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CONTACT METAMORPHISM AT RYE PATCH, NEVADA

BY CHARLES J. VITALIANO

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ABSTRACT

In the Rye Patch area in the west-central part of the Humboldt Range, Nevada, Triassic limestones interbedded with silty layers have been intruded by igneous rocks, the principal ty being a quartz monzonite. The quartz monzonite is surrounded on the north, east, and south by aureole of contact metamorphism. On the western side faulting has cut the intrusion so that metamorphic rocks which may have been formed are not seen at the surface. A long narrow cont zone east of the aureole extends northward a considerable distance.

Metamorphic changes range from recrystallization of limestone to complete replacement contact silicates. The contact-metamorphic minerals include garnet, diopside, epidote, clinozoi idocrase, tremolite, recrystallized calcite, quartz, and minor scheelite.

The sediments are deformed by the intrusion into a small northerly trending arch. Aplite di and quartz veins appear related to the arching and also to the formation of scheelite.

INTRODUCTION

In the mineralized area accompanying the Rye Patch intrusion, both invading an invaded rocks are well exposed. Study of such a region should yield information value in the interpretation of the mineral processes responsible for the associat tungsten mineralization and at the same time contribute to a better understandin of the stages of contact metamorphism in the Humboldt Range.

This investigation has comprised the study of: (1) the original sediments; (2 igneous intrusions; (3) contact-metamorphic products; (4) paragenetic sequence o the contact-metamorphic minerals; (5) reasons for the localization of the metamorp ism; and (6) later phases of the igneous invasion—namely, the pegmatitic and hydr thermal phases, including most of the tungsten mineralization.

Tungsten mineralization along the western slope of the Humboldt Range may b associated with two granitic intrusions. The Rocky Canyon intrusion, essentiall quartz monzonite (Jenney, 1935, p. 37), lies north and east of the Oreana tungste mine, while the Rye Patch intrusion, also quartz monzonite, lies about 10 miles t the north of the Rocky Canyon intrusion along Rye Patch Agnes Canyon.

Portions of the summers of 1938 and 1939 were spent in the field mapping part of the area in detail. The mineral relationships have been further investigated i the laboratory microscopically, chemically, and by X-rays.

The writer is deeply indebted to Professor Paul F. Kerr of Columbia Universit who suggested the problem and who has given helpful criticism both in the field an in the preparation of the report; to Mr. Charles H. Segerstrom, president, and M Ott F. Heizer, general manager, of the Nevada-Massachusetts Mining Compan

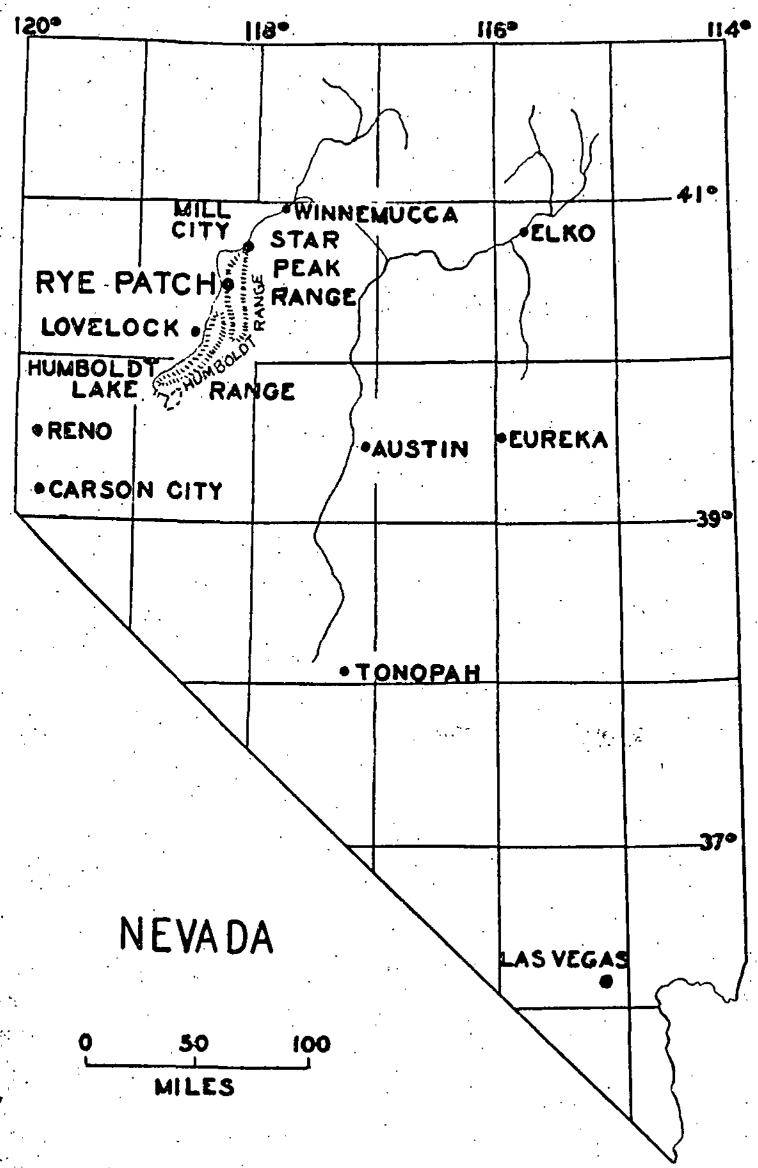


FIGURE 1.—*Index map of Nevada*
Showing the location of the area studied

with whose kind permission the writer stayed as a guest at Tungsten, Nevada; to Mr. Donald W. Davis of Columbia University, who assisted in the field during the summer of 1938; to Mr. Charles Shortino of Rye Patch, Nevada, for information concerning the mining operations in the area under discussion and permission to examine the Rye Patch Agnes workings; and to Columbia University, for the award of the James Furman Kemp Fellowship in Geology, through which this investigation was made possible.

GENERAL GEOLOGY

The Rye Patch area is largely underlain by blue, thin-bedded, northeasterly striking limestones, the prevailing dip being to the west. In Rye Patch Agnes Canyon a roughly oval-shaped area of brownish rock of about 20 acres marks the outcrop of the quartz monzonite here described as the Rye Patch intrusion.

The intrusion has produced two areas of contact-metamorphic rock, separated by a zone of relatively unmetamorphosed limestone. The first of these (called in this paper the inner area) contains some tactite and recrystallized limestone but is chiefly light silicate rock. It appears to surround the intrusion on the north, east, and south sides but does not outcrop on the western side because of faulting. The second (called the outer area) is linear in outcrop with a trend parallel to the strike of the sediments and is situated east of the first area. It is composed more abundantly of tactite but also contains light silicate rocks with appreciable recrystallized limestone.

Aplite and pegmatite dikes, along with quartz veins, represent later stages of the quartz monzonite intrusion. Pegmatites are limited to the border of the intrusion, while the aplites and quartz veins are more prominent in the rocks some distance removed. Some sulphide and tungsten mineralization has accompanied vein filling, and an attempt is being made to work sulphide-bearing veins containing silver in the Rye Patch Agnes mine. Tungsten mineralization is almost lacking in the immediate vicinity of the intrusion, but some scheelite is found in the quartz veins associated with the aplite dikes to the northwest.

Two other types of intrusive rocks, whose effect on the limestone has been negligible in contrast to that of the quartz monzonite, are dikes of an older metadiorite and a younger camptonite.

The broader structural features are shown on the map (Fig. 2). In general, the limestone and its metamorphic derivatives strike rather uniformly N. 15° E. (±10°) and dip 46° to 74° W. Across these dipping beds the surface of the monzonite intrusion, which occupies rougly the center of the map, rises from west to east at an angle of 12°.

The intrusion is bordered by an aureole of metamorphosed limestone, exceptionally wide near the middle of the northern rim. This wide triangular area coincides with an anticlinal bulge in the beds, the axis of which pitches toward the intrusion.

If the surface of the intrusion continued as a methematical plane with the dip as indicated, the outcrop should continue up the valley. Since it does not, either the intrusion dips into the hill at a lesser angle or ends here. The recurrence of metamorphosed limestone 500 feet to the east suggests that here either the same intrusion or an offshoot once again comes close to the surface (Fig. 11).

Near the eastern end of the outcrop of the intrusion, steeply inclined dikes lead off toward the NNE. and SSE., along fractures that essentially parallel the beds and the near-by contact of the limestones and the quartz monzonite. The whole feature is too small to warrant speculation concerning its origin other than that the fractures opened as a consequence of the intrusion itself. A few quartz dikes occupy related directions as do several small faults.

The intrusion is cut off near the western margin of the map by a normal fault that dips about 45° W.

SEDIMENTARY STRATA

Thin-bedded blue calcareous limestones with some intercalated silty beds cover most of the area. Later calcite veinlets are often present. Microscopically the limestone strata are almost entirely fine-grained calcite (chemical tests show only a trace of magnesium) with carbonaceous impurities and minor quartz. The more silty members contain varying amounts of quartz in addition to the carbonate.

The sediments are covered by valley alluvium on the west and abut against the Weaver rhyolite of the Koipato series on the east. The limestones are a continuation of those described by Ransom (1909, p. 31–32), Knopf (1924, p. 29), Jenney (1935, p. 29-30), and Kerr (1938, p. 398), in the area immediately to the south. Jenney assigned them to the upper Middle Triassic of the Star Peak formation, on the basis of a fauna representing the *Daonella dubia* zone. Near the mouth of Rye Patch Canyon a few coiled cephalopods were found, but they were too poorly preserved for identification.

The contact between the limestone and the Weaver rhyolite where it crosses Panther Canyon suggests that the sediments overlie the rhyolite disconformably. At Rye Patch, part of the contact between the limestone and the rhyolite is faulted, but exposures in other places immediately adjacent on either side of the contact suggest the existence of a slight angular unconformity, although the actual contact is not well exposed. Wheeler (1936, p. 394) tentatively assigns the Weaver formation to the late Paleozoic, on the basis of this disconformity and on the absence of volcanics in the lower Star Peak formation. Cameron (1939, p. 579) classifies the rhyolite formation as either Upper Paleozoic or Triassic.

INTRUSIVE ROCKS

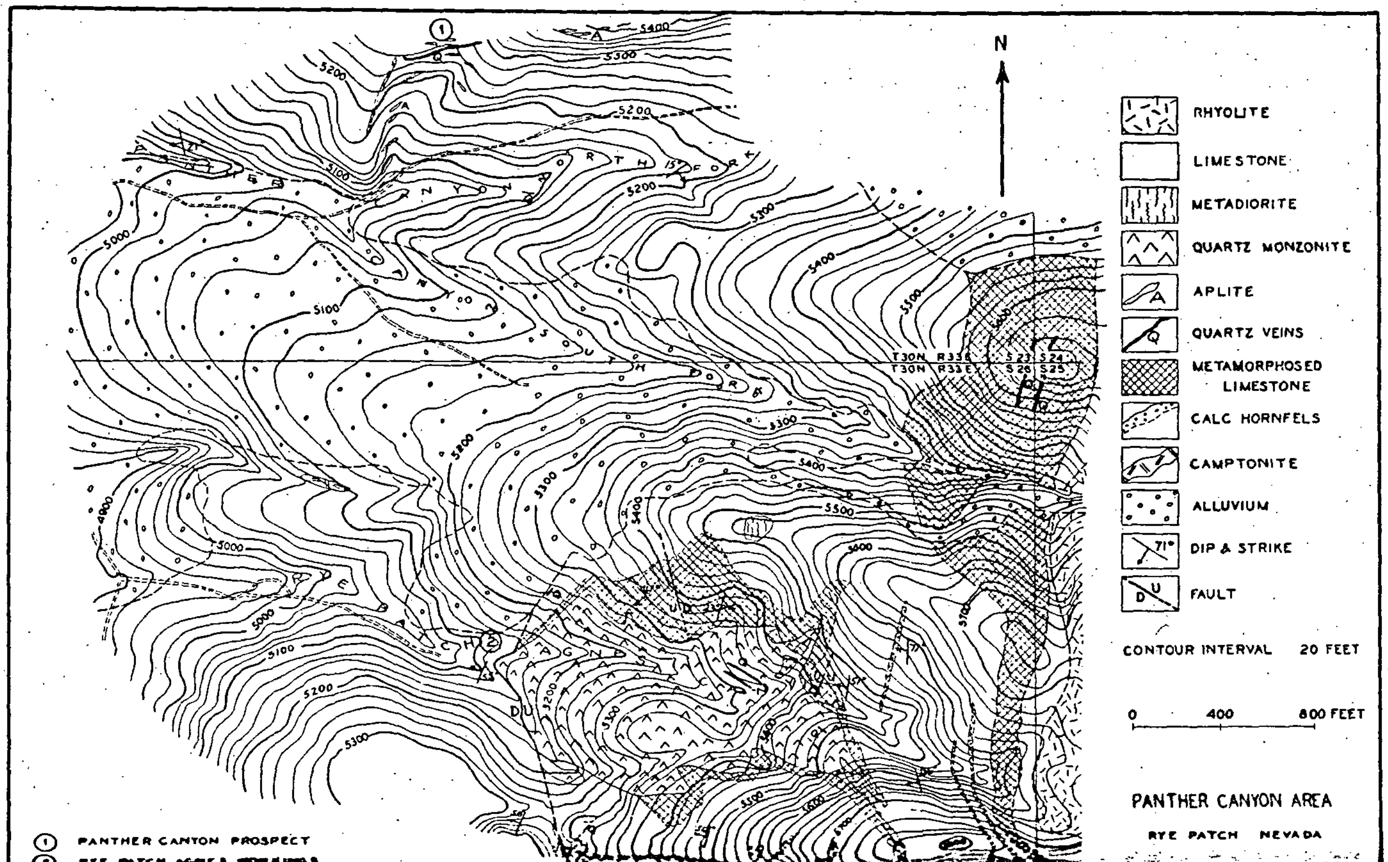
GENERAL STATEMENT

Both acid and basic rocks intrude the sedimentary strata of the Rye Patch area. The earliest is a metamorphosed diorite, exposed in two small outcrops. The largest and most important is the quartz monzonite, found in Rye Patch Agnes Canyon. Dikes of camptonite are the latest igneous rock.

METADIORITE

One outcrop of metadiorite is situated about 1300 feet northeast of the main portal of the Rye Patch Agnes Mine (Fig. 3), and the other lies about 900 feet to the south-southeast. The latter is cut on the west by a fault which also truncates the western part of the inner contact area. In the south-southeast the metadiorite appears to be cut by later dikes.

Mineralogically, the metadiorite is chiefly oligoclase showing albite twinning, fibrous actinolite, biotite, and magnetite. Small amounts of sphene, epidote, zircon, and some apatite, along with infrequent interstitial quartz which locally may be present in fair amount, are accessory. The amphibole (Fig. 4A) occurs in sheaves similar to that in the metadiorite of the Rochester district (Knopf, 1924, p. 31). Another facies is composed of quartz and feldspar grains averaging 0.02 mm. in diameter between folia of chlorite. In all sections the schistosity is very marked (Fig. 4B).



N
RHYOLITE
LIMESTONE
METADIORITE
QUARTZ MONZONITE
APLITE
QUARTZ VEINS
METAMORPHOSED LIMESTONE
CALC HORNFELS
CAMPTONITE
ALLUVIUM
DIP & STRIKE
FAULT
CONTOUR INTERVAL 20 FEET
0 400 800 FEET
PANTHER CANYON AREA
RYE PATCH NEVADA
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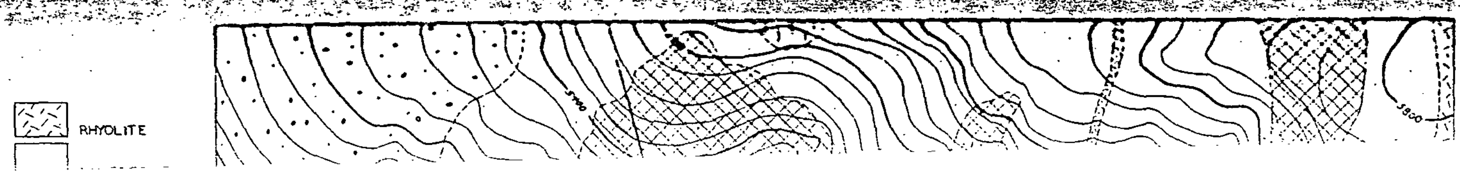
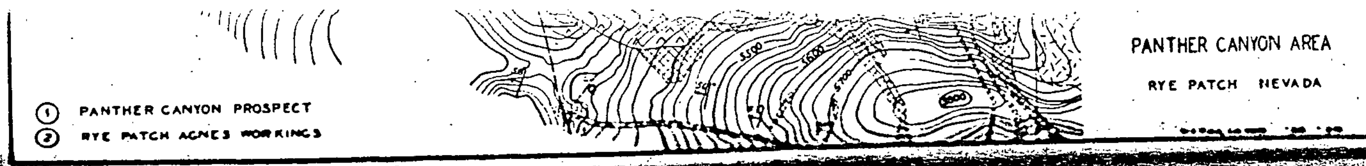


RHYOLITE



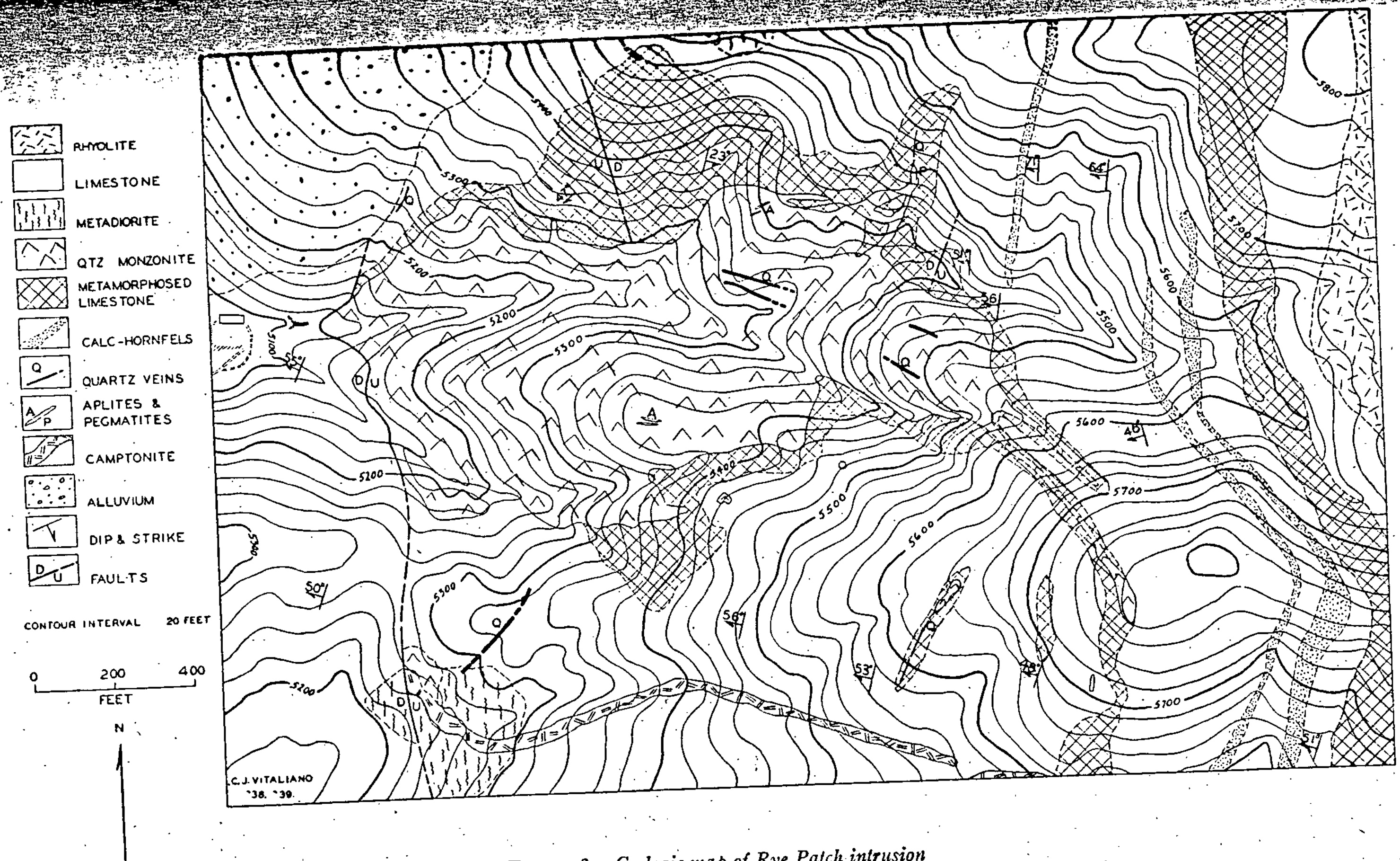
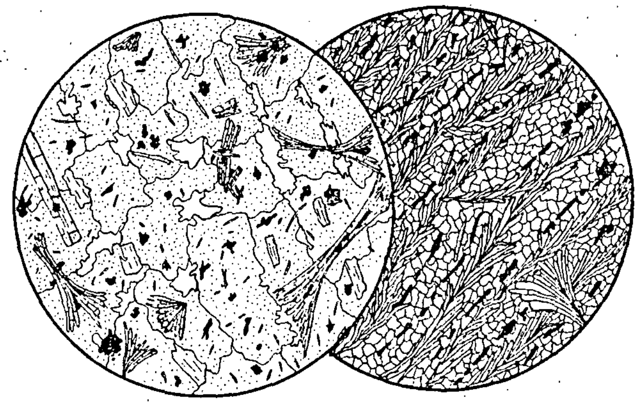


FIGURE 3.—*Geologic map of Rye Patch intrusion*

Knopf (1924) dated the metadiorite as Triassic or earlier because of its metamor character and connected it with the Triassic igneous activity. Kerr (1938, p. and Jenney (1935, p. 30) described rocks of the same type from the central Humb Range, just south of Rye Patch.



A B

FIGURE 4.—*Metadiorite phases*

A. Maculose phase:—quartz, white; oligoclase, spotted; actinolite, sheaf like aggregates; biotite, dashed l *magnetite*, black. × 15.

B. Schistose phase:—chlorite, lath like grains; actinolite, sheaf like aggregates; quartz and feldspar, uncol epidote, black. × 15.

Diagrammatic sketches from microscopic field.

QUARTZ MONZONITE

The quartz monzonite is light-colored, medium-grained, composed of qua feldspar, and mica. Orthoclase, oligoclase, microcline, and microperthite make most of the rock. Myrmekite and free quartz occur in anhedral grains. Bio and some accessory minerals—sphene, apatite, magnetite, and pyrite—complete th mineralogy. The biotite occurs in well-developed grains averaging 5.0 mm. in leng and showing marked absorption—(X) colorless, (Y) dark green, (Z) dark gre Both sericitization and carbonation of the feldspars occur along fractures, wh biotite grains have been slightly corroded. The following is an analysis of this m determined by the traverse method:

	Per cent		Per cent
Quartz	24.8	Apatite	0.1
Oligoclase	21.4	Epidote	0.1
Microperthite	19.6	Calcite	0.1
Orthoclase	17.5	Hematite	0.1
Microcline	9.0	Chlorite	0.1
Biotite	5.9	Zircon	tr.
Magnetite	0.6		
Muscovite	0.5	Total	100.1
Sphene	0.2		

Jointing is well developed in the northeastern part of the intrusion. The joi fall into two patterns: one set strikes N. 25° E. and dips 48° ESE., and the oth strikes N. 70° E. and dips 65° NNW. Near the northern edge of the intrusion pro some small aplite dikes parallel the latter set of joints.

The quartz monzonite has been intruded into the limestone strata. At the eastern edge of the limestone the contact can be seen in numerous exposures and conforms to the bedding of the sediments (Fig. 5). The western contact is obviously faulted, as indicated by the existence of a crush zone (Fig. 5).

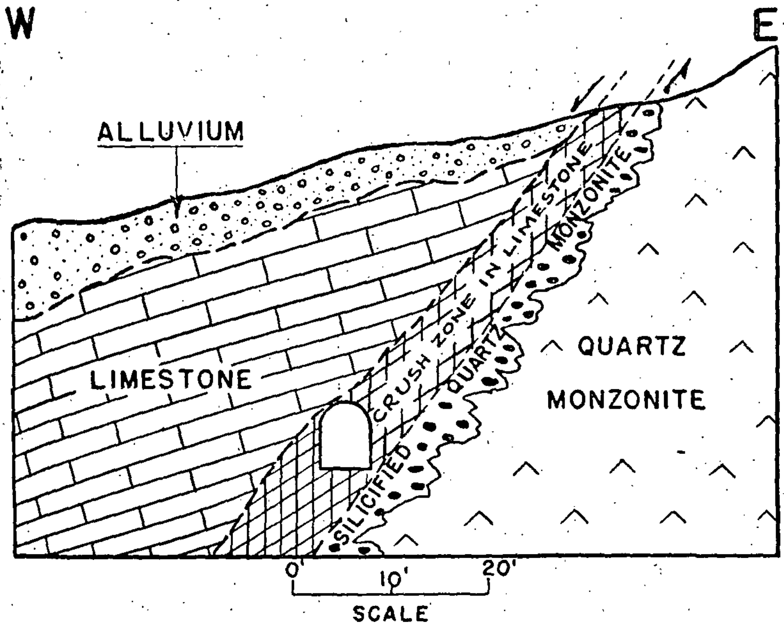


FIGURE 5.—*Diagrammatic representation of the western contact of the quartz monzonite*
The crush zone and the zone of silicified monzonite are shown

Exposures on the northern side of Rye Patch Canyon clearly indicate that in the upper reaches of the intrusion the limestone beds have been pried apart by the invading magma. Arching of the sedimentary rocks has been accompanied by fracturing of the competent beds and drag folding of the incompetent (Fig. 6). The extension of the arch northward is believed to be due to the continuance of this sill-like character of the intrusion.

A petrographic comparison with the Rocky Canyon intrusion about 10 miles south of this area shows that the Rye Patch rock is finer-grained, more compact, and contains a little more biotite than the former, but otherwise the two appear to be substantially the same. Probably both extend downward to the same granite mass. In the Rye Patch area, the lack of Mesozoic sediments later than Middle Triassic limits the quartz monzonite to post-Middle Triassic. Unless positive evidence to the contrary can be established, it is reasonable to assume that the quartz monzonite belongs to the same magmatic epoch as the widespread intrusions of western Nevada. These, according to many different investigators,[1] are probably post-Jurassic.

[1] Louderback (1904, p. 318); Spurr (1905, p. 133); Ball (1908, p. 42); Diller (1908, p. 90); Lindgren (1915, p. 14); Knopf (1918, p. 11); Kerr (1934, p. 14); Jenney (1935, p. 47); Ferguson and Muller (1936, p. 394); Gianella (1936, p. 43); Kerr (1938, p. 401).

APLITES

The aplite dikes either fill joints or occur at random throughout the quartz monzonite. They vary in width from 1 inch up to 1 foot. Aplites also occur about half a mile north of the intrusion, where they reach $2\frac{1}{2}$ feet in width and where they have

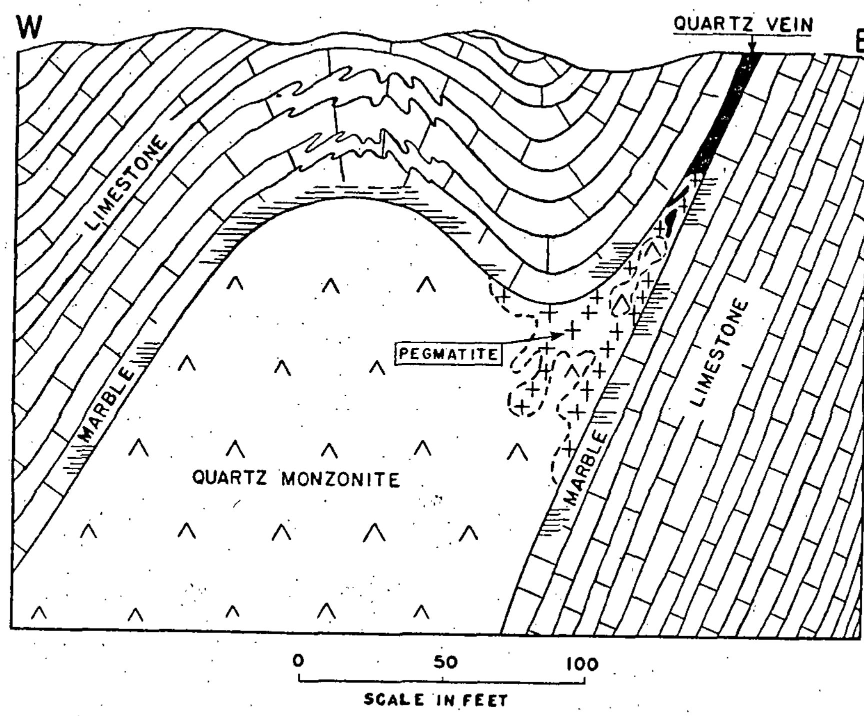


FIGURE 6.—*Section along north wall of Rye Patch Agnes Canyon*

Showing local arching of the overlying limestone beds over the intrusion. Note the conformable relation between the limestone and the intrusion which probably exists only in the upper reaches of the igneous mass.

invaded and altered the limestone. Here tungsten mineralization has resulted at a late phase of this invasion. Sill-like aplitic layers occur intercalated with the limestone immediately below a scheelite-bearing quartz vein and across the crest of the structural arch.

Quartz, orthoclase, microcline, oligoclase, and some microperthite make up most of the aplite, the remainder consisting of a few scattered grains of biotite and occasional muscovite. The texture is medium- to fine-grained.

PEGMATITES

Quantitatively, the pegmatite stage of the intrusion at Rye Patch has not been extensive. Unlike the aplites, the pegmatites are restricted to the immediate vicinity of the intrusion. They pass downward into the quartz monzonite, and upward into quartz veins (Fig. 7). The passage of pegmatites into the parent magmatic body, into quartz masses, or into aplites has been reported from many mass. It is particularly characteristic of the Humboldt Range (Kerr, 1938). At Rye Patch, an excellent exposure shows the transition from the quartz monzonite into pegmatite, which in turn becomes more and more quartz-rich and passes finally into a quartz vein; the entire change is accomplished within 25 feet (Fig. 7).

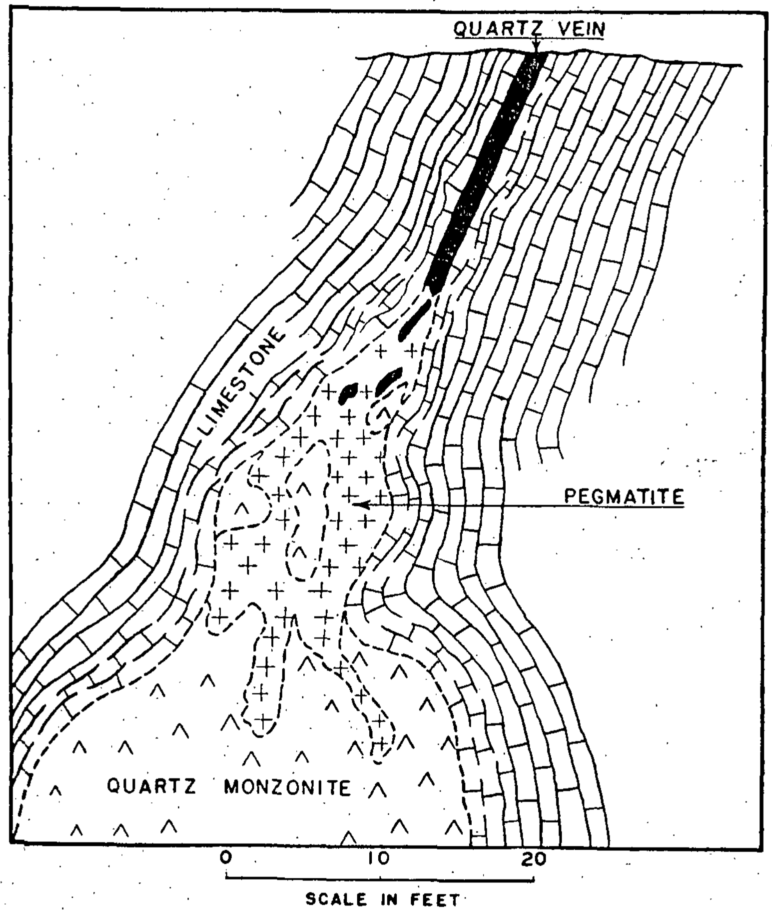


FIGURE 7.—*Pegmatitic relations*

The sketch shows the gradation of pegmatite into quartz above and into quartz monzonite below. This change is very gradual, with small isolated patches of the new phase appearing first. These grow more numerous and larger, and pass finally into the solid mass.

LAMPROPHYRES

In many places basic dikes younger than the quartz monzonite are found. In the area mapped these have been found only in limestone. Immediately south of the area Jenney (1935, map) has shown these same dikes cutting the Rocky Canyon granite. The dikes are nearly always vertical and in some cases—*e.g.*, at the Rye Patch Mine—they follow fault planes. Their width never exceeds 25 feet. In several places schistosity is developed near the walls of the dikes. Occasionally, contact-metamorphic lime-silicate minerals are found at the contact. These new

minerals are patchy in distribution, idocrase generally being the most abu
(Fig. 8).

An east-west line, drawn just south of the Rye Patch intrusion, divides these rocks into two groups: Those north of this line contain hornblende and biotite,

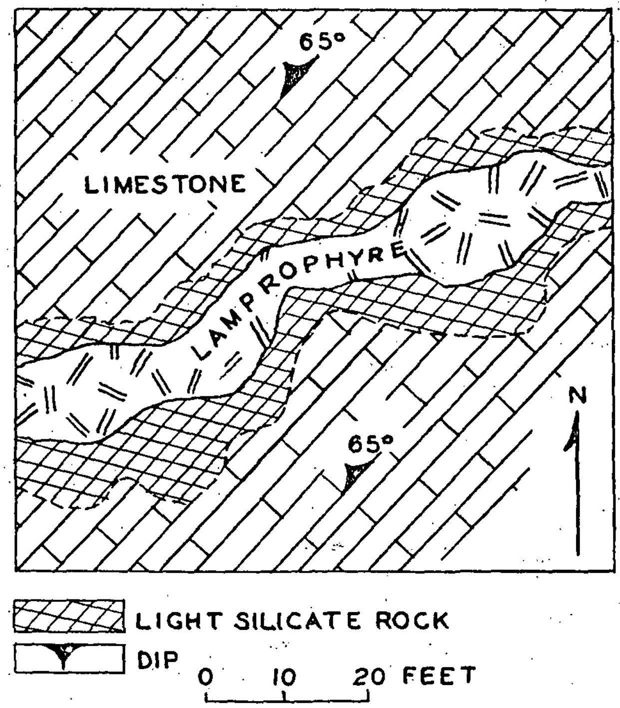


FIGURE 8.—*Contact metamorphism around lamprophyre dike*

Pace-compass map showing contact metamorphic phenomena produced by the intrusion of lamprophyre into the limestone. Occasional masses of idocrase are developed.

south of it biotite alone. The remaining minerals are the same. The feldspar andesine ($n_\alpha = 1.549$, $n_\gamma = 1.558$), optically positive, showing excellent zonal development and twinned according to both the albite and pericline laws (Fig. It and the ferromagnesian minerals occur both as phenocrysts and in the groundmass. Occasionally these minerals occur in two generations of phenocrysts (Fig. Magnetite is the most prominent accessory mineral. Hydrothermal alteration has caused sericitization of the feldspar, carbonation of the feldspar and amphibole, and chloritization of the biotite and amphibole. Various stages of alteration may be seen, the extreme being carbonate pseudomorphs after andesine and hornblende. Weathering has oxidized magnetite to limonite, particularly along fractures. In view of the mineralogy it seems proper to classify these rocks as hornblende lamprophyre and mica lamprophyre, respectively.

Thin sections of a related dike rock occurring to the south near the portal of

Rye Patch Mine were compared with those in the area mapped. Andesine and biotite form phenocrysts in this rock, while hornblende is absent. This dike was referred to by Ransome (1909, p. 44) as a diabase and mapped as such by Jenney (1935, map).

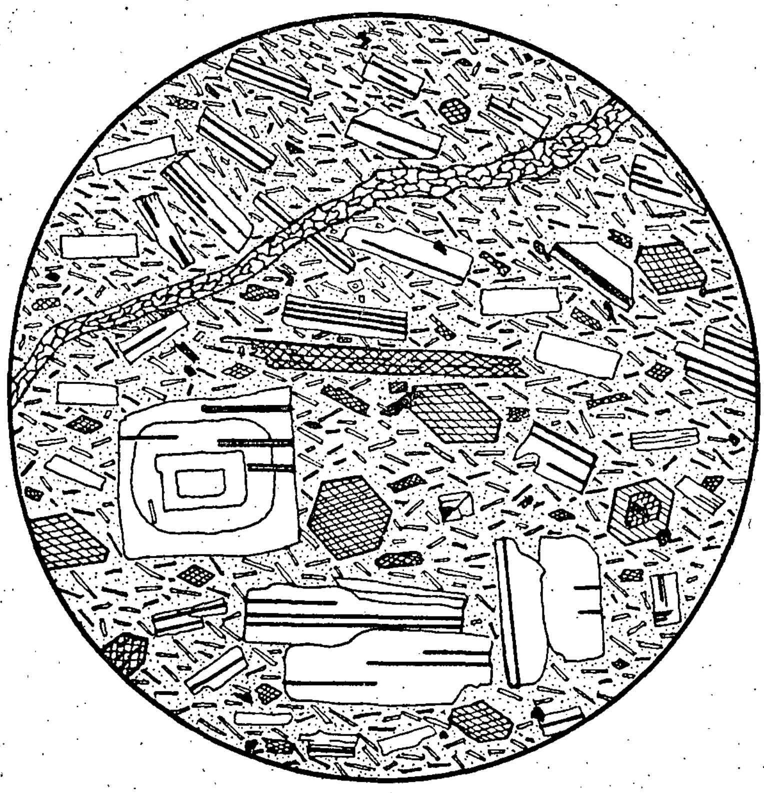


FIGURE 9.—*Hornblende lamprophyre*

Andesine, colorless or twinned; hornblende, cross-ruled. The dotted area represents very fine-grained groundmass in which some glass is present. A veinlet of later quartz traverses the rock. Diagrammatic sketch from microscopic field. × [illegible]

CONTACT METAMORPHISM

GENERAL STATEMENT

The intrusion of the quartz monzonite has resulted in three types of contact metamorphism: (1) the recrystallization of the original limestone; (2) the most widespread,—the formation of lime-silicate rocks, believed to represent the higher stages of contact metamorphism in the area; and (3) a slight development of calc-hornfels. The role of the lamprophyres in the contact-metamorphic history of the Rye Patch area has been negligible. Recrystallization of the limestone sometimes occurs without silicate mineralization, but the formation of silicate minerals requires a preceding or accompanying stage of recrystallization of the limestone.

The inner area of contact metamorphism surrounds the igneous rock on three sides. The outer area is linear and varies in width (Fig. 10). It starts southeast of the quartz monzonite and follows the strike of the sediments northward for appro-

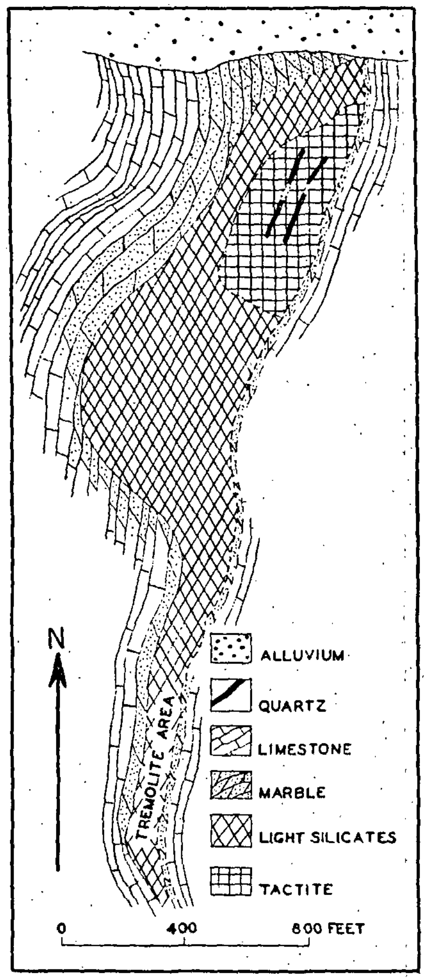


FIGURE 10.—*Sketch map showing distribution of rock types in outer contact area*

Tactite occurs in the northeast portion of the area, and grades westward and southward into light silicate rock. This passes on the west into marble, which in turn grades into unaltered limestone.

mately three-quarters of a mile. Between this and the inner area lies a strip of lime-stone about 400 to 600 feet wide, which is unmetamorphosed except for a few lenses of calc-hornfels.

RECRYSTALLIZED LIMESTONE

Large areas of white recrystallized limestone are scattered throughout the Rye Patch area. In the inner contact aureole, they occur on the northern and southern sides of the intrusion. Two limestone pendants in the extreme northern part of the intrusion (Fig. 3) have been almost entirely recrystallized. In many instances, the marble comes into contact with the igneous rock. In the outer contact area, the northwestern margin is bordered by a band of marble about 300 feet wide.

Mineralogically, the marble is composed of irregular interlocking calcite grains, which vary in size depending upon the location of the rock, growing coarser toward the intrusion. Locally a few grains of silicate minerals, generally diopside, are scattered throughout the marble. The contact with almost pure limestone on the one side and the increase of silicate grains toward the main tactite mass on the other side suggest that these are the result of introduced mineralization.

Umpleby (1917, p. 66) raised the question of time continuity between marmorization and silication. He states:

"Whether or not there was a distinct break between the two stages is not definitely determinable from the available evidence.... It is the opinion of the writer, however, that two separate and distinct epochs of magmatic emanations are represented...."

At Rye Patch, however, the evidence seems to indicate little time between the two processes. This is especially apparent in thin section, where unaltered areas of limestone grade into contact silicate rock. In each instance studied, there is a distinct zone of marble between the unaltered and the silicated limestone. In some cases this zone is only 0.02 mm. wide, but it is invariably present. Evidently the advancing wave of contact silicate mineralization recrystallized the limestone at least at its front, and sometimes for a considerable distance in advance.

CALC-HORNFELS

Three layers of a brown, sugar-textured rock are observed in the sediments in the zone between the contact areas. These range from 6 to 20 feet in width. The rock in the three layers is fine-grained, averaging about 0.02 mm., and is composed largely of highly interlocking quartz and orthoclase with some calcite, epidote, and diopside in prominent fine-grained aggregates, accompanied by needles of actinolite, occasional grains of idocrase, some chlorite, antigorite, and a little sericite. The entire mass has been fractured, and later epidote, pyrite, and carbonate were introduced, while a definite quartz vein traverses one layer.

SILICATE ROCKS

Inner area.—In the inner area, well-developed masses of contact-metamorphic silicate rocks occur on the north and south sides of the intrusion. In exposures on the eastern side they are present but are not developed so extensively. At this contact the sediments lie conformably beneath the igneous rock. This fact may have restricted the upward spread of the metasomatic agents (Fig. 11).

At the western contact, however, no exposures of silicate minerals occur. The limestone here is composed almost entirely of unrecrystallized carbonate and some carbonaceous impurities, with a few scattered grains of diopside. Similar limestone occurs north and south of the intrusion and at the outer edge of the silicated area. Underground, the lower workings of the Rye Patch Agnes mine cross this contact. In the main tunnel, the limestone is separated from the quartz monzonite by a prominent crush zone and a zone of silicified quartz monzonite (Fig. 5). A drift northerly from the main tunnel on this contact is reported to have encountered similar material along its entire length, some 75 feet, but the caving of this drift prevented verification of the report. A similar, though smaller, crush zone can be seen at the western margin of a small quartz monzonite satellite area about 500 feet directly

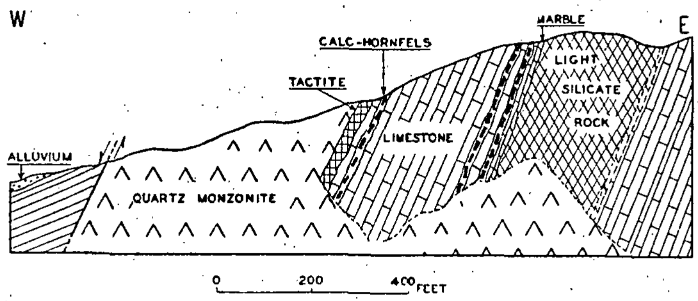


FIGURE 11.—*Section along north wall of Rye Patch Agnes Canyon*
Showing the exposed relations of the various rock types and their probable continuation in depth

south of the tunnel. The alignment and comparable attitude of these crush zones indicate a continuous fault.

The absence of more strongly silicated limestone at the western contact thus must be attributed to faulting rather than to selective replacement of the limestone. The silicification of the quartz monzonite along the fault without any corresponding alteration of the adjacent limestone indicates post-hydrothermal movement.

The highest stage of contact metamorphism is represented by tactite, which is mainly a medium-grained, grayish, compact rock, composed of epidote, garnet, and diopside accompanied by a few accessory minerals—feldspar, quartz, sphene, and apatite. At two or three scattered localities limited to the southern boundary of the quartz monzonite, coarse epidote and garnet occur. In one of these localities some scheelite has been found, but on the whole tungsten mineralization is absent in this zone. Occasional monomineralic masses of epidote or garnet, up to 6 inches in diameter, are encountered. Remnant masses of original limestone up to 2 or 3 inches in their largest dimension are encountered in the tactite of this area. They still retain the grain size, bedding, and carbonaceous impurities of the sediments and are always rimmed by marble.

The light silicate rocks are usually composed of idocrase, light-colored garnet, fine-grained epidote, and diopside, with some quartz and orthoclase. No definite boundary can be drawn between these and the tactite. In a few places, widely scattered segregations of idocrase or tremolite are the only evidence of the light silicate zone. Unmetamorphosed remnants of limestone were not found in the light silicate rocks of this inner area.

Outer area.—On the whole, the same types of contact-metamorphic silicate rocks are represented as in the inner area, but they differ strikingly in areal distribution. The tactite is more limited in extent but mineralogically it is similar to that of the inner area although the texture is slightly coarser. On the south and west it passes into the light silicate zone (Fig. 10).

The light silicate rock in the northern part of the zone is composed of diopside, idocrase, feldspar, fine-grained epidote, and some quartz, while in the southern part of the zone tremolite and recrystallized calcite predominate. The decrease in the extent of silication to the south seems to indicate gradation to lower-temperature

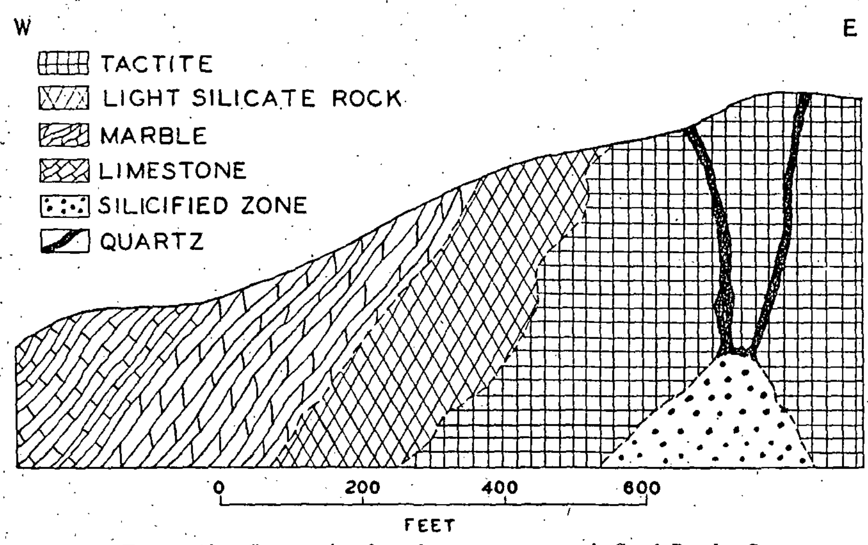


FIGURE 12.—*Cross section through outer contact zone in South Panther Canyon*

Showing gradation from the silicified zone in tactite, existing at the bottom of the canyon, into quartz veins (solid black), which are found on the upper walls of the canyon.

conditions. Associated with the tremolite marble are remnants of unmetamorphosed limestone up to 15 feet long.

The light silicate rock passes on the west into recrystallized limestone, which occurs in a broad band in the northern part and grows narrower southward (Fig. 12).

CONTACT METAMORPHIC MINERALS AND PARAGENESIS

Contact metamorphism involves, first, rising temperature and increasing amounts of volatile matter from the magma, until each reaches a maximum (but not necessarily both simultaneously), followed by a gradual decrease in temperature and emanations as the mass cools and crystallization progresses. Assuming the composition of the emanations to be nearly constant during a contact-metamorphic period, lower-temperature minerals would form first and would be replaced by higher-temperature forms until the maximum had been reached; then these would be replaced by lower-temperature minerals as the temperature fell. Some of these might be the same species that were formed during the rise of temperature, but in other cases irreversible reactions would prevent the reappearance of minerals replaced during the period of rising temperature. Fluctuations in temperature and in the character of the emanations would introduce additional complications. In any case, the descending order of minerals would be more clearly preserved, while the evidence for the ascending series might be entirely obliterated. Furthermore, the age relationships would be purely relative, since minerals of different temperature ranges might form simultaneously at different locations.

At Rye Patch, evidence for the complete paragenetic sequence is lacking. Probable relationships are as follows:

GARNET: Garnet is much more abundant in the inner area than in the outer. Although generally medium- to fine-grained in the former, some masses up to 2 cubic inches across occur. In the outer area, only the finer-grained variety is found. The mineral is typically reddish in hand specimen, and two different varieties may be distinguished when examined under the microscope—a massive brownish form, in part anisotropic, probably andradite, and a colorless, wholly anisotropic variety, probably grossularite, which occurs as veinlets in the former. About 10–15 per cent of all the massive garnet found at Rye Patch is truly anisotropic. This occurs only in two places—the one in the inner area, near the southern contact of the intrusion, and the other and larger in the northeastern part of the outer area.

It has been abundantly shown that garnet developed in contact-metamorphic lime-silicate zones, as a rule, contains several different molecules. The garnet at Rye Patch is similarly complex. Chemical and modal analyses of the purest available garnetiferous tactite gave the following:

	Per cent
Almandite	5.48
Grossularite	34.65
Andradite	35.99
Spessartite	2.48
Wollastonite	7.77
Diopside	2.80
Sphene	0.59
Quartz	10.38
Total	100.04

	Per cent
SiO_2	45.04
Al_2O_3	9.47
Fe_2O_3	11.36
FeO	2.38
CaO	29.50
MgO	0.51
MnO	1.17
TiO_2	0.22
H_2O	0.36
Total	100.01

The veinlets of colorless garnet indicate fracturing before the completion of the garnet stage. In addition, more fracturing occurred in a post-metasomatic stage, for the garnet is transected by later veinlets of hydrothermal epidote as well as quartz and still later carbonate (Fig. 13).

DIOPSIDE: Diopside is common at Rye Patch, where it occurs in all phases of the contact-metamorphic rocks and as a reaction mineral in the border phases of the quartz monzonite. Not very striking in the hand specimen, it appears microscopically as anhedral to euhedral colorless crystals, varying in size from extremely small particles to grains 1 millimeter long. Cleavage is well developed, and $Z \wedge c$ is slightly less than 40°. The indices of refraction are: $n_\alpha = 1.670$, $n_\beta = 1.677$, $n_\gamma = 1.684$ (diopside 92 per cent—hedenbergite 8 per cent).

Ordinarily the diopside is closely associated with garnet, epidote, and idocrase. Often veinlets of diopside transect the garnet (Fig. 14). In view of its widespread occurrence, diopside probably began to form before garnet and certainly ended after garnet. Veinlets of epidote cut the diopside.

Diopside also occurs as scattered grains in relatively unmetamorphosed limestone, associated with a narrow rim of recrystallized calcite. Here, it probably represents the recrystallization of scattered original impurities in the limestone. Coarse radiating aggregates of diopside were obtained from a ledge in the northwestern part of the inner contact area (Fig. 15).

EPIDOTE (AND CLINOZOISITE): Epidote is widespread in the contact-metamorphic zones at Rye Patch, and it is also found in the quartz monzonite itself near the contact, where it is the result of endometamorphism. The grain size varies from fine

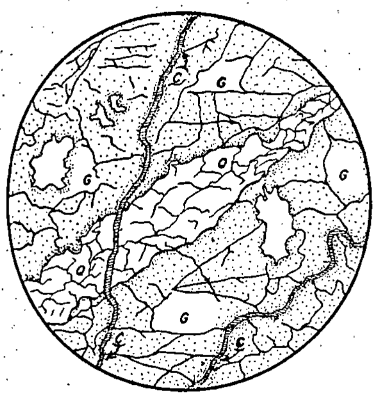


FIGURE 13.—*Garnet in tactite*

Garnet (G) transected by quartz (Q) and later calcite (C). Diagrammatic sketch from microscopic field. × 15.

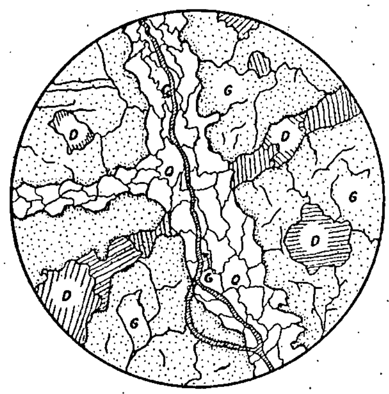


FIGURE 14.—*Garnet and diopside in tactite*

Showing garnet (G) transected by diopside (D), and diopside inclusions in the garnet. Later quartz (Q); calcite (C). Diagrammatic sketch from microscopic field. × 15.

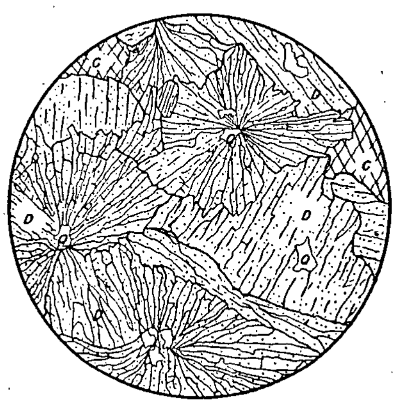


FIGURE 15.—*Radiating aggregates of diopside*

Quartz grains (Q) often occur at the centers of radiation. Interstitial calcite (C). Diagrammatic sketch from microscopic field. × 15.

to coarse, while the crystals are anhedral and distinctly pleochroic. In the inner contact area, epidote occurs only in the tactite, ranging from irregular grains associated with garnet and diopside to pure concentrations averaging 6 inches in diameter (rarely, up to 1 foot). In the outer contact area it is found in the light silicate rock as well as in the tactite. In the tactite, the medium- to coarse-grained pleochroic epidote (X, colorless; Y, green; Z, pistachio green) is closely associated with diopside, garnet, feldspar, early and late calcite, and a little quartz. Occasional grains are twinned parallel to (100). In the light silicate rock, epidote is almost always present as fine grains in linear arrangement. In addition to the granular type, both contact areas contain later veinlets of epidote.

The mutual boundary relationships suggest that the granular epidote replaces diopside and garnet and is in turn replaced by idocrase. The vein material, however, is definitely later than the feldspar. Epidote therefore seems to have been formed either in one long period which probably overlapped diopside and garnet during contact metamorphism and continued into the hydrothermal stage, or in two distinct stages, one purely contact metamorphic, the other hydrothermal. Epidote sometimes occurs as a zone between grains of recrystallized calcite and feldspar. Hence it must have been formed soon after the introduction of the feldspar, as a reaction between the latter and the carbonate. Later fracturing and alteration have affected all the epidote, as seen by the quartz and carbonate veins which transect and in some instances replace it.

CLINOZOISITE is not common. It is rather rare in the inner area, but is more abundant in the outer. Prismatic grains, often 2.0 mm. long, show the weak birefringence (0.01) and positive optic character which distinguish this mineral from epidote. The clinozoisite is commonly associated with true epidote and diopside. Colorless, nonpleochroic clinozoisite sometimes rims epidote. The iron content of the emanations must at one time have fallen too low to permit the continued formation of epidote, and clinozoisite formed instead.

TREMOLITE: Fibrous tremolite occurs as a contact mineral in association with recrystallized calcite, forming a tremolite marble in the southern part of the outer area. In the inner area it sometimes replaces diopside and, more often, coats slightly metamorphosed limestone.

The relative age of the tremolite is obscure, since a few grains of epidote and orthoclase are the only other such minerals found in the tremolite marble; but its presence in the zone of weakest metamorphism suggests that it may have formed there early, possibly before the anhydrous minerals were developed in the inner contact zone. According to Bowen (1940), it is characteristic of the lower-temperature stage of metamorphism. Radiating sheaves of tremolite of similar origin are found just north of Panther Canyon in silicified limestone.

SCHEELITE: The small amount of scheelite found in the tactite appears to have formed in a rather short period along with garnet, diopside, and epidote, possibly continuing after the epidote.

IDOCRASE (VESUVIANITE): Idocrase in euhedral elongated crystals is uniformly distributed throughout the light silicate rock of the outer area. In the inner area it occurs largely in brown clusters varying up to 2 or 3 feet in their largest dimension. In this form it is found also in contact with the basic dike rocks and generally is the only contact-metamorphic mineral formed by these rocks. Identification was confirmed by X-ray diffraction patterns.

The boundary relations with epidote indicate that the idocrase was the last mineral to form. Its absence in the tactite seems to show that it was not formed during the period of highest temperature, but it may have been deposited in the earlier period of rising temperature, as well as after the epidote.

WOLLASTONITE: Wollastonite is not common in these contact-metamorphic rocks. Thin-section examination shows a colorless lath-like form which is, at least in part, definitely late, since it replaces diopside, epidote, clinozoisite, and idocrase. X-ray diffraction patterns were identical with known wollastonite.

CALCITE: The simplest, probably the earliest, change resulting from the intrusion of the limestone by the quartz monzonite was the recrystallization of the calcite. This is indicated by the occurrence of recrystallized calcite at every boundary between unaltered limestone and silicate rocks or mineral grains. The last feeble expression of contact metamorphism might also have been simple recrystallization of the calcite.

APATITE occurs in the inner area in small euhedral crystals not more than 0.05 mm. in length. The crystals usually consist of a brownish core, surrounded by a colorless rim, and are generally associated with sphene, epidote, and orthoclase. Apatite was not noted more than 5 feet from the contact, and then only in the neighborhood of the pegmatites.

SPHENE also occurs in the inner tactite near the quartz monzonite-limestone contact and, like the apatite, only in association with pegmatite. It is always found in small euhedral grains which show pleochroism (X, colorless; Y, brown; Z, brownish red). The small crystals of apatite and sphene occur in a matrix of quartz, feldspar, and carbonate between the larger grains of diopside and epidote. Their definite association with pegmatite seems to limit both minerals to this stage of igneous activity; but there is no reliable evidence for their exact place in the sequence with respect to the other minerals, which undoubtedly were forming over a longer period, including the pegmatite stage. The apatite and sphene are earlier than most of the feldspar and quartz, however.

FELDSPAR (orthoclase and microcline) and QUARTZ are interstitial to the lime silicate minerals and in veinlets traversing them. Their formation seems to have been insignificant until the pegmatite phase. The quartz becomes more prominent in the hydrothermal stage.

CHEMICAL CONSIDERATIONS

Although sufficient chemical data are not at hand to permit an accurate quantitative estimate of the changes occasioned by the metamorphism in the area, an approximate idea may be obtained by mineralogical examination.

The unaltered limestone contains, in addition to the calcium carbonate, carbonaceous impurities and some quartz. Magnesia is present only in traces. Recrystallization has involved chiefly the elimination of the carbonaceous impurities; examination of the recrystallized limestone indicates an absence of the myriad tiny opaque inclusions so characteristic of the original sediment. The formation of scattered grains of diopside may in part be attributed to the recrystallization of lime, magnesia, and silica of the original rock. With the quantitative increase of silicate minerals toward and including the tactite, addition of material from an outside source must be sought to account for all the substance needed.

The assemblage of minerals in the silicate zone requires the addition of silica, alumina, iron oxides, some magnesia, a little manganese, titania, chlorine, phosphorus, tungsten, fluorine, and water. It may be concluded, therefore, that these substances have been added to the sedimentary rocks from the intrusion in the process of contact metamorphism. At the same time, carbon dioxide was driven off.

The preservation of original structures of the sediments points to the retention of their volume practically intact. In many instances, especially in the outer area, the original bedding and the attitude of the former sediments are preserved even in the tactite. Splendid examples of this phenomenon may be observed in Panther Canyon and south of Agnes Canyon. In the latter locality, remnants of limestone occur in the light silicate rock, and the bedding passes undisturbed from the unaltered m into the silicated mass.

LOCALIZATION OF METAMORPHISM

The distribution of rock types in many areas of limestone contact metamorphism may be summarized by the following typical statement: "Certain beds retain nearly their original texture and composition close up to the [intrusion], while others are obviously altered for long distances from the intrusive contact" (Ransome, 19 p. 84). The following relations are found at Rye Patch, where the distribution of metamorphic rock types is similarly complex:

(1) Two large areas of metamorphic rocks separated by a zone of limestone un metamorphosed except for—

(2) Three layers now completely changed to calc-hornfels.

(3) A definite zonal arrangement of silicate minerals and recrystallized limestone in the outer area.

(4) Irregular distribution of the metamorphic rocks of the inner area.

(5) Small scale local alterations of the metamorphosed and unmetamorphosed beds near the intrusion.

(6) Unmetamorphosed limestone in contact with the quartz monsonite for about 500 feet at the southwestern border of the intrusion.

The extreme irregularities encountered in limestone contact metamorphism may be explained in several ways. No single factor can explain all the phenomena; but probably several have operated simultaneously. Some of these factors and their bearing on the problem at Rye Patch may be summarized as follows:

(1) Composition of the magma. Lindgren (1904, p. 520) states that at Clifton-Morenci there seems to be a direct relation between the contact-metamorphic effects and the amount of quartz in the igneous rock. The small size and the uniformity of the Rye Patch intrusion would rule out composition of the magma as a factor.

(2) Distance from the intrusion. All other things being equal, the intensity of the metamorphism should be greater nearer the intrusion. At Rye Patch, the distribution of the various metamorphic facies in the outer area may be ascribed to distance from the source of heat and emanations, but the inner area, while reflecting the influence of distance, requires an additional explanation for the less regular arrangement of metamorphic products.

The second belt of metamorphosed limestone, the outer area,—similar in its complex character to the inner area but showing well-defined zoning—suggests that an offshoot of the main intrusion lies not far beneath the surface, presumably more or less sill-like in its upper reaches at least (Fig. 11). Within this outer area, we find a higher grade of metamorphism in the north, decreasing gradually southward and westward (Fig. 10). In the north, silication is much more extensive, and the variety of contact minerals is greater. The marble zone is broader, while the unmetamorphosed remnants of limestone are fewer and smaller. In the south, conditions are q different; tremolite is the only common silicate mineral, and it is not abundant; the marble zone is narrow; and the unaltered remnants are frequent and large. The gradation from strong to weak metamorphism in the outer area can easily be accounted for by increasing distance from the source of heat and emanations; in other words, to the south the intrusion lies farther below the surface.

In the inner area, where tactite is encountered at the contact, light silicates and then marble succeed outward from the intrusion; where light silicate rock occurs next to the quartz monzonite, a marble zone follows; and where marble fringes the intrusion, it becomes finer-grained and contains fewer patches of silicates away from the igneous body.

(3) Structural features in the invaded rocks. Bedding planes afford easy passage for mineralizing solutions. Inclined strata, particularly, may aid their upward migration (Barrell, 1902, p. 394). At Rye Patch, bedding control of the extent of metamorphism is evinced in at least three ways:—(a) the widening of the inner area of metamorphism along the strike; (b) the relation of the outer contact area to the dip and strike; and (c) the narrowness of the aureole at the eastern contact, believed due to the fact that the strata conformably underlie the intrusion at this point (Fig. 11).

The influence of fractures on contact metamorphism has been discussed by Hess and Larsen (1920) but does not apply to Rye Patch because of the absence of any extensive fractures traversing the invaded rocks.

Variation in porosity of different beds may be important in aiding selective replacement. Lindgren (1904, p. 520) states that coarser-grained (and impure) limestones are more susceptible to metamorphism than compact (and pure) limestones. At Rye Patch, porosity may have been a factor guiding the silicating solutions along the layers now composed of calc-hornfels, and possibly along replaced beds.

(4) Composition of the invaded rock. Impure limestones are most susceptible to alteration, igneous rocks are least. In the Rye Patch area, however, the country rock as a whole is uniformly pure limestone. The manner in which the inner contact area cuts across a considerable thickness of these similar beds indicates that in the immediate vicinity of the magma metamorphic effects were due largely to emanations from it and not to differences inherent in the intruded rocks. An extended analysis of the question of original differences in country rock versus additions from the magma was made by Uglow (1913). Similar beds can be traced along their strike into different products of metamorphism. Obviously, the larger distribution of contact-metamorphic effects did not depend upon composition of the country rock.

One outstanding example of selective replacement due to differences in composition, however, seems to have been the three layers of calc-hornfels near the edges of the unmetamorphosed limestone separating the inner and outer areas (Fig. 10). These, probably, were originally more silty layers, similar to those occasionally encountered in the limestone outside the sphere of contact metamorphism, and thus readily underwent complete metamorphism, aided no doubt by greater porosity and favorable attitude, while the surrounding pure, more compact limestones remained unchanged.

A similar feature occurs nearer the intrusion on a very small scale. Here the original differences in composition are harder to understand, for the silicated beds can be traced along the strike into limestone apparently similar to that of the adjacent unaltered layers. However, even though mineralogical composition and porosity appear the same, there must have been enough difference to render these beds more soluble, so that emanations chose these layers in preference to their neighbors. Boutwell (1905, p. 193) has advanced difference in solubility as an explanation of selective

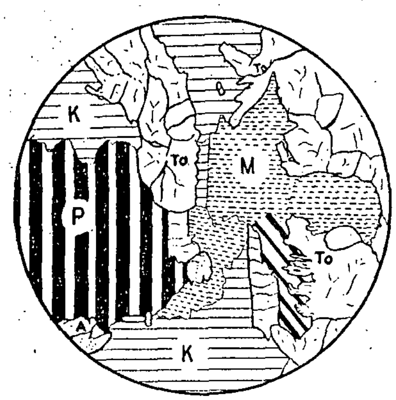


FIGURE 16.—*Tourmaline-bearing pegmatite*

Showing tourmaline (To) replacing orthoclase (K), plagioclase (P), and microcline (M); apatite (A). Diagrammatic sketch from microscopic field. × 15.

replacement at Bingham, Utah. An alternative explanation, less reasonable in view of the small scale of the feature, would be local absence of emanations.

(5) Variations in heat and emanations at the margins of the intrusion. The Rye Patch intrusion is believed to be an offshoot of a larger buried intrusive, in fact, essentially a cupola, and probably as a whole differed from its parent body somewhat in temperature and escaping volatiles. Within its own comparatively small extent, however, such variations would be of a smaller order of magnitude. Nevertheless, by elimination of other determinable factors, these must account for the differences in degree of metamorphism along the actual contact. The reasons for such variations are not clear.

LATER PHASES OF THE INTRUSION

GENERAL STATEMENT

The petrography and distribution of the aplite phase have already been mentioned, and its significance is discussed later.

PEGMATITIC PHASE

The pegmatitic phase of mineralization is marked by the development of pegmatite and a small amount of tourmaline. The pegmatites and associated apatite and sphene have already been discussed. The tourmaline occurs in veinlets in the northern margin of the quartz monzonite and in the aplites and pegmatites, where it replaces orthoclase and, less often, plagioclase (Fig. 16).

Concerning the volatile emanations given off during this phase of mineralization, it would seem that the halogens were somewhat lacking, although no doubt a little fluorine and possibly a trace of chlorine were present, and a limited amount of boron.

HYDROTHERMAL PHASE

General considerations.—The hydrothermal phase is represented by silicification, by the prominent quartz veins which cut the major rock units, by tungsten and sulphide mineralization, and by carbonate veins.

Silicification.—Silicified areas are irregularly distributed throughout the limestone, which they resemble so closely that they are difficult to distinguish in the field. The most prominent example of silicification is at the faulted western edge of the intrusion, where specimens of the quartz monzonite from the mine show replacement of almost all the original constituents by quartz. A few remnant grains, chiefly zircon and biotite, indicate the nature of the original rock. The quartz shows typical secondary structures, such as feather and mosaic structure. Some later disturbance, probably the faulting, has sheared and bent the quartz. Silicification has also occurred in the outer contact area accompanied by introduction of orthoclase and sulphides. In this location, the silicified zone passes upward into tourmaline-bearing quartz veins (Fig. 12).

Quartz veins.—Quartz veins are common in the area, occurring in the quartz monzonite, in the tactite of the outer area, and in the limestone. They consist largely of massive white to grayish-white quartz. Sulphides are carried in the veins cutting the quartz monzonite, while conspicuous needles of tourmaline are found in the two large quartz veins traversing the tactite of the outer zone (Fig. 17). In the hand specimen these needles are dark brown and under the microscope, greenish brown. They are often replaced by calcite.

Within the limestone the quartz veins sometimes parallel the bedding. In the northwestern part of the area, a prominent bedding vein carries scheelite associated with calcite, but no tourmaline. This vein is associated with aplitic material which has invaded the limestone.

Sulphide mineralization.—The sulphides accompanying the silicification in the outer zone and in the limestone are arsenopyrite, pyrite, pyrrhotite, sphalerite, some galena, and tetrahedrite. Pyrite is the most abundant, forming euhedral grains especially in the replaced limestone (Fig. 18). The inner contact zone is almost devoid of pyrite and contains none of the other sulphides.

The quartz veins within the monzonite carry sulphides and are being developed in the Rye Patch Agnes mine in the northern part of the intrusion. Mineral relations are better exposed in the workings of the mine. Openings have been made on three levels; the upper two had reached the silver-bearing veins, while the lower one, starting some distance to the west, had not yet done so when the writer was last in the field. Most of the workings are in the intrusion proper, some are actually on the quartz veins, and some pass into the adjacent limestone.

The veins which carry the economic minerals are of white massive quartz, which shows abundant evidence of later crushing. In general, the walls of the veins are clearly marked, although in several instances silicification of the quartz monzonite on both walls tends to destroy this demarcation. The veins dip steeply and the ore-bearing ones strike east-west.

Greisenization and a slight amount of tourmalinization have occurred in the vein walls. Molybdenite, pyrite, chalcopyrite, sphalerite, galena (silver-bearing), and tetrahedrite represent the complete suite of ore minerals.

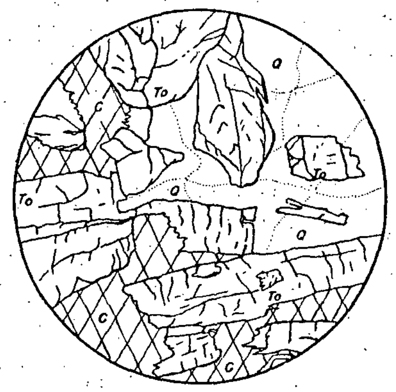


FIGURE 17.—*Tourmaline in quartz vein from outer contact zone*

Tourmaline, To; quartz, Q; calcite, C. Diagrammatic sketch from microscopic field. × 15.

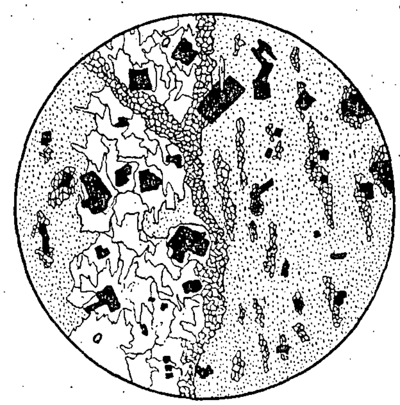


FIGURE 18.—*Silicified and pyritized limestone*

Showing various stages of quartz (Q) introduction. Pyrite represented by black grains. Diagrammatic sketch from microscopic field. × 15.

Deposition of some of the early minerals was followed closely by shattering; thus pyrite and sphalerite are noticeably fractured, and the pyrite in some instances has been so ground up that it consists of a linear arrangement of tiny fragments.

The paragenesis of the ore minerals appears to follow Lindgren's "normal" order. The ore mineralization period was probably closely connected in time with the pyritization in the east, in the outer contact zone.

A slight amount of leaching has left remnant cavities corresponding in form to pyrite crystals.

The occurrence of molybdenite, generally regarded as a higher-temperature mineral, does not necessarily mean a hypothermal origin for the veins. Vanderwilt (1933, p. 571–572) describes molybdenite-bearing quartz veins associated with sulphides, a condition similar to that found in the Rye Patch Agnes mine, and concludes that this type is "probably formed under conditions more closely approaching those of the mesothermal." The well-defined vein walls support the mesothermal origin for the Rye Patch veins.

Tungsten mineralization.—In the limestone almost half a mile north of the intrusion are scheelite-bearing quartz veins of the bedding and fissure types, associated with the numerous aplitic injections. Four claims covering the known occurrence of the ore are situated on the ridge just north of Panther Canyon—constituting the Panther Canyon prospect. One large bedding vein is exposed in a trench which extends for 320 feet along the steep canyon wall. Three other small bedding veins have been exposed in the workings.

These tungsten veins are associated with the silicified and silicated areas bordering the aplite and camptonite dikes. The extent of such metamorphism is negligible around the camptonite but is significant near the aplites. The brownish, fine-grained aplites, whose outcrops are sometimes lenticular, are somewhat similar to those of the Oreana area (Kerr, 1938). Certain limestone beds change color along

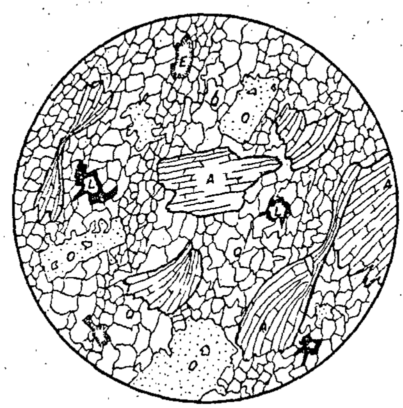


FIGURE 19.—*Silicified lens in limestone*

Near the Panther Canyon prospect. Quartz, Q; orthoclase, O; actinolite, A; epidote, E; limonite, L. Diagrammatic sketch from microscopic field. × 15.

the strike and resemble the aplite intrusions. Thin-section examination shows that these beds are progressively silicified; in addition, orthoclase and innumerable sheaves of actinolite have been produced (Fig. 19). Further silicification away from the brownish layers has produced numerous nodules of white chert, accompanied by fibrous actinolite. The relation between the quartz veins and the altered zones is indicated by the occurrence of quartz veins in the center of the zones and their occasional gradation into each other.

The vein quartz is massive, white, frequently crumbling with ease in the hand specimen, and contains occasional vugs lined with quartz crystals. Quartz, scheelite, and calcite are the only vein minerals. In contrast to the quartz in the outer contact zone, tourmaline is exceedingly rare. Quartz was the earliest mineral to be deposited, followed closely by scheelite. Calcite transects both the quartz and the scheelite. A trace of scheelite was found in an aplite dike within the quartz monzonite, and further traces were found in the epidote-garnet rock on the southern contact of the intrusion. When the locations of the tungsten occurrences are mapped they show a decided linear trend, coinciding with the axis of the arch in the sediments, suggesting that the localization was controlled by this structure (Fig. 20).

Aplites are abundant where tungsten is prominent and appear to have afforded passage for the tungsten-bearing solutions. The association of scheelite deposits with aplites has been described at Oreana, Nevada (Kerr, 1938), and in the Federated Malay States (Willbourn and Ingham, 1933), but the genetic relationship between the two has not been established. Recently Kerr (1940, p. 208) stated: "Aplite and pegmatite dikes or quartz veins favor concentration of tungsten evidently as conduits from the magmatic sources. The conduits frequently contain traces, but rarely concentrations of tungsten minerals."

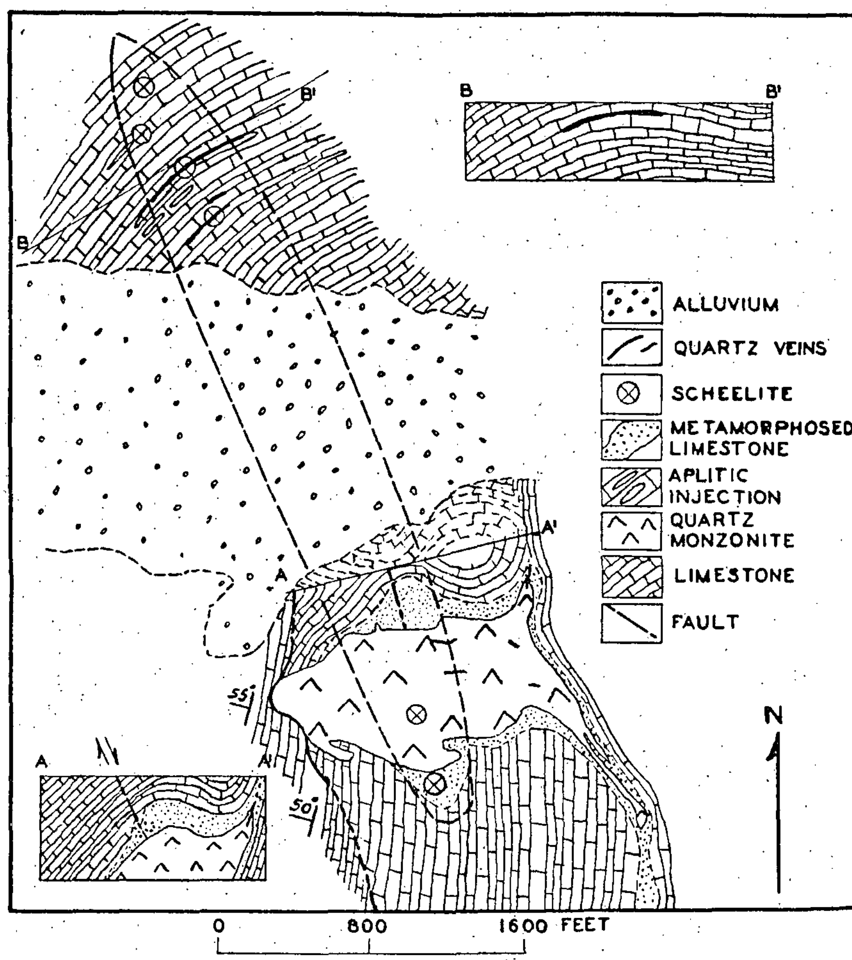


FIGURE 20.—*Plan of tungsten occurrences*

Showing their relation to the arch in the sediments, which is outlined by dashed lines

The scheelite found at the Panther Canyon prospect is evidently hydrothermal, differing from the deposit at Oreana, where the scheelite is associated with pegmatites. According to Butler (1927, p. 238) and Finlayson (1910, p. 26) scheelite is not necessarily formed only at high temperatures but continues to be deposited, probably in decreasing amounts, at lower and lower temperatures. A similar occurrence of scheelite has been described by Hulin (1925, p. 77) at Atolia, California.

The scheelite was formed when most volatiles except water were either rare or absent, as suggested by the absence of any considerable mineralization in the veins

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U. S. Geological Survey, Gabbs, Nye County, Nevada.

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paper. In the isolated instances of scheelite found in the aplite and in the contact rock, there is no evidence of hydrothermal activity; this scheelite may have been formed contemporaneously with the aplite and the contact metamorphism, respectively.

CONCLUSIONS

(1) Contact metamorphism at Rye Patch, Nevada, involved considerable change in composition, mainly the addition of silica, alumina, and iron oxide, and subtraction of carbon dioxide.

(2) No appreciable volume change occurred.

(3) The contact-metamorphic changes depended mainly on the magmatic emanations, since the original sediments were uniformly pure limestones, except for three horizons where they may have been silty.

(4) The distribution of metamorphic effects is believed to be due primarily to distance from the intrusion, modified locally by (a) bedding of the invaded strata, (b) variations in composition, porosity, and solubility of the original limestone, and (c) variations in heat and emanations at the margins of the intrusion.

(5) The outer contact area is thought to be due to another tongue of the intrusion which has not yet been uncovered by erosion.

(6) In its upper reaches, the intrusion is sill-like and has pried apart the limestone beds.

(7) The arching of the sediments is believed to indicate a northward extension of the intrusion, parallel to the strike.

(8) The diopside and andradite are the oldest contact-metamorphic minerals; andradite was succeeded at some stage by grossularite and was in part altered to epidote. Some diopside was altered to tremolite. The exact relations of the idocrase, tremolite, and wollastonite are not so clear.

(9) The distribution of the tungsten mineralization and aplite dikes in a linear belt coinciding with this arch suggests structural control.

(10) The scheelite veins are of low-temperature hydrothermal origin.

(11) The aplites associated with the scheelite-bearing quartz veins probably afforded passage to the tungsten-bearing solutions.

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