. The one mine of the area which has operated recently, the Weden Creek Mine, has a road leading up to it and was accessible during most of the seasons when it was being worked.

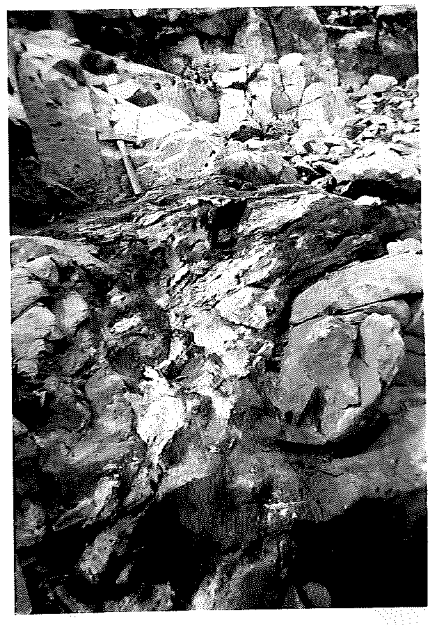
The ore pockets most commonly occur as large lenticular masses in the veins or fracture zones. The major mineral is almost always arsenopyrite and the minor minerals may be any one of a series of sulphides. These lenses may be as much as 300 feet in length, 200 feet in width and 20 feet in breadth; the normal ones are much smaller. In the veins many areas of barren country rock, quartz, and calcite are found. The straighter the shear zone the higher the values seem to run. The deeper one goes in the vein the lower the values seem to run; while gold remains fairly constant in unweathered zones, silver seems to decrease at depth.

Specific Deposits

The Monte Cristo Mine. This mine is a consolidation of the old Mystery Mine and the Pride of the Mountains Mine. It is located about one mile to the east of Monte Cristo along the Glacier Creek trail. The Mystery Mine lies on the three veins that cut across Mystery Hill (which is between Lower Glacier Basin and the Upper Glacier Basin). The Pride of the Mountains Mine is located a quarter of a mile further east on the far side of Upper Glacier Basin. The three major veins, upon which both of these mines lie, strike N. 75° E. and dip 75° N. W. On Mystery Hill they are located in andesite and schist while on

Ore Deposits, Pride of the Mountains

Plate VIII



The photograph is taken about 2,000 feet above upper Glacier Basin on the side of Monte Cristo Peak. In the upper left, the contact between the darker, fine-grained andesite and the lighter, coarser-grained intrusive tonalite may be observed. Immediately below this contact is a solid sulphide vein. It is about 10 feet wide and extends below the bottom of the picture. In the right foreground is a block of andesite which is entirely surrounded by the vein material and in the lower right a small tunnel may be observed cutting into the vein. On the surface the minerals of the vein are quartz, orpiment, and arsenopyrite. This vein has an unworked section of well over 1,000 feet but is almost inaccessible.

the east side of Glacier Basin they lie in tonalite and andesite. The ore minerals seem to be arsenopyrite, pyrite, chalcopyrite, galena, sphalerite, realgar and orpiment. The ore was mined for gold and silver, most of which is held by the arsenopyrite. Assays show as much as $50.00 per ton in the high grade ore. In the past these mines produced at least 300,000 tons of ore with a total value exceeding $2,000,000. This was shipped down the railroad to the smelter in Everett where the gold and silver was extracted. When the capitalists moved out of the area, the smelter was no longer used. However, some later miners brought the arsenopyrite ore to Marysville, where an arsenic smelter was set up. That metal was obtained from the ore for a short while and years later the tailings were re-worked for their gold content. The original Monte Cristo and Everett Railroad ran its main spur to this mine and when railway operation ended the mine ceased production. Some carloads of hand-picked ore have been shipped since 1908.

Structurally, the veins of this mine are in very close contact with both andesite and tonalite. This is probably a hydrothermal deposit formed in a central fracture zone; the mineralization is typical of a deep-seated deposit, which is in apparent contrast with the conformity of the vein to the general structure of the area. The schist, which is found in the Mystery Mine, seems to be an intermediate member between the tonalite and the andesite, it apparently has little to do with the mineralization. An interesting feature of the mineralization is the proximity of the galena and sphalerite to the surface; their absence from the deeper workings. This fact has been used, by others, as evidence of a deposit formed by enrichment by downward descending meteoric waters.

The Justice Mine. Formerly called the Golden Cord Mine, it is located on the northwest side of the Needles Peak and may be reached by the Glacier Creek trail. The mine is about three-quarters of a mile from Monte Cristo and the major adit is at an elevation of 4,000 feet. Much early development work was done on this vein and three levels were developed. While the railway was in operation, over 100,000 tons of ore were produced. It was concentrated below the tunnel mouths and taken downhill to a railway spur from where it was shipped. The ore minerals are arsenopyrite, pyrite, and chalcocite; assays from the vein material run as high as $30.00 per ton, which is lower than the values in the weathered surface zones. Total development includes over 3,000 feet of underground tunnels; the mine was worked after the railway was shut down.

Structurally, this vein is in conformity with the major jointing of the district and it is possible that it swings around to become one with the veins upon which the Monte Cristo Mine is located. It is narrower than many of the other veins, but contains a higher concentration of sulphides. While most of the apparent ore has been removed it is possible that there are large areas of bonanza quality in this joint zone. One of the more striking mineralogical features is the large quantity of realgar and orpiment associated with comb quartz. This indicates at least one era of filling and that mineralogical association is more of a surface than of a deep-seated deposit. The vein is almost exclusively in andesites but fragments of tonalite and replacement breccias are found in the tunnels and in the dump. Development of this property might prove the presence of other ore shoots.

The Rainy Mine. This vein is located about one-quarter of a mile northeast of Monte Cristo along the Glacier Basin trail. As it was the most easily accessible of the major deposits, it was readily developed. Over 20,000 tons of ore were mined from a single major ore body; the vein itself was about 5 feet wide. Strike of the vein is N. 10 E., the dip is almost vertical. Unlike the two preceding veins, which were in andesite, this deposit is surrounded by schist, but tonalite is found nearby.

Structurally, the deposit seems to be in a clearly mineralized fracture zone. The ore minerals were arsenopyrite and pyrite; the high grade assayed as much as $50.00 per ton. Unfortunately, the mine workings were made low, near the valley floor, and surface waters continually flooded them. The large amount of snow in winter also made this unworkable and when the railway was abandoned the inavailability caused the mine to close down. Considerable development would have to be done to rehabilitate these workings.

Northwest Consolidated Mine. The vein is located on the west side of Weden Creek at an elevation of about 4,000 feet. The vein runs along joint planes both in conformity and at right angles to the major jointing. Certain intersections bear massive sulphides that are rich in gold but comparatively poor in silver. This mine has never had accessibility via railroad; in the past the ore was concentrated on the spot and the concentrate was carried down to the railroad by burro. Reportedly more than 20,000 tons of ore were mined. The relationship to the country rock is different than any of the other mines; it cuts through the early sedimentary formations of the district. There are sections of tonalite and of breccias to be found in the tunnel; it is very close to the contact between the sedimentary rocks and a large tonalite dike. Mineralization is unique; pyrrhotite is the major mineral with large quantities of chalcopyrite present, while arsenopyrite, pyrite, and quartz are also found. There are pockets of almost pure sulphides that are very rich. Should a road be put through Weden Pass, to the south, this mine would become a distinct economic possibility.

Seventy-six Mine. The mine is located on the east side of Seventy-six Gulch at an elevation of 4,500 feet about one mile to the south of Monte Cristo. The vein was the first to be discovered in the area and surface mineralization seems to indicate a very rich ore deposit. However, development work, which consists of two adits, has never encountered any rich zone. The mineralization is arsenopyrite, chalcopyrite, galena, and bornite.

Structurally, this is perhaps the most interesting of the veins; it cuts through the massive side of Wilmon Peak striking N. 60° W. and dipping 75° to the N. W. The vein may be seen cutting up the side of the mountain until it disappears under the permanent ice and snow. Although not verified, it is quite possible that this is the same vein that comes out as the Golden Cord vein on the north side of Wilmon Peak. It is a well-mineralized fracture zone showing every indication of deep-seated origin. The vein itself lies in andesites but the float on the dump and specimens taken from the tunnels show that the tonalite cuts the vein and that many replacement breccias are present. Surface assays show spot values of $50.00 per ton in gold and silver. If the area as a whole were developed this mine would almost certainly be worked.

O. and B. Mine. Located about half a mile to the south west of Monte Cristo at an elevation of 4,500 feet, the vein is found on the north slope of Silver Tip Peak. It is essentially a wide fracture zone in the andesite which strikes N. 30° E. and dips 65° N. W. While located in the andesite, many specimens taken from the vein are identical with the tonalite. As might be expected, the ore bodies are lenticular in shape and generally are rather small, with the principal minerals: chalcopyrite, arsenopyrite, and pyrite. The ore, on the surface, assays up to $35.00 per ton. There has been considerable development work done along this fracture zone but no large ore bodies have been encountered. Production has consisted almost entirely of carloads of hand-sorted ore. While further development may discover a large workable deposit present indications are not favorable. With development of the area as a whole, further exploration would certainly be done along these workings.

Weden Creek Mine. This mine is located on the east side of Weden Creek about half a mile from the road and about two miles west of Monte Cristo. It is in the shear zone in the ultrabasic dike which cuts the sedimentary rocks. Apparently, the mineralization zone is on the hanging wall. The rock, in which the ore sulphides are located, seems to be almost entirely serpentine. Ore minerals are chalcopyrite, pyrite, calcite, pyrrhotite, and possibly pentlandite; although exact values are not known, the mine was operated for gold, silver and copper. The serpentine has altered to talc on the surface. The mine itself consists of two adits driven into the serpentine rock close to the contact with the sediments. During the recent war this mine had a road bulldozed from the highway up to it; this road, which is the most recent development in the area, cuts off from the highway to Monte Cristo just after Weden Creek enters the Sauk River. It runs from an elevation of 2,000 feet to 3,500 feet.

Structurally, as well as mineralogically, the deposit is quite different than any of the others. The vein strike is N. 65° W. and the dip about 85° to the N. E. It is in close proximity to the basalt and there is a distinct probability that this dike is the conduit for the materials that compose the basalt lava. This is apparently confirmed by the concentrates of similar sulphides at the base of the basalt flow and the similarity of olivines and pyroxenes. Some development work on this mine and the area nearby might turn it into a profitable workings.

Theory of Ore Deposition

The majority of veins are located along the joint planes of the region, frequently in close proximity to the intrusive tonalite, and the average strike is about that of the jointing. The best veins are those in Glacier Basin, in Seventy-six Gulch, and those on the north side of Silver Tip Peak. These veins are all found in the andesite, but there are also veins in the sedimentary rocks, along tonalite contacts, and along schist contacts. Although many veins show signs of fracturing, the amount of movement in most cases was slight. The only clearly defined shear zone is that of the ultrabasic dike.

While many of the veins are in the andesite series, in every case examined by the author, tonalite float was found on the dump and in many cases the inside of the workings showed granitic rocks. There were also a large number of andesite breccias which were not formed by normal fracturing. Thin sections of both of these types of rock indicate that they are of replacement origin. In those veins that cut through the schist, replacement zones were likewise apparent, however, the contact between the schist and the tonalite is normally quite sharp.

The mineralogy of the veins is varied; quartz and arsenopyrite are almost always the first minerals, followed by pyrite, chalcopyrite, sphalerite, galena, bornite, quartz, realgar, calcite, and orpiment, with the last four named minerals always secondary in nature. A series of polished sections made of the ore samples showed that a typical paragenesis would follow the above outline. In some cases pyrrhotite is present and when found it is usually the first mineral. The mineralogical association is fairly typical of a deep-seated sulphide vein and the ore minerals frequently occur together in large lenticular bodies.

The mineralized zones extend from the valley floors up to the crests of the mountainous ridges; there seems to be no decrease in amount of sulphide material deposited at great height. This fact has been used as evidence that the veins must have been formed by downward descending meteoric waters; certainly the realgar, orpiment, calcite and late quartz were clearly deposited by meteoric waters, probably filling in cavities caused by fracturing. The surface ores are richer in gold and silver than those at depth. While the silver seems to have been definitely enriched, the gold values have increased simply because much of the surrounding material was removed by weathering. There seems to be no zone of secondary sulphide enrichment.

Some of the ore deposition has taken place through the action of descending waters. It is the author's opinion that the majority of deposition took place from hot ascending sulphide solutions which may well have had a magmatic body or residuum as their source. In the hydrothermal zonal classification these veins would probably be considered as Hypothermal Deposits. The structure supports this theory, the mineralization is favorable and thin section analysis shows that the mineralization is a replacement rather than a filling phenomena. In favor of this theory is the great elevation to which some of the ore deposits are found; if descending waters had done the deposition, these ore bodies should certainly have been weathered by now. The presence of arsenopyrite and pyrrhotite in the ores is typical of a hypothermal deposit and the fact that they increase in quantity as one goes down in depth would seem to favor this.

A study of the breccias and the ore contacts in the veins, which shows the ore minerals replacing the country rock, also supports this theory for it is doubtful that meteoric waters could do quite as much replacement work. The presence of sphalerite and galena near the surface has been taken as indicating a zonal development by descending waters; this might just as easily be zonal deposition by ascending waters. The galena seems to be found only in the highest zones and the sphalerite in intermediate zones; below this arsenopyrite, pyrrhotite, chalcopyrite and pyrite are the sulphides. Considering the facts, the author has classified the veins as hypothermal.

SUMMARY AND CONCLUSIONS

The ore deposits of the Monte Cristo district lie in veins which are located along fracture planes or in contact zones between the country rock and the granitic rock. As a rule they strike about N. 70° E. and dip 70° to the N. W. While they are frequently located in andesitic rocks the tonalite seems to be present in all of the deposits. The mineralogy is that of a hydrothermal sulphide vein: pyrrhotite, arsenopyrite, quartz, pyrite, chalcopyrite, galena and sphalerite. In all cases the ores have been introduced by replacement processes. The ore bodies are usually lenticular in shape and frequently are enriched where cross joints encounter the major vein; the veins are probably hypothermal in origin.

The ore deposits seem to be tied in with the granitization of the area. The tonalite has apparently been formed by replacement of the country rock by hydrothermal solutions; likewise, the ore deposits have been formed by hydrothermal replacement of the country rock. It is the belief of the author that these are both phases of a single continuous process of replacement by hot ascending magmatic solutions. If so, the general geologic history of the area would necessarily follow that previously outlined until the late Pliocene uplift. At that time the many joint cracks of the area were undoubtedly formed. With the development of these planes of weakness residual magmatic solutions were able to work their way up to the surface. While so doing, they mineralized the fracture zones and the ore deposits were formed.

There are many good prospects in the region which lack accessibility but which may become economically feasible once the district has opened up. New road work is being done at the present time and better transportation facilities may enable some of the older mines to reopen. If these mines come into production, the way will be open for development of the entire area.

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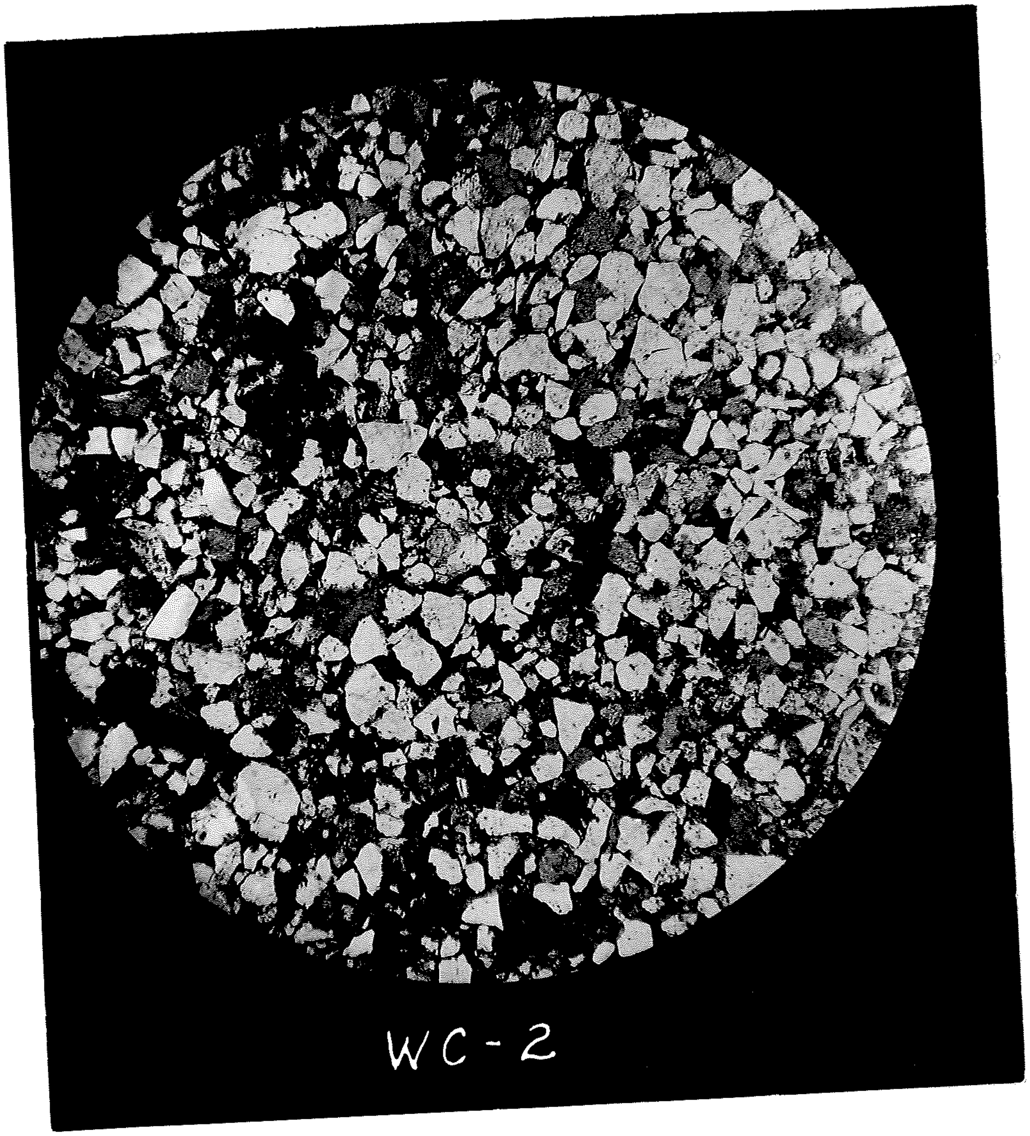
Thin Sections, Sandstone

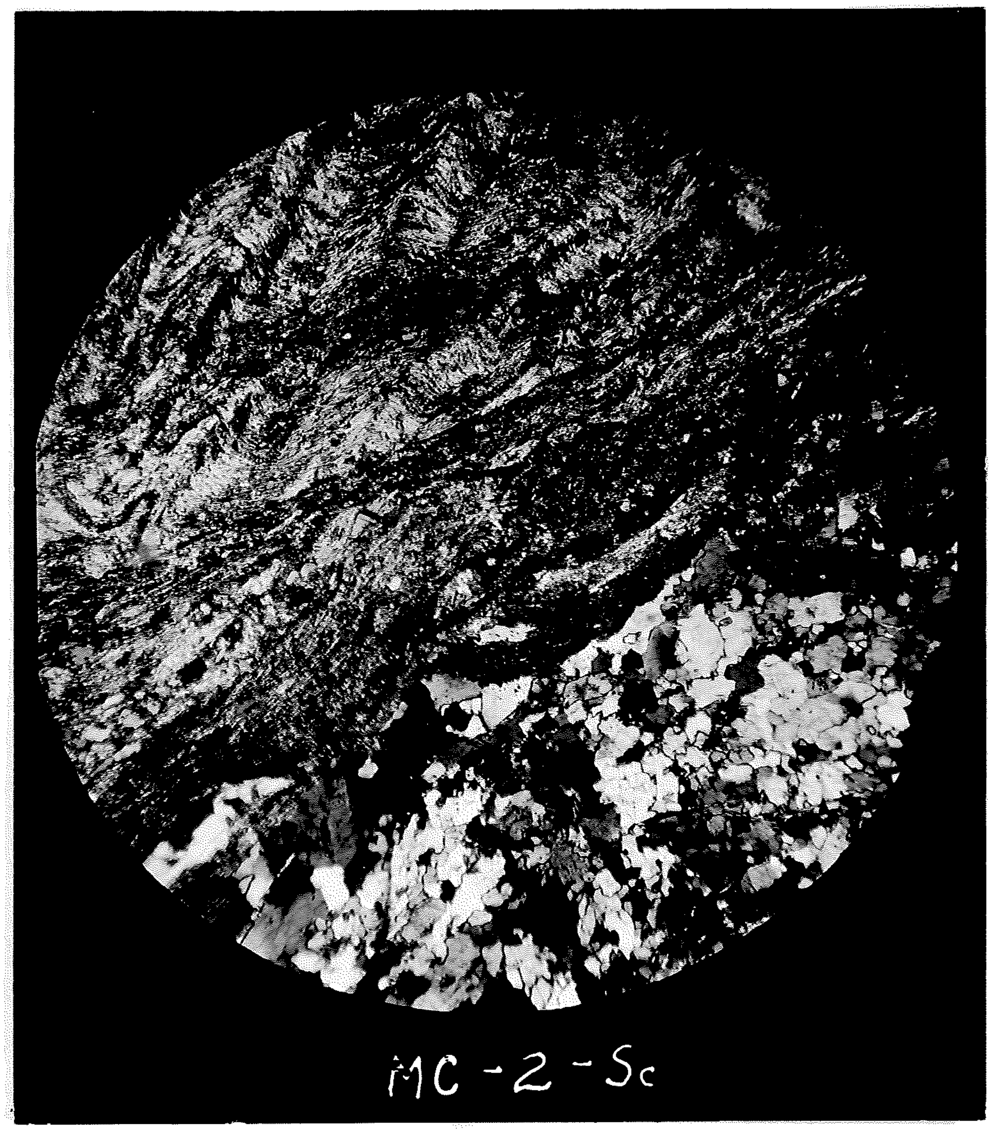
Plate IX



The angulate quartz grains of this sandstone show that they did not travel very far; the rock is a land sediment in origin. Shales and arkoses of the sedimentary series show the same feature.

Thin Sections, Schist

Plate XI



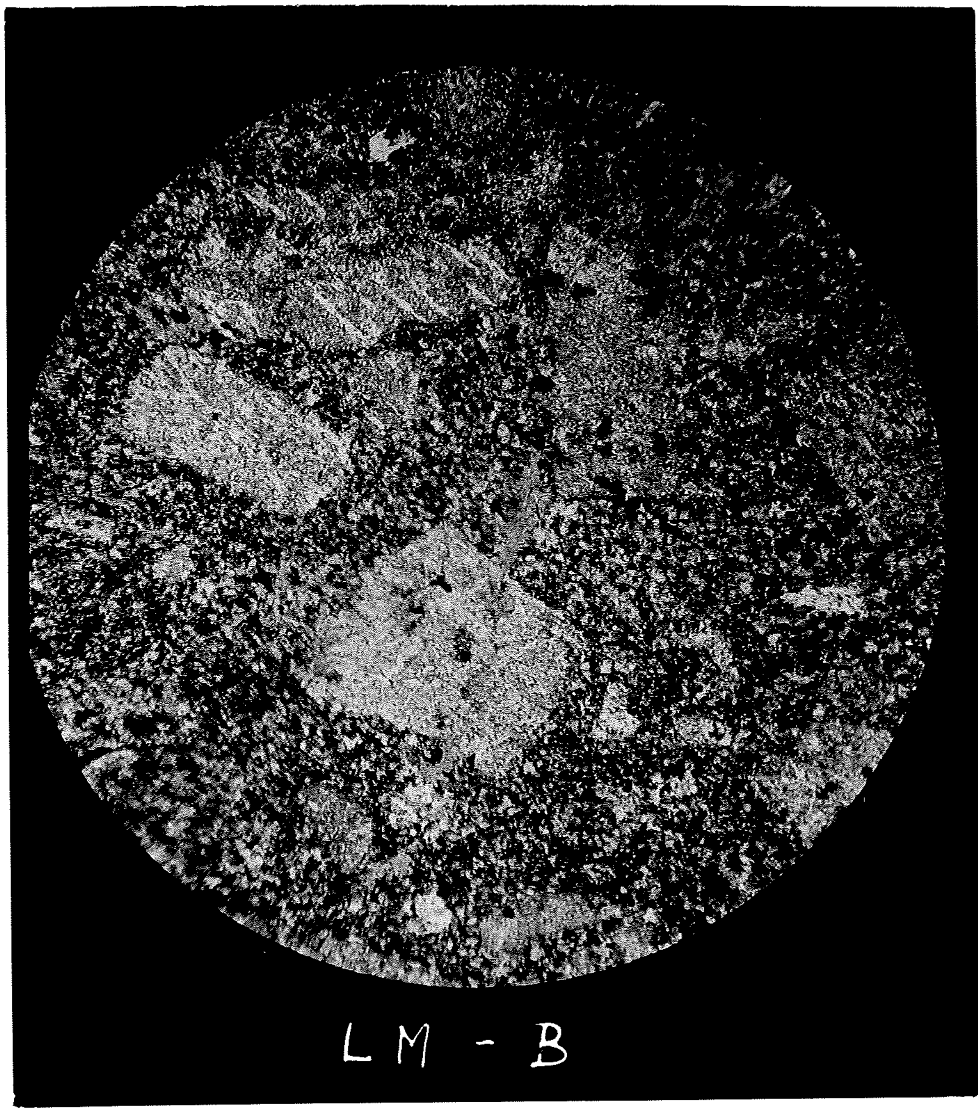
The schist is from the south side of Coney Peak. The rock is probably derived from sedimentary rocks. It shows excellent, minute folds in the upper left of the photograph.

Thin Sections

Plate XII

Taken in plane light, the many small crystals of epidote stand out all over the thin section due to their high relief. The crystals are both isolated and in clusters; epidote is common in the metamorphic rocks near the edge of the intrusive tonalite. This particular rocks section is from Glacier Falls.

In the center of this photomicrograph is a large, striated crystal which shows a central zone of kaolinitic material. This would seem to indicate a porphyroblastic growth of the feldspar around this core. Throughout the tonalites this feature is observed. This rock is a tonalite from upper Glacier basin.



The incipient growth of plagioclase feldspar crystals may be seen in this photomicrograph. The rock is an andesite from Silver Tip Peak. The porphyroblasts are not visible to the naked eye in the hand specimen.

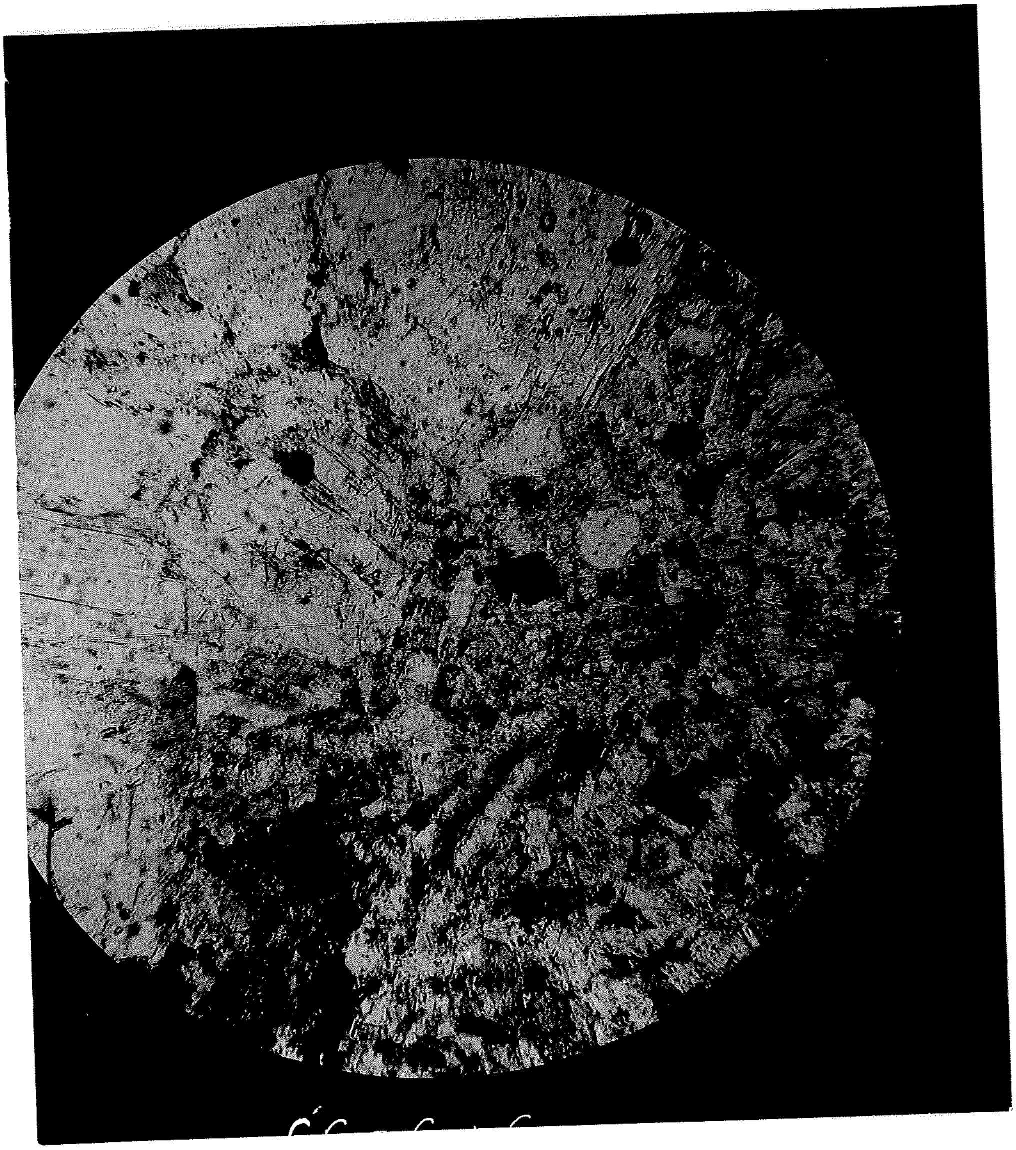
Plate XV

Thin Sections, Tonalite

In the upper left-hand corner of the photomicrograph is a large, zoned plagioclase crystal which has an inner zone of oligoclase and an outer zone of labradorite. It also contains inclusions of sericitic material. This seems to indicate a metamorphic origin. The tonalite is from the dike on the west side of Weden Creek.

Thin Sections, Tonalite-Andesite Contact

Plate XVI

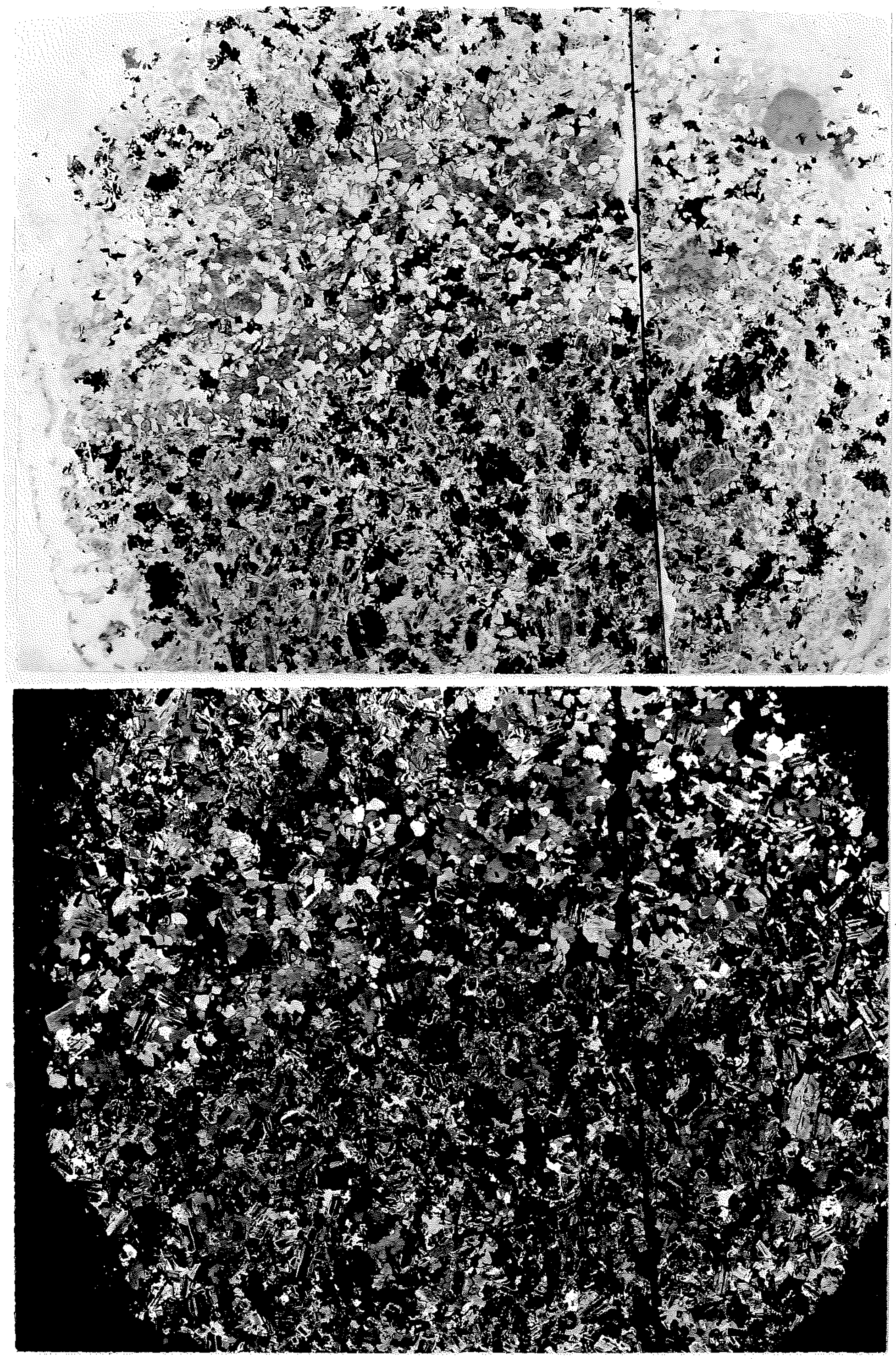


This is a section made of the contact between the tonalite, upper left, and the andesite, lower right. This photograph was made in plane light. The rock is from upper Glacier basin.

Thin Sections, Tonalite-Andesite Contact Plate XVII

This is the same thin section as in the preceding plate, but in this photomicrograph the nicols are crossed. In the lowere right may be seen the developing porphyroblastic feldspar crystals.

Large Section, Replacement Dikelet — Plate XVIII

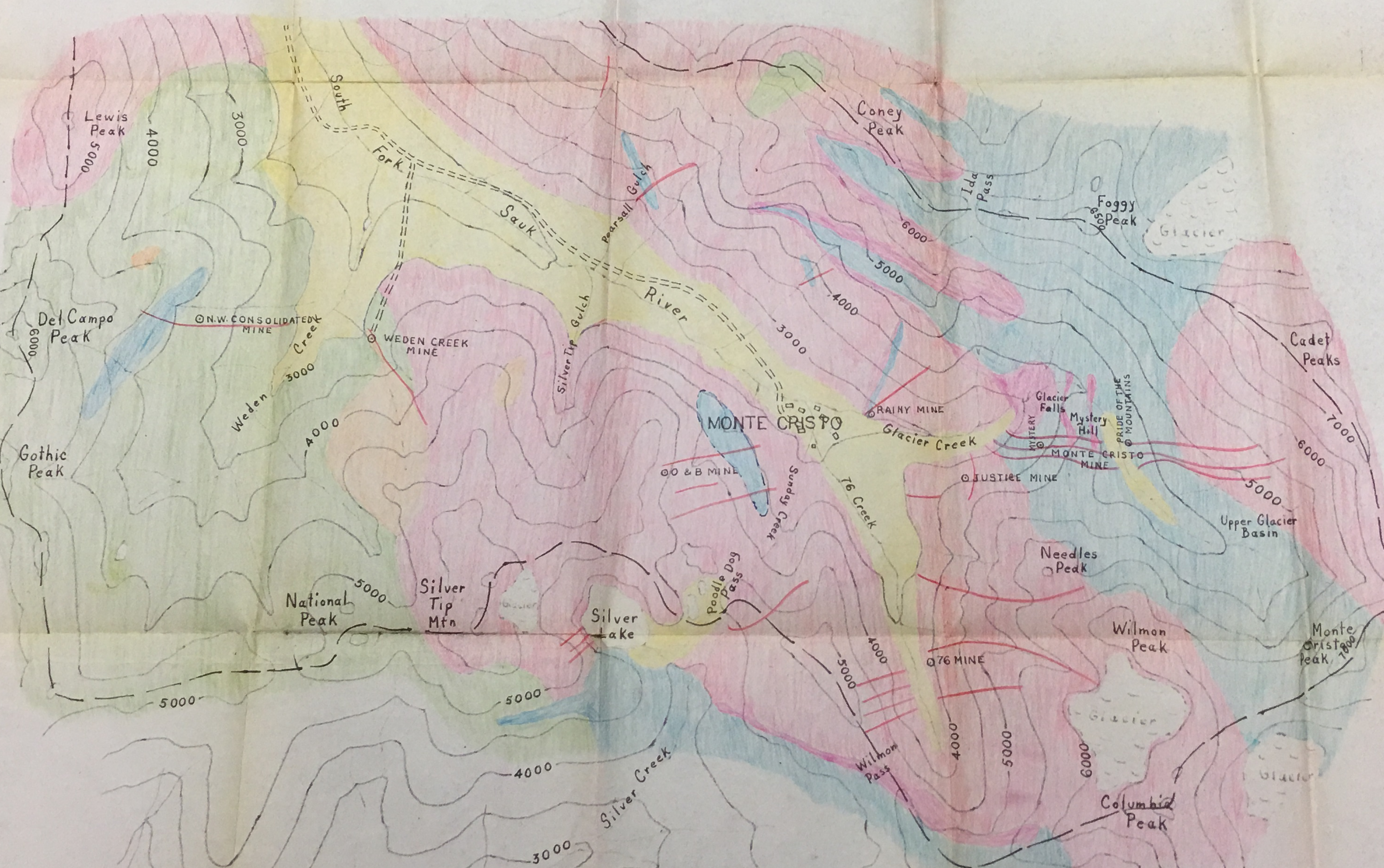


The upper photograph was taken in plane light; the dikelet shows up clearly. The lower photograph was taken under crossed nicols; the dikelet is undeterminable for it possesses the same features as surrounding rock.

PLATE I

GEOLOGICAL SKETCH MAP OF THE SOUTH FORK OF THE SAUK RIVER

BY B. E. GRIFFIN



LEGEND

- PLEISTOCENE–RECENT — ALLUVIUM
- MIOCENE — TONALITE
- MIOCENE — SCHIST
- MIOCENE — BASIC ROCK
- EOCENE–PLIOCENE — ANDESITE SERIES
- EOCENE — SEDIMENTARY SERIES
- PLIOCENE — MINERAL VEINS
- MINES
- DIRT ROADS

True North 25° Mag North

SCALE: 1 INCH = 1250 FEET

1250 0 1250 2500

CONTOUR INTERVAL — 500 FEET