TEXTURAL STUDIES IN IGNEOUS ROCKS NEAR TWENTYNINE PALMS, CALIFORNIA

Thesis by

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ABSTRACT

A description of a sequence of igneous rocks south of Twentynine Palms has been undertaken for the purpose of describing and determining the origin of the major textural variations within individual igneous bodies. The work involved field mapping and sampling, petrographic study, and spectrochemical analysis.

The Pinto gneiss, a middle rank metamorphic rock, is the oldest formation in the area. It is intruded by a sequence of plutonic rocks including (in chronologic order) the Gold Park gabbro-diorite (oldest intrusive rock), Palms quartz monzonite, monzonitic porphyry, and White Tank quartz monzonite. Other igneous rocks include basalt and silicic and basic dikes. The major rocks, and the ones most intensively studied, are the Palms quartz monzonite-monzonitic porphyry complex and the White Tank quartz monzonite.

The Palms quartz monzonite is divided into three units on the basis of slight differences in mineralogy and texture. Most of the quartz monzonite is characterized by very complex, irregular intergrowths between potash feldspar and plagioclase; these intergrowths are possibly the result of crystallization from a relatively dry melt during the latter stages of formation of the rock. Widespread reaction between the quartz monzonite melt and portions of the Pinto gneiss has caused the formation of a monzonitic porphyry along some contacts between quartz monzonite and gneiss. Plots have been made of mineral compositions and grain sizes of a sequence of rocks from gneiss through porphyry to quartz monzonite. Potash and soda have been added to the gneiss by the melt, and development of coarse crystals of potash feldspar in the porphyry is caused by incorporation of solid gneiss in the melt. Some contacts (ranging from relatively abrupt to broadly gradational) between quartz monzonite and gneiss do not exhibit development of porphyry.

The White Tank quartz monzonite is divided into four units, two of which have two separate facies. The units are distinguished by differences in mineralogic composition and texture. The different facies and units are grouped into two differentiation sequences: the trend in each sequence is toward a more silicic rock, but one sequence results in the formation of large crystals of microcline, whereas the other sequence results in the formation of muscovite and garnet. The trace element content of potash feldspar varies throughout each sequence roughly in accordance with differentiation trends previously established by other workers. Measurements of the grain sizes of potash feldspar (in the field) and quartz and plagioclase (in thin section) also reflect the sequence of differentiation. The White Tank quartz monzonite is believed to have formed by the intrusion, differentiation, and solidification of a magma.

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INTRODUCTION

I. Purpose:

As partial fulfillment of the requirements for a Ph. D. degree at the California Institute of Technology, the writer undertook a study of textural variation in the igneous, or apparently igneous, rocks south of Twentynine Palms, California. The investigation was directed toward determining, insofar as possible, the physical and chemical causes of the textural variations observed within individual rock units exposed in the area.

Specifically, the principal objectives were

1. The explanation of the differences in texture and composition among the four separate units of White Tank quartz monzonite exposed in the thesis area. Also the explanation of the vertical variation in the largest unit.

2. The explanation of the differences in texture and composition among the three types of Palms quartz monzonite.

3. Determination of the relations between the monzonitic porphyry and both the Palms quartz monzonite and the Pinto gneiss.

In the study of these major problems, some time was spent on minor textural details such as myrmekite and perthite. These special textures were not, however, studied exhaustively in the manner of Alling's study of perthite (Alling, 1938), or Drescher-Kaden's study of myrmekite and graphic granite (Drescher-Kaden, 1948). Individual textural features are considered only in relation to the major variations in and among rock units. For example, the distribution of various types of myrmekite in the White Tank and Palms quartz monzonites was studied in detail, but a comparison with myrmekite in other rocks throughout the world, necessary for a complete understanding of the formation of myrmekite, was not made. Thus, the primary problem considered in this thesis is the origin of large scale textural variations in igneous rocks. The writer chose to study this problem because he felt that textural variation, although far less understood than compositional variation, is a very important feature of igneous rocks.

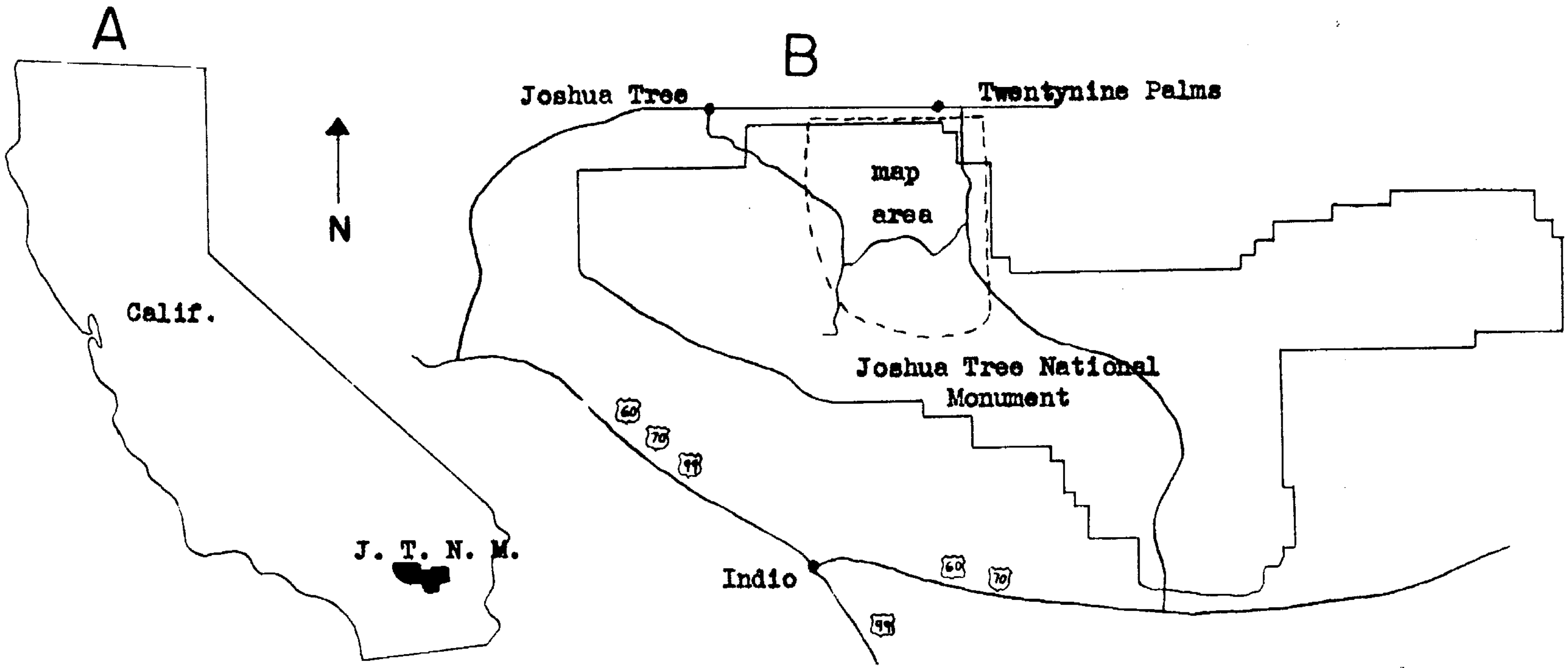
II. Location and Desirability of Area:

The area studied in detail is shown on the index map (Fig. 1). At present it is almost entirely included within Joshua Tree National Monument, and in fact, includes those portions of the Monument most frequently visited by tourists.

Few areas considered by the writer as possible locations for the study of igneous rocks offered as many advantages as Joshua Tree National Monument. A study of the area by Miller (1938), had outlined the general features of the geology. Four major plutonic rock units are present: two quartz monzonites, a monzonitic porphyry, and a gabbro-diorite. Basic and rhyolitic dikes and one basalt (possibly a plug) complete the list of igneous rocks. The region mapped is surrounded on three sides by large areas of Pinto gneiss which, thus, delineate a region of igneous activity. Outcrops are abundant owing to the lack of soil and plant cover, which, in turn, is primarily the result of the desert environment. Therefore, in many places, it was possible to find the exact contact between rock units, and a detailed

Fig. 1

Index map. Part A shows the location of Joshua Tree National Momment. Part B shows the portion of the Monument mapped by the writer.



study of the relations at these contacts afforded evidence for many of the conclusions drawn in this thesis.

Unfortunately, granitoid rocks in the desert tend to undergo granular disintegration to depths of many feet. Thus, although map units are easily distinguishable in the field, procurement of reasonably fresh specimens of the major rock types was very difficult. The gabbro-diorite is generally so completely weathered that it appears as a black soil. The gneiss is the most resistant of the major rock types.

III. Topography of Area Studied:

Topographically, the area is extremely varied. The mountains south of Twentynine Palms rise abruptly along a line parallel to, but approximately one fourth mile south of, the Pinto Mountain fault (Hill, 1928). The principal mountain mass is south of Twentynine Palms and extends south to Queen Mountain, the highest point in the map area (elevation of 5676 feet). The high central portion of this mountain mass is bordered by valleys and an outer rim of hills. The south side of Queen Mountain is an abrupt face (Fig. 2) that forms the north side of Queen Valley. There is some evidence for believing that this face is a fault scarp.

A low divide separates Queen Valley from a surface that slopes gently southward to Squaw Tank. To the west of Queen Valley and this southward slope are the Lost Horse Mountains. The area mapped for this investigation is bordered on the east by the Pinto Mountains, on the south by the Hexie and Lost Horse Mountains, on the west by Lost

Fig. 2. Queen Mountain.

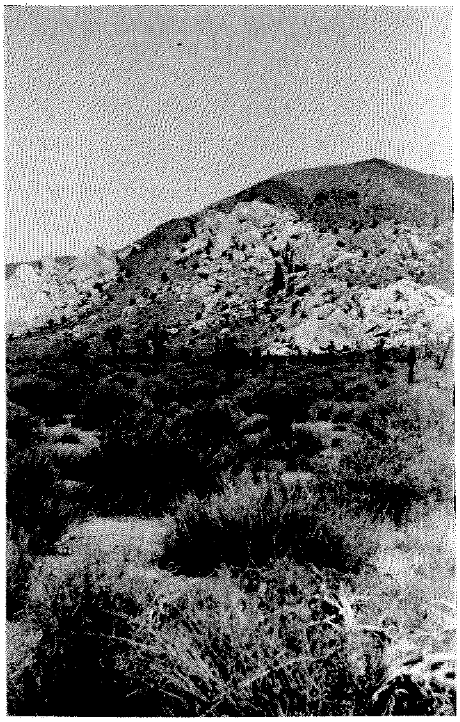


Fig. 3. Contact between White Tank quartz monzonite and Pinto gneiss in Lost Horse Mountains.

Horse Valley, and on the north by the valley in which Twentynine Palms is situated.

In general, the mountains are composed of gneiss, Palms quartz monzonite, or monzonitic porphyry, whereas the broad valleys consist largely of the White Tank quartz monzonite. Intrusive contacts (e. g., Fig. 3) between gneiss and remnants of the quartz monzonite high on the slopes of the Pinto, Hexie, and Lost Horse Mountains indicate that the relief is not caused by faulting along the contact between the two rocks. Probably the local relief is caused by differential erosion, the disintegrated quartz monzonite being easily eroded.

The valleys in the White Tank quartz monzonite are studded with monoliths of the rock (e. g., Fig. 4), up to several hundred feet high and a half mile in diameter. Each monolith is cut into many large joint blocks, and the resulting grotesque appearance has led to such descriptive names as "Wonderland of Rocks" and "Jumbo Rocks."

IV. Previous Work:

The only detailed work done previously in the area mapped by the writer was that of W. J. Miller in 1938. He gave the original names to all rock units in the region (although the present writer has seen fit to modify two of his names). Miller's conclusions as to the origins of the various rocks are discussed separately along with each rock described in this thesis.

Although textures are mentioned briefly by most writers who discuss igneous rocks, comprehensive analyses of textural variations in one rock unit are rare. Specific references to most of these reports

Fig. 4. Well jointed monoliths of White Tank quartz monzonite in Lost Horse Valley.

are made at appropriate points throughout the thesis, and it is unnecessary to discuss them fully in this section. Some of the more important papers concerning textural variations in igneous rocks are van Biljon, 1939; Sargent, 1925; Mackie, 1909; and Walker and Mathias, 1946.

V. Procedure:

The investigation involved work of three types: field mapping and sampling; petrographic study of 300 thin sections; and spectrochemical study of trace element distribution in potash feldspars from 24 localities in the White Tank quartz monzonite.

A. Field Mapping and Sampling:

Mapping was done on aerial photographs obtained from the U. S. Air Force, Photographic Records and Services Division. The photographs covered part of a region designated by the Air Force as the Pine Knot Area. The scale of the photographs was 3000 feet to the inch, and the planimetric map made from them, by projection through a Salzman Projector onto a control grid, was on the same scale.

In making the planimetric map, a horizontal control of eight points throughout the entire 175 square mile area was obtained from maps prepared by the U. S. Land Office in 1912 at a scale of one half mile per inch. The control was extended by means of a mechanical templet. Owing to the lack of good horizontal control, no great accuracy can be claimed for the map prepared by the writer, but it does serve to illustrate the geologic features important for the thesis. The final map (Plate I) is on a scale of one mile to the inch. Some of the geology on this map was adapted from Miller's work of 1938.

One phase of the field work involved measurement of the relative sizes of potash feldspar grains both in the White Tank quartz monzonite and in the monzonitic porphyry. The method was simply to measure the maximum dimension of grains on the outcrop. Repeated measurements on the same and neighboring outcrops at different times and using different numbers of grains showed that measurement of 25 grains gave a size value reproducible within 1.0 millimeters for grains six to eight millimeters long. Data concerning the reproducibility of these measurements are presented in Table 1.

The area represented by one set of grain size measurements is, of course, smallest in portions of the rock where the textural variation is the most abrupt (near contacts, for example).

In order to determine roughly the percentage of potash feldspar in an outcrop, a rapid point count was made in the field by laying a ruler on the rock along a series of parallel lines and counting the grains under the half-inch marks. Approximately one hundred points gave results reproducible within five percent for a rock containing 40 percent potash feldspar.

Rock samples were taken and immediately placed in individual, new paper bags, thus preventing contamination in the field of specimens used for trace element analysis.

B. Petrographic Study:

For many sections, estimates of the mineral percentages and grain sizes were sufficient, but for some sections, quantitative data were

Table 1. Reproducibility of Field Measurements of Size of Potash Feldspar Grains in White Tank Quartz Monzonite:

Location	Number of grains measured	Size (maximum dimension)
central part of Unit 4,	25	10.6 mm.
northwest of Anaconda Mine	25	11.2
	25	11.2
	50	9.9
upper part of Unit 1,	50	7.9
east of Jumbo Rocks	50	7.6
central part of Unit 2,	25	6.3
near Cap Rock	25	6.6
edge of Unit 2, near gneiss	25	6.6
east of Cap Rock	25	5.8
middle part of Unit 1,	50	6.1
near White Tank	25	6.3
lower part of Unit 2,	25	5.1
near Indian Cove	25	5.6

All measurements in a group were made in essentially the same place at different times.

needed. In such cases, mineral percentages were determined by a point count of 1000 to 1500 points. The average grain size of each mineral was determined by measuring the maximum diameter of 25 grains of the mineral as shown in section.* The number used to represent the "grain size" of a mineral was the average of these 25 measurements.

The composition of the plagioclase in most rocks was determined by the Michel-Levy method. In specimens of particular importance, these compositions were checked by measurement of indices in immersion oils. The composition of untwinned plagioclase was determined by index measurements.

C. <u>Spectrochemical Study</u>:

Determinations of trace element content were made on 24 potash feldspar samples and one biotite sample from the White Tank quartz monzonite. The analysis of the biotite was made in order to determine the effect of contamination of the feldspar by small amounts of biotite impossible to remove before analysis.

The first five specimens analyzed (numbers 37, 83, 90, 127, and 133) constituted a preliminary study to determine the best procedure to be used and the accuracy to be expected. Each rock sample was broken into two portions and the separate pieces prepared and analyzed individually, as shown below, to determine the variation within one hand specimen. All of these specimens had been sawed for thin sections before the writer anticipated using them for trace element analysis, and it was feared that the sectioning process may have introduced some contamination. (Later comparison of results from sectioned and non-

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* See Feniak (1944) for a slightly different method of measuring "grain size."

sectioned samples from the same portion of the rock indicates that sectioning has little effect on the purity of the potash feldspar.) All of the sections showed less than five percent alteration (kaolinization) of the potash feldspar.

These five rocks were first broken into centimeter-sized fragments by pounding them with a hammer on a steel plate. Next, the samples were crushed in a diamond mortar, and clean cleavage flakes of potash feldspar were picked out under a binocular microscope. These grains were crushed again in a diamond mortar, sieved through a silk screen to remove all material finer than 200 mesh (to prevent dust from accumulating in the Frantz separator), and passed through a Frantz Electromagnetic Separator (Model 506). The separator was set for 1.6 amperes and a 10° forward and 10° side tilt. Biotite and muscovite were removed by the separator.

An examination, in index oils, of the samples at this stage of preparation showed that most samples had a contamination of plagioclase up to 10 percent, and sample 133, which originally contained the lowest proportion of potash feldspar, had about 25 percent plagioclase. Biotite was less than 0.1 percent. Owing to the difficulty of removing any more plagioclase by further hand picking, the samples were analyzed without further preparation.

Analysis for most of the elements involved first mixing the samples with an equal weight of "iron quartz," which is otherwise pure quartz containing two percent ferric oxide by weight. Twenty-five milligram duplicates of each sample were then placed in one-quarter inch pure graphite electrodes (which served as anodes during the burn), and were analyzed with the following exposure conditions:

Spectrograph: Jarrell-Ash 21 ft. diffraction grating instrument with a dispersion of 5.2 Å/mm in the first order.

Excitation: 15 ampere DC arc. Sample as the anode. 4mm analytical gap magnified five times and focussed on the slit. Central 2 mm used with a slit width of 25 microns.

Wavelength range: 2300-4800 Å, first order.

Plates: Eastman Kodak III-O developed at 20° C for four minutes in DK-50.

Densitometer: Applied Research Laboratory (ARL) model no. 2250.

Each plate of ten (duplicate) unknown samples was calibrated by measuring iron lines of known intensities in four pegmatite standards, burned two at the top of the plate and two at the bottom. From measured transmission percentages and known intensities of the iron lines, a curve was plotted which permitted reading intensities of the lines of other elements from transmission readings made on them. Then the measured intensities could be converted to concentrations of the elements from standard curves, already prepared by Mr. Chodos for the spectrograph and the densitometer used. Lines so dense that they showed less than five percent transmission were measured by clocking the time needed for the densitometer motor to scan through the range below five percent. Comparing these times with the time needed to scan the standard Fe 4405 Å line in the pegmatite standards gave a time value for the unknown which could be translated from prepared curves into concentration of the element.

Analysis for the alkali elements was made on samples prepared by mixing 90 percent feldspar and ten percent Specpure sodium carbonate. Duplicate 25 milligram samples were burned for five seconds past the last visible alkali volatilization with the following exposure conditions:

Spectrograph: Same as for other elements.

Excitation: Same as for other elements. Red filter added.

Wavelength range: 6100-8700 Å, first order.

Plates: Eastman Kodak I-L.

Densitometer: Same as for other elements.

In all burns the bead was lost by its popping out of the electrode after the alkalies were completely removed. Standards from 0.000012 percent to 1.0 percent of each alkali were burned on each plate and provided the calibration for determining the concentration of alkalies in the unknown.

Although the spectrographic procedure was identical for all samples, the methods used in preparing the last 19 samples were different from those used with the first five. Specimens 14, 102, 169, 356, 358, 502, 503, 504, 505, 506, 507, 508, 509, 510, 512, and 513 were not prepared in duplicate samples from different parts of the hand specimen. Instead the whole specimen was ground in a rotating mill set to pass 0.2-millimeter-sized fragments, and the powder was then treated as one unit.

There were three reasons for adopting a different procedure for the last 19 samples than for the first five. First, the agreement between results from two parts of the same hand specimen was so good that it was believed justifiable to analyze the specimen as a whole. Second, it was believed that the heavy liquid separation of potash feldspar (used for all but the pegmatites in the last 19 samples) would provide a better separation of potash feldspar and plagioclase than hand picking. Third, it was desired to compare the two methods of preparation by analyzing samples from the same parts of the rock by both methods.

Following the grinding of the rock, the next step in the preparation of these samples was a screening out (with a silk screen) of all powder less than 200 mesh size. The remaining powder was then placed in a tetrabromoethane-acetone mixture of specific gravity 2.60, which just floated the perthitic potash feldspar and allowed sodic plagioclase to sink. The first separation was made in a beaker, and material which floated in it was decanted into a separatory funnel where the final separation was made. Investigation of the light material in immersion oils showed that it was more than 99 percent potash feldspar (perthitic) in all cases. This final separate was then passed through the Frantz Separator and, finally, was hand cleaned under a binocular microscope to remove the last traces of dark impurity. After this procedure the remaining contaminants were largely plagioclase and quartz.

The pegmatite samples, 49, 388, and 501, were prepared by hand-picking the feldspar cleavage fragments. The analyzed samples were entirely perthite.

After completing the analysis of all 19 samples, two of the feldspar powders which had not been completely used up in the investigation were chosen by a person not connected with the work and renumbered so that the writer could not identify them. These were then prepared and analyzed by the same methods used previously (the spectrographic work being done by Mr. Chodos) and the results used to check the reproducibility of the results previously obtained. The reproducibility is shown in Table 2.

Contamination by various elements was unavoidably introduced at various stages during the analytical process. Ferro-alloy elements were added by the different steel tools used during the separation process. Copper was added by the Frantz Separator. Vanadium and some titanium came from the electrodes. Thus, the only elements which gave significant figures were Li, Rb, Mn, Ca, Ba, Sr, Pb, Ga, Zr, Y, and Yb. Manganese may be an indication of contamination by biotite. Zirconium is undoubtedly introduced by small grains of included zircon. Calcium and part of the strontium are probably present in the plagioclase part of the perthite or in plagioclase contamination. The effect of contamination by as much as one percent biotite may be judged by the analysis of "502 biotite" given in Table 3. Inasmuch as the content of biotite was less than one percent in all analyzed samples, its effect is believed to be negligible, with the possible exception that the presence of biotite accounts for the ytterbium and yttrium reported in two samples. The elements of major importance in this study, then, are barium, lead, rubidium, lithium, and gallium.

Table 2. Reproducibility of Spectrochemical Data:

Sample	Ba 3072	Ba 4554	Ca 3159	Ca 3179	Cu 3274	Ga 2943	Li 6104	Li 6708	Mn 2801	Pb 2833	Rb 7800	Rb 7948	Sr 3464	Sr 4607	Ti 3349	Zr 3273	Zr 3392
37A	----	6	3000	3000	9	20	----	3	20	60	3000	3000	----	7	20	----	----
37B	----	3	2500	3000	20	20	----	2	20	40	4000	3000	----	4	20	----	-----
83A	2000	3000	6000	6000	20	7	20	30	10	80	3000	2000	400	600	60	30	30
83B	2000	3000	5000	5000	5	8	30	40	10	100	3000	3000	300	600	40	20	20
90A	1000	1000	2000	2000	5	6	----	2	4	20	2000	2000	----	100	60	----	----
90B	1500	1500	2000	2000	25	7	----	2	6	30	2000	2000	----	200	50	----	----
127A	1000	1000	2000	2000	10	9	?	?	4	30	?	?	----	150	60	----	----
127B	1000	1000	2000	2000	20	8	----	2	3	40	2000	2000	----	150	70	----	-----
133A	1000	1000	10000	10000	6	9	?	?	10	40	?	?	500	800	60	30	30
133B	1500	2000	7000	6000	4	7	----	2	5	60	2000	2000	300	700	70	15	----

	Ba	Ca	Cu	Ga	Mn	Pb	Sr	Ti	Zr
509	900	2000	----	6	2	40	250	100	trace
A	1000	2000	4	10	6	50	300	150	10
504	1000	1500	----	7	4	30	100	80	trace
B	900	1500	3	10	10	40	150	80	6

All values are in parts per million.
Numbers just under the symbol for the element in the first section (e.g., Ba 3072) designate the wave length in Angstrom Units of the line measured.
A defective burn or missing sample is indicated by a "?". Undetectable amounts are indicated by "----".

Table 3. Trace Element Content of Biotite from Sample 502:

element	concentration in parts per million
Ba	6000
Ca	10000
Co	30
Cr	7
Cu	20
Ga	50
La	1000
Mn	4000
Pb	100
Sb	100
Sn	90
Sr	100
Ti	25000
V	100
Y	700
Yb	40
Zr	1000

The full significance of the results will be found in the discussion of the White Tank quartz monzonite, but a few general remarks as to the reproducibility of results may be appropriate here. The correspondence between two parts of a hand specimen may be seen by comparing the A and B parts of the first five specimens listed in Table 2. Comparison of sample A with sample 509 and sample B with sample 504 indicates the reproducibility obtained upon repeating the entire preparation and analysis procedure. Trace element concentrations are reported only to one significant figure except in cases where the measured value is midway between two figures.

On the basis of correlation between the various duplicate analyses, it is believed that a difference in composition of more than one in the first figure for any element is significant. The degree of certainty as to whether or not a given difference is significant, of course, increases with the difference.

THE PROBLEM OF TEXTURE

As with all scientific terms, the word texture should be defined before it can be discussed. The writer proposes the following definition: "Texture is a lithologic property comprising all relations which exist between individual grains and which may be described independently of the entire rock mass." By way of distinction, a structural property is a pattern of movement or feature of orientation which must be defined in its relation to the rock mass as a whole. This concept and definition of texture and the distinction between texture and structure are similar to definitions and distinctions adopted by many other petrographers. In the writer's opinion, the best summary of previous thought on texture and structure was made by Johannsen in 1948 (pp. 32-34).

The following examples are given for the purpose of clarifying the distinction between structure and texture.

1. If a petrofabric analysis be made on quartz in a granite, it may be found that the optic axes will bear some constant relation to the contact between the granite and wall-rock. This relation is a structural property inasmuch as it may be described only by relation to the contact between the two rocks, which is a feature of the entire granite mass rather than of its individual grains. A similar petrofabric analysis, however, on the quartz in a graphic granite may show that, within a given feldspar crystal, all of the quartz grains have a single optic orientation. Inasmuch as this orientation may be related to a single feldspar crystal, and need bear no relation to

any other grains in the rock or to the rock contact, it is a textural feature according to the definition given above. To carry this example a bit further, if all of the feldspar crystals are so oriented that the optic axes of the included graphic quartz grains show a uniform orientation with respect to the granite contact, then the quartz orientation is also a structural feature.

2. A fault cutting and offsetting a granite body is a structural feature related to the rock as a whole. A fractured feldspar grain filled by a veinlet of quartz is a textural feature related only to the feldspar grain and to the quartz. If a large number of feldspar grains were broken, and the fractures were consistently oriented, then the individual fractures would also be structural features.

Although structure certainly may not be ignored, this thesis is primarily concerned with texture.

Texture may be subdivided into several parts. In the writer's opinion, the best classification of texture is the one made by Cross, Iddings, Pirsson, and Washington in 1906. The broad subdivisions of this classification are

1. Crystallinity: the degree to which a rock is crystalline or glassy.
2. Granularity: the size of the grains.
3. Fabric:
   - A. Relative sizes of parts: equigranular or inequigranular.
   - B. Shape: euhedral signifies a grain bounded entirely by

crystal faces; subhedral signifies some crystal faces; and anhedral signifies the absence of crystal faces.

C. Arrangement: the orientation and distribution of different grains with respect to each other.

The writer, in modifying the CIPW classification for his own use, has found it desirable to add a few factors. The modified classification is given below, and a discussion of it follows.

1. Crystallinity.
2. Granularity.
   A. Average grain size of each mineral.
   B. Range in grain sizes of each mineral.
3. Fabric.
   A. Shape.
      1. The grain surface in detail.
      2. The general form of the grain.
   B. Arrangement.
      1. The distribution of each mineral throughout the rock.
      2. The optical orientation of the grains.
      3. The morphologic orientation of the grains.

1. The concept of crystallinity is the same as in the CIPW classification. All of the rocks dealt with in this thesis are completely crystalline.

2. The granularity of a rock is very difficult to describe. Ideally, the size of a grain is its volume, but measurement of grain volume appears impossible for most igneous rocks. The writer has

devised various methods (see pages 9-11) for determining relative grain sizes in various rocks, but no method of measuring absolute sizes has been found. Naturally, the average size and size range will generally be different for different minerals within the same rock, and separate data (both average size and range) should be recorded for each mineral measured. The difference in grain sizes among the separate minerals in the same rock indicates that the "grain size of a rock" is only an approximate quantity.

3. Fabric is even more difficult to describe than granularity. In some rocks studied by the writer, potash feldspar grains up to six inches long appeared megascopically to be well-formed crystals. In thin section, however, it was apparent that many of these grains did not have good crystal faces, but rather had very irregular borders which were shaped around neighboring, smaller, grains. Thus, although these crystals are certainly subhedral to euhedral in any normal usage of the term, they do not satisfy the original definition (made by CIPW), that euhedral crystals must be bordered by crystal faces. The writer does not propose to make any change in the normal usage of the terms "euhedral," "subhedral," and "anhedral," but he feels that a description of the shape of a grain should mention both the general outline and the detailed surface features.

The arrangement of minerals in an igneous rock involves both the distribution of the minerals throughout the rock and the orientation of the minerals. Certainly an igneous rock in which all of the quartz grains are randomly distributed among the other minerals is different from a rock in which quartz is in multi-grain aggregates; but the writer can find no good quantitative measurement to describe this difference. Both morphologic and optical orientation of grains must also be considered, for the two types of orientation do not always occur together.

GENERAL GEOLOGY

The area consists entirely of crystalline rocks of unknown age. The major types present are a gneiss and a series of silicic plutonic rocks.

The oldest formation in the area is the Pinto gneiss. It is a middle-rank metamorphic rock characterized by a well-developed foliation and a mineral assemblage of quartz, plagioclase, and biotite, with minor muscovite, hornblende, and potash feldspar. The foliation trend is generally north to northwest, and the dip is highly irregular but commonly nearly vertical. The layered appearance, shown best in the Lost Horse Mountains, and the high content of quartz (about 50 percent) indicate that the gneiss is largely a metasediment. In places the gneiss is intimately mixed with granitoid material and grades into the Palms quartz monzonite.

The Gold Park gabbro-diorite occurs in small, isolated masses scattered through the gneiss and Palms quartz monzonite. It is a fine to coarse grained rock consisting primarily of plagioclase and hornblende with local concentration of olivine, biotite, and possibly pyroxene. Its age with regard to the Pinto gneiss cannot be determined definitely.

The Palms quartz monzonite apparently formed later than the gneiss, but its age with regard to the gabbro-diorite is uncertain. The quartz monzonite to the north of Queen Mountain is a coarse to fine grained, inequigranular, seriate rock consisting of approximately equal amounts of quartz, potash feldspar, and plagioclase, with scattered biotite and hornblende and a characteristic assemblage of sphene, magnetite, apatite, and members of the epidote group. The quartz monzonite south of Queen Mountain and in the western part of Lost Horse Valley is a fine grained, approximately equigranular, rock of the same general mineralogical composition.

The monzonitic porphyry grades into the Palms quartz monzonite in some places, into the gneiss in other places, and has sharp contacts against either rock in some areas. The porphyry is characterized by large, highly poikilitic, potash feldspar crystals, which may attain a length of six inches. Slightly smaller and non-poikilitic plagioclase phenocrysts are about as abundant as potash feldspar. The other major minerals are quartz and either (rarely both) greenish hornblende or greenish-brown biotite. The accessory minerals are identical with those of the Palms quartz monzonite. The groundmass of the porphyry generally comprises about ten percent of the rock and consists of fine grained, highly intergrown, plagioclase, quartz, and potash feldspar. Most portions of the porphyry are massive, but in places there is a definite planar structure broadly parallel to the contacts.

Dikes of Palms quartz monzonite cut the monzonitic porphyry and vice versa. This evidence, together with their gradational contacts, suggests that the two rocks are essentially synchronous.

The White Tank quartz monzonite is the youngest plutonic rock in the area. Contacts with the adjacent rocks are invariably sharp. The rock is a coarse grained, equigranular to inequigranular, massive quartz monzonite with approximately equal amounts of quartz, potash feldspar, and plagioclase. Most samples contain a few percent of biotite and rare accessory minerals. The quartz monzonite in Queen Valley and the area to the south shows a vertical variation, the rock becoming more acidic and the potash feldspar grain size increasing toward the top.

Faults in crystalline rocks are very difficult to recognize, and the three mapped by the writer may not be the only ones. Two faults, along straight canyons which intersect at Forty Nine Palms, uplift a wedge of White Tank quartz monzonite north of Queen Mountain; apparently these faults die out southward. Another fault along the southern base of Queen Mountain may account for the sharp contact between two types of the Palms quartz monzonite.

Jointing is a conspicuous feature of the White Tank quartz monzonite and portions of the Palms quartz monzonite. The general pattern of the joints passes through the contact between the two rocks with absolutely no deflection.

In addition to the plutonic rocks mentioned above, several minor igneous rocks are present. The White Tank quartz monzonite is cut by aplite, pegmatite, and basic dikes. The Palms quartz monzonite and monzonitic porphyry contain, in places, abundant silicic and basic dikes averaging about six inches in width. Presumably the youngest rock in the area is the basalt which makes up the Malapai volcanic plug. There is no indication that any flows ever originated from this plug.

PINTO GNEISS

I. Introduction:

The Pinto gneiss, first named by Miller in 1938, appears to make up a large part of the mountain range south of the Pinto Mountain fault. Although no accurate conclusions can be drawn as to the extent of the gneiss, very similar rocks occur along much of the mountain front between Twentynine Palms and Morongo Valley (25 miles west), and the formation may extend to the Eagle Mountains (25 miles to the east). Although the southward extent of the gneiss is unknown, the rock near Twentynine Palms is very similar to the rock mapped as the Berdoo series in the Little San Bernardino Mountains by Maclellan in 1936.

In the area shown on Plate I, the gneiss comprises the Pinto Mountains on the east, the Hexie and Lost Horse Mountains on the south, the Quail Mountain area on the west, and smaller outcrops north of Queen Mountain.

II. Structure:

Near Twentynine Palms the gneissic foliation shows a general north to northwesterly strike and nearly vertical dip. Both on a broad scale and in detail, the foliation trends parallel to the contact with the White Tank quartz monzonite in the Pinto, Hexie, and Lost Horse Mountains. The small, isolated, patches of gneiss in the monzonitic porphyry northeast of Indian Cove show a remarkable uniformity of foliation, but the patches north of Forty Nine Palms either show no general orientation or represent a syncline overturned to the east and plunging southward.

In the Pinto and Hexie Mountains, for distances up to a mile from the quartz monzonite contact, the gneissic foliation strikes parallel to the contact but shows extreme variation in dip. In fact, the entire gneiss in this region is contorted into nearly vertical, isoclinal, folds with a width seldom exceeding fifty feet. The dip of the foliation, of course, varies from vertical through horizontal and back to vertical in the space of a few feet. In the Lost Horse Mountains this intricate folding and variation in dip is not present, and the reason for its presence in one place and absence in another is not known.

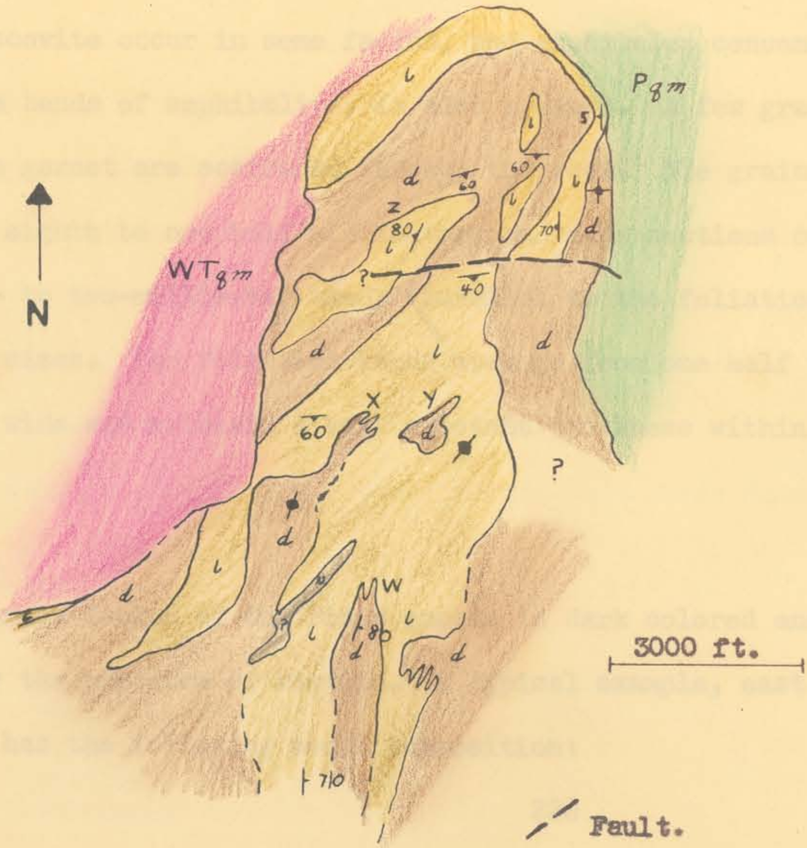
Detailed mapping in the Lost Horse Mountains (Fig. 5) shows the presence of folded structures, although the general trend is north-south. In detail, the foliation parallels the contact with the quartz monzonite, and in the northern part of the mountains there is some indication that a regional foliation making an angle up to 30 or 40 degrees with the contact is warped into parallelism within a foot or so of the contact. In other places, however, gneiss with a regional strike at an angle of approximately 60 degrees to the contact is cut obliquely by the quartz monzonite.

Lineation arising from intersecting directions of foliation, streaks of biotite within the planes of foliation, etc., are common in the gneiss but were not mapped.

Broad zones of mylonitization occur in the gneiss northwest of the Anaconda Mine and east of Lone Palm. Smaller shear zones are scattered throughout the gneiss in other areas.

Fig. 5

Map showing relations between biotitic and feldspathic Pinto gneiss in the Lost Horse Mts. just south of Sheep Pass



Fault.

Strike and dip of foliation.

Strike of vertical foliation.

Horizontal foliation.

WTqm White Tank quartz monzonite.

Pqm Palms quartz monzonite.

l Light colored, feldspathic, gneiss.

d Dark colored, biotitic, gneiss.

u Unknown rock; may be very light colored, non-biotitic, gneiss.

At points marked "W", "X", "Y", and "Z" there is definite gradation between the two types of gneiss along the trend of the foliation.

III. Composition and Texture:

A. General:

The Pinto gneiss is a middle-rank metamorphic rock characterized by plagioclase (albite to andesine), biotite, and quartz. Potash feldspar and muscovite occur in some facies, and amphibole, concentrated into thin bands of amphibolite, is also present. A few grains of reddish-brown garnet are scattered through the rock. The grain size varies from one eighth to one half millimeter, and some sections contain alternating one- to two-millimeter bands (parallel to the foliation) of different grain sizes. The foliation bands average from one half to two millimeters wide and maintain a very constant thickness within a given specimen.

B. Detail:

The most common facies of the Pinto gneiss is dark colored and characterized by the presence of biotite. A typical example, east of Queen Mountain, has the following modal composition:

	228
quartz	46.2%
potash feldspar	11.9
plagioclase	24.1
biotite	17.7
accessory	0.1
total points	1032

The plagioclase has a composition of An_{24} as measured by the Michel-Levy method. Some layers approximately one millimeter wide are pure quartz, and other layers up to four millimeters wide are quartz and feldspar with no mica. The plagioclase is twinned, unzoned, and may contain numerous small optically-oriented quartz grains. The biotite is pleochroic from light tan to colorless. All of the minerals are elongate parallel to the foliation. The largest grains are plagioclase, with an average size of one millimeter; the quartz and potash feldspar average one fourth to one half millimeter, and the mica one eighth millimeter.

A similar sample (number 130) of biotitic gneiss from the north side of the Hexie Mountains contains 30.8 percent biotite, pleochroic from yellow to dark brown, 2.8 percent accessory minerals, and the same relative proportions of quartz and the two feldspars as in sample 228. The plagioclase in number 130 has a composition of An_{40}.

Two modal analyses of biotitic rocks from the Lost Horse Mountains gave the following results:

	29b	29c
quartz	55.3%	55.0%
plagioclase	16.9	0.9
biotite	21.4	17.2
muscovite	6.5	25.6
accessory	0.2	0.5
total points	1038	1047

All grains are about one half millimeter in diameter, quartz being slightly larger than biotite and plagioclase. Biotite, pleochroic from yellow to dark brown, occurs in bands approximately one millimeter wide between bands of quartz and feldspar. Muscovite forms masses, one to two millimeters in diameter, of tiny, interlocking crystals. Plagioclase is generally untwinned, but indices show it to be in the albite range.

Fig. 6. Sample 29b of Pinto gneiss from Lost Horse Mountains. Aggregate of muscovite flakes is denoted by "m". Other constituents are biotite (b) and quartz (q). Crossed nicols, X25.

Biotitic gneiss right at the contact with White Tank quartz monzonite southeast of White Tank shows extensive chloritization of the biotite and the presence of a few rutile grains. A few veinlets of bleached biotite with some chlorite and muscovite cut the foliation.

Less common than the biotitic facies is a light tan, feldspathic gneiss. Modal analyses of three typical specimens are as follows:

	246	34	167
quartz	35.0%	41.3%	53.8%
potash feldspar	29.6	28.8	15.3
plagioclase	30.9	28.4	23.0
biotite	4.6	1.1	4.8
muscovite	---	---	3.2
accessory	0.2	0.4	0.1
total points	1035	1044	1048

246. north of Forty Nine Palms
34. south of Sheep Pass
167. east side of Lost Horse Valley

The average grain size in this light colored gneiss is one eighth to one half millimeter, thus being slightly smaller than the grain size in the biotitic gneiss. Grain orientation is not as well developed as in the biotitic gneiss. Plagioclase in sample 246 is An_{25}, and in samples 34 and 167 is An_{05}. In sample 167 the plagioclase is twinned on the albite law, unzoned, and commonly oriented with the twinning planes normal to the foliation, uncommonly with the twinning planes parallel to the foliation, and rarely with the twinning planes at an askew angle. Both twinned and untwinned potash feldspar occur in the same section.

Portions of the feldspathic gneiss east of Stirrup Tank contain only 25 to 30 percent quartz and have the composition of a quartz monzonite. Otherwise, the rock is indistinguishable from the remainder of the feldspathic gneiss.

In addition to the biotitic and feldspathic types of gneiss described above, a few thin (less than ten feet wide) bands of black amphibolite are scattered throughout the Pinto gneiss. Sample 427, from the Lost Horse Mountains, contains an estimated 65 percent yellow to greenish-blue hornblende prisms, 30 percent untwinned, anhedral plagioclase (An_{50}), five percent biotite, and rare quartz, magnetite, and apatite. The average grain size is one fourth millimeter.

Another band in the Lost Horse Mountains contains an estimated 50 percent median andesine, 25 percent cummingtonite, and 25 percent chlorite, with rare magnetite and quartz. The average grain size is one fourth to one half millimeter.

In a patch of gneiss north of Forty Nine Palms is a thin lens consisting entirely of sutured quartz grains with an average diameter of three millimeters. It is not known whether this is a quartzitic lens in the gneiss or a silexite.

IV. Compositional Variations:

As indicated above, the gneiss may be divided into two principal facies: one a dark colored quartz-biotite or quartz-feldspar-biotite rock, and the other a light colored quartz-feldspar rock. In the Lost Horse Mountains these two types form layers 100 to 500 feet thick and generally parallel to the foliation. Although there are small gradations between the two types, a sample will generally contain more than ten or less than five percent biotite.

Thus, for example, in the Lost Horse Mountains a detailed map was made showing distinct layers of dark and light gneiss generally parallel to the foliation (Fig. 5). At points on this map marked W, X, Y, and Z, the contact (actually a zone from six to 100 feet wide) cuts the foliation.

The amphibolitic layers are lithologically distinct and show no gradation with the surrounding facies.

V. Origin:

In 1938 Miller proposed that a large part of the Pinto gneiss had formed by reaction between the Gold Park gabbro-diorite and the Palms quartz monzonite and shearing out of the products. Admittedly, in many places the gneiss is intimately mixed with, and grades into, the quartz monzonite, but for reasons listed below it seems likely that the bulk of the gneiss is metasedimentary or metavolcanic material.

1. Layers of different composition several hundred feet wide and parallel to the foliation (for example, in the Lost Horse Mountains) seem most easily explained by metamorphism of a layered sequence. This evidence does not distinguish between metasediments and metavolcanics, but it does argue against a parent rock of quartz monzonite or gabbro.

2. The differences in the composition of the plagioclase in different layers indicates formation in a chemically non-homogeneous system. If, as seems probable, this inhomogeneity represents chemical differences in the original rock, then the parent rock was more likely sedimentary or volcanic than plutonic.

3. The average quartz content of the gneiss is approximately 50 percent. Such a high percentage indicates a sedimentary rather than an igneous parent rock.

In addition to the above reasons for believing that the gneiss is metasedimentary or metavolcanic, two specific arguments may be made against the origin proposed by Miller:

1. If Miller's proposal is correct, the original mass of gabbro-diorite must have been many tens of miles in diameter, which does not seem likely.

2. If Miller's proposal is correct, one would expect to find far more gabbro-diorite mixed with the gneiss than is actually present. In a large area such as the Lost Horse Mountains, there is absolutely no gabbro-diorite.

Assuming that the Pinto gneiss formed by middle-rank metamorphism of sedimentary or volcanic rocks, it is difficult to determine the exact nature of the parent rock. The composition indicated by modal analysis of the gneiss (and assuming isochemical metamorphism) is similar to the composition of graywackes* except for a higher potash/soda ratio (K/Na averages 1 to 1.5 in the Pinto gneiss). The total silica content seems too high for normal igneous rocks but may well represent the composition of mixed sedimentary and volcanic material. No relict textures or structures, other than the large scale layering, have been found which would aid in determining the nature of the parent material. The gneiss of quartz-monzonitic composition east of Stirrup

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* Pettijohn (1949), page 250.

Tank may be a true metamorphosed igneous rock, or it may represent a transition into the Palms quartz monzonite.

GOLD PARK GABBRO-DIORITE

I. Introduction:

The Gold Park gabbro-diorite was first named and described by Miller in 1938. It occurs in small, isolated outcrops scattered throughout the area. Its age with respect to the Pinto gneiss cannot be accurately determined, but it seems to have intruded either the gneiss or the unmetamorphosed rock which now comprises the gneiss.

II. Structure:

No structure has been found in the gabbro-diorite, but the intense weathering of most outcrops makes detection of structure difficult.

III. Composition and Texture:

Although the gabbro-diorite shows extreme textural variation, the poor exposures prevent describing these textures in relation to each other or to their position in the intrusion as a whole. Section 177, from an outcrop northeast of the Lost Horse Mountains, contains hornblende prisms three millimeters long and poikilitically enclosing 0.5-millimeter, subhedral, laths of plagioclase. The matrix in this specimen consists of plagioclase laths identical to the poikilitically enclosed ones. Section 81 (Fig. 7), from an outcrop west of the Anaconda Mine, is remarkably equigranular; all minerals are anhedral and have an average diameter of 0.25 to 0.5 millimeter.

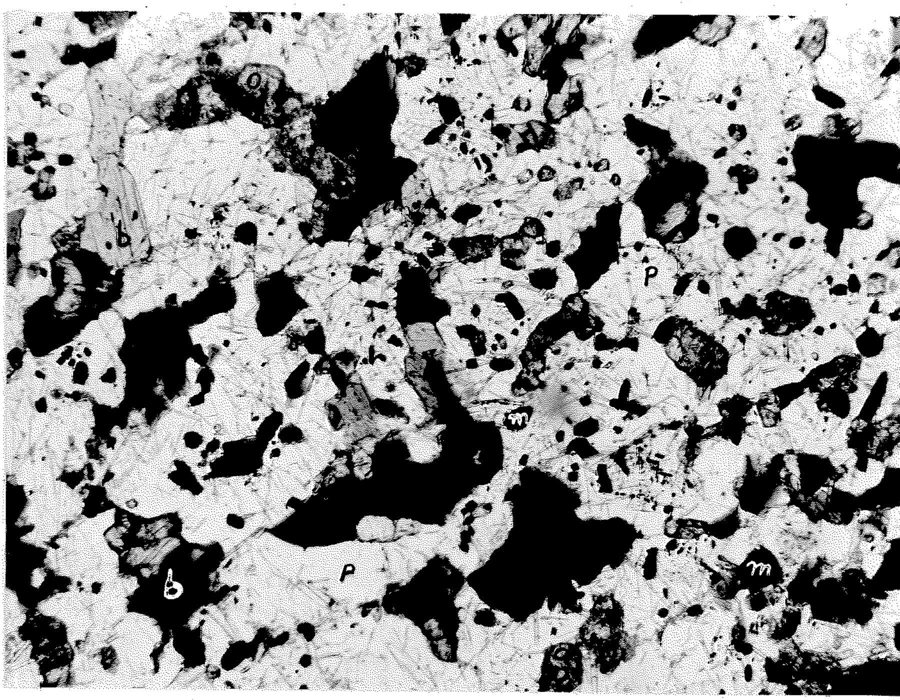

Fig. 7. Sample 81 of Gold Park gabbro-diorite west of the Anaconda Mine. The tiny transparent needles are apatite (?). Other minerals are plagioclase (p), olivine (o), biotite (b), and magnetite (m). Plain light, X65.

Modal analyses of two samples of gabbro-diorite are as follows.

	81	177
plagioclase	47.4%	43.8%
hornblende	7.3	46.7
biotite	28.5	---
olivine	3.8	0.2?
chlorite	---	3.6
augite?	0.9?	---
magnetite	6.4	not separated from other accessories
other accessory	5.8	5.6
total points	1088	1115

The plagioclase in both rocks is generally strongly zoned and may or may not be twinned. In sample 177 the composition of the plagioclase varies from An_{65} in the center of the grains to An_{50} at the edge. A sharp compositional break at about An_{60} produces a Becke line in many grains. Zoning in the plagioclase of section 81 is also normal, ranging from An_{45} to An_{25}. Some of the plagioclase in section 81 is antiperthitic.

Hornblende in both sections mentioned above is pleochroic from yellow green to greenish blue; in section 177 it forms large, poikilitic grains, but in section 81 it occurs as small grains partially mantling the olivine. The identification of pyroxene in section 81 is uncertain. Biotite is pleochroic from yellow to dark brown.

Section 81 contains approximately five percent of colorless, low birefringent, tiny needles with hexagonal cross-sections; they are tentatively identified as apatite.

Alteration products are scarce in section 81. In section 177, however, the plagioclase is intensely sericitized, and the hornblende is altered to chlorite and a mineral tentatively identified as sphene.

IV. Origin:

Although the Gold Park gabbro-diorite probably formed by crystallization of a melt, some mineralogical details are difficult to explain by such a process. The presence of olivine and hornblende in section 81 and the absence or scarcity of pyroxene seems to contradict crystallization according to the standard Bowen reaction series. The abundance of apatite (?) in section 81 also seems unusual.

PALMS QUARTZ MONZONITE AND MONZONITIC PORPHYRY

I. Introduction:

In 1938 Miller first named the Palms granite for its type exposures near Forty Nine Palms. His identification of the rock was based on modal analyses which showed a potash feldspar content of approximately 50 percent and an oligoclase content of 8.3 percent. The present writer, however, has been unable to find any true granite in the entire outcrop area of the rock, and he has renamed the formation the Palms quartz monzonite on the basis of a potash feldspar to plagioclase ratio of approximately 1:1. Miller also named the monzonitic porphyry from exposures along the front of the mountains south of Twentynine Palms, and the present writer has found his definition adequate.

In the type locality and the mountainous area to the south, the Palms quartz monzonite is typically coarse to medium grained and very inequigranular. Fine grained, equigranular rocks in Queen and Lost Horse Valleys have been mapped as the same formation, although the correlation between the different types is not certain. Miller's original definition of the granite included the fine grained rock in Queen Valley, but his area of investigation did not include the similar formation in Lost Horse Valley.

The monzonitic porphyry crops out around the northern periphery of the Palms quartz monzonite body. The quartz monzonite and the porphyry are discussed together because they are thought to be intimately related genetically for reasons which will be fully discussed on pages 118-120.

The Palms quartz monzonite and monzonitic porphyry are younger than the gneiss, as is shown by dikes of each rock in the gneiss at various places. Contacts between the quartz monzonite and gabbro-diorite are invariably so gradational that no exact age relations may be stated, although in places, the quartz monzonite appears to invade and inject the gabbro-diorite. The absolute age of the Palms quartz monzonite and monzonitic porphyry is unknown.

II. Brief Statement of Conclusions:

Conclusions concerning the origin of the Palms quartz monzonite and the monzonitic porphyry will be discussed in detail following general descriptions of the two rocks and the nature of their contacts. It would be well here, though, to indicate briefly the writer's conclusions as to the origin of each rock.

The relatively abrupt transitions between quartz monzonite and gneiss where the two rocks are in contact and the dikes of quartz monzonite in gneiss indicate that the Palms quartz monzonite formed largely by crystallization of an intruded melt. The distribution of monzonitic porphyry along some borders between gneiss and quartz monzonite, and the gradational contacts commonly shown between porphyry and both of these rocks, indicate that the porphyry has formed by reaction of quartz monzonite melt with gneiss. During its formation, at least part of the porphyry must have been sufficiently mobile to intrude both gneiss and quartz monzonite and form very sharp contacts with these rocks in some places.

III. Description of Palms Quartz Monzonite, Monzonitic Porphyry, and Contact Relations:

A. General Description of Palms Quartz Monzonite:

The Palms quartz monzonite may be divided into four types: coarse grained rock as in the type locality in Forty Nine Palms Canyon; finer grained rock in the upper part of the mountains south of Twentynine Palms; fine grained rock in Queen and Lost Horse Valleys; and dikes of quartz monzonite in older rocks. These four types are described below.

1. Coarse grained quartz monzonite (Unit A):

As shown on Plate I, the type rock in Forty Nine Palms Canyon, hereafter referred to as Unit A, occurs throughout the mountainous area south of Twentynine Palms. The rock is coarse grained, very inequigranular, generally massive, and ranges from brown to gray. Foliation, caused by alignment of biotite flakes, is present in some places, but no general foliation trends could be found, even over small areas. Modal analyses of six samples of this facies are shown in Table 4. Sample 354 (Fig. 8) is typical of Unit A.

Quartz occurs either in two- to four-millimeter aggregates of undulant, fretted grains or as scattered, individual grains. The ratio between quartz in aggregates and in individual grains varies throughout the rock but is generally about 1:1. The average size of quartz grains is about one half millimeter, with those in aggregates being slightly larger than the individual grains.

The ratio between grid-twinned and untwinned potash feldspar varies randomly from section to section. Some grains contain both twinned and

Table 4. Modal Analyses of Unit A of Palms Quartz Monzonite:

	112	316	322
quartz	18.0%	28.4%	15.4%
potash feldspar	26.9	21.3	28.6
plagioclase	41.6	42.0	47.0
biotite	8.8	7.7	7.0
hornblende	3.5	---	trace
accessory	1.2	0.6	1.9
total points	1108	1175	1141

	344	354	369
quartz	17.0%	28.1%	26.4%
potash feldspar	34.7	25.2	24.0
plagioclase	36.8	40.5	35.0
biotite	9.4	4.3	13.3
hornblende	---	---	---
accessory	2.1	1.7	1.3
total points	1104	1040	1088

Fig. 8. Sample 354 of Unit A of Palms quartz monzonite east of Forty Nine Palms. Major minerals are quartz (q), plagioclase (p), and microcline (m). Large crystals are seriate down to the small grains shown here. Crossed nicols, X25.

untwinned portions. Almost all potash feldspar grains are anhedral. Their average size is 1.5 millimeters as measured in thin section. In one section east of Forty Nine Palms about one third of the potash feldspar occurs in thin veinlets (Fig. 9), which cut all of the other minerals. This late, untwinned, vein feldspar also occurs in other samples near the wall rocks in the northern part of the mountains and may be the result of hydrothermal activity.

Plagioclase has three main habits, each of which is associated with a different composition:

(1.) About one half or more of the plagioclase in Unit A forms subhedral to anhedral laths with an average size of 1.0 to 1.5 millimeters and a small range in size of individual grains. Grains generally show excellent albite twinning and also some pericline twinning. Some grains are zoned from An_{30} or An_{35} in the center to An_{20} on the edges. Some unzoned grains have a composition of An_{15}. A few percent of potash feldspar is common as rod antiperthite in these laths. Some laths are complexly intergrown with potash feldspar on the borders.

(2.) All sections of the quartz monzonite contain an anhedral, fine grained, irregularly shaped, untwinned, commonly myrmekitic, plagioclase in addition to the laths mentioned above. The composition of this plagioclase ranges from An_{15} to pure albite. It forms sodic rims around the plagioclase laths; small, irregular grains scattered interstitially throughout the rock; and most commonly, irregular intergrowths with potash feldspar. Grains range from very small up to one millimeter in diameter. This type of plagioclase commonly, but not invariably, occurs next to potash feldspar.

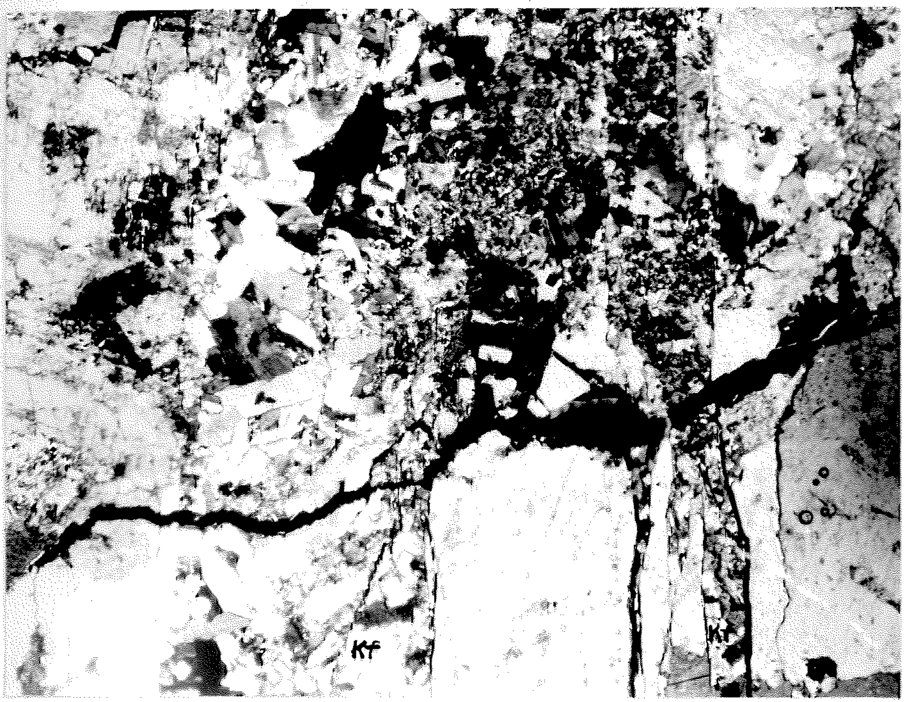

Fig. 9. Veinlets of untwinned potash feldspar (Kf) in sample 352 of Unit A of Palms quartz monzonite east of Forty Nine Palms. Crossed nicols, X25.

(3.) In some sections a third type of plagioclase can be distinguished. It has a composition of An_{15} (intermediate to the first two types). Grains range from well twinned to untwinned, are unzoned, and are commonly intergrown with potash feldspar. Small quartz grains may be included in this type of plagioclase where it is in contact with potash feldspar, but the quartz shows no morphologic or optical orientation as in most myrmekite.

The distinction between these various types of plagioclase is very difficult and cannot be made in all cases.

In the Unit A of the Palms quartz monzonite, most of the myrmekite forms teardrop-shaped grains in which the quartz blebs appear to radiate from a point near the small end of the grain. These grains may either be separate or attached to a plagioclase lath.

Both rod and vein perthite are common.* Some undoubted rod perthite contains plagioclase of the same composition as the plagioclase in the associated antiperthitic laths, which is to be expected if both are features of exsolution. Most of the vein perthite is more sodic than the plagioclase laths, but discrimination between rod and vein perthite is not possible in some cases.

A characteristic feature of the quartz monzonite is the irregular intergrowth between plagioclase (An_{15} to pure albite) and potash feldspar. In any section, most of the plagioclase in the perthite has the same composition as the plagioclase in the associated intergrowths. Fig. 10 shows characteristic textural relationships between potash feldspar and plagioclase in Unit A.

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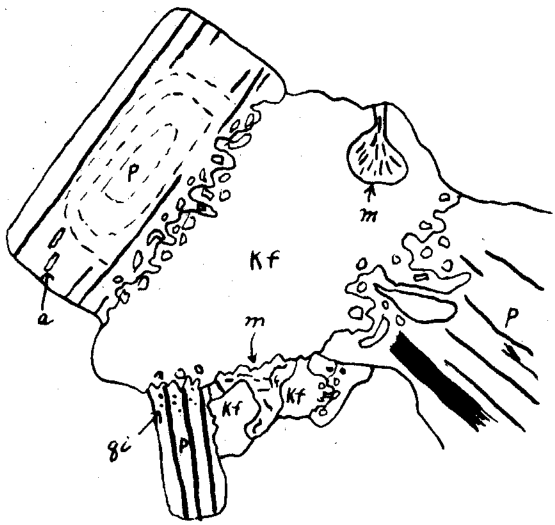
* The nomenclature for the various types of perthite is taken from Alling (1938).

Fig. 10

Diagrammatic sketch showing relationships of plagioclase and potash feldspar in Unit A of Palms quartz monzonite



P = plagioclase; one lath is partly twinned and partly zoned, one lath is twinned and unzoned, and one irregularly shaped grain is partly twinned and unzoned.

Kf = potash feldspar; most borders show irregular intergrowths with plagioclase.

m = myrmekite; two different types.

qi = small, round, inclusions of quartz in plagioclase near potash feldspar.

a = antiperthite.

Thus, on the basis of the compositional and textural relationships between plagioclase and potash feldspar, the following general paragenesis may be inferred:

1. Growth of plagioclase laths and start of growth of potash feldspar with later exsolution of the two feldspars in each phase;
2. Growth of most of the potash feldspar and formation of the sodic plagioclase with abundant intergrowth between the two feldspars and some formation of sodic rims on plagioclase laths.

Most of the myrmekite and perthite are associated with the simultaneous intergrowth of the two feldspars, and neither texture seems to have formed by replacement (see similar conclusion for the White Tank quartz monzonite on pages 187-190). There is no textural feature which indicates that either the sodic plagioclase or the potash feldspar grew later than the other feldspar, and the appearance of the intergrowths suggests simultaneous crystallization. The medium of growth in this process need not have been fluid, but its exact nature cannot be determined.

Biotite in Unit A generally forms irregular flakes with an average length of 0.25 millimeter. It is pleochroic from yellow to reddish- or greenish-brown, but slight chloritization obscures the colors in some sections. Commonly it forms clusters with the accessory minerals.

Hornblende is pleochroic from yellow to bluish green and is identical to the hornblende in the monzonitic porphyry. In some sections it forms small inclusions, (relics?) in biotite grains, but in others it occurs as discrete, subhedral prisms.

Unit A contains a very characteristic suite of accessory minerals. Magnetite, sphene, apatite, and epidote are present in almost all sections. Part of the epidote is in euhedral grains unrelated to plagioclase and may be primary, but some grains have probably formed by alteration of plagioclase. Zircon and allanite are rare.

The more calcic plagioclase is generally strongly altered to sericite*, but the sodic plagioclase is not sericitized. Kaolin is densest on the plagioclase but also coats some of the potash feldspar. Some of the biotite has been altered to white mica.

2. Finer grained quartz monzonite (Unit B):

In the higher parts of the mountains around and south of Forty Nine Palms is a facies of quartz monzonite slightly different from Unit A. This facies (Unit B) everywhere lies above Unit A, but the contact between the two rocks is so gradational that it is difficult to locate.

In distinction to the massive Unit A, Unit B is poorly to well foliated. Generally the foliation is nearly vertical and parallels the northwesterly trend of the Pinto gneiss. Foliation is marked by orientation of both biotite flakes and elongate aggregates of quartz grains. Some parts are apparently massive.

The plagioclase in Unit B is more sodic than in Unit A and the percentage of biotite is less. Otherwise, the chemical composition

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* See page 132 for a discussion of the meaning of "sericite" in this thesis.

of the two rocks is about the same. Modal analyses of two samples of Unit B near Forty Nine Palms are given below.

	363	365
quartz	16.9%	22.6%
potash feldspar	35.2	28.4
plagioclase	45.8	46.2
biotite	1.1	2.2
accessory	1.1	0.8
total points	1033	1101

Section 363 (Fig. 11) is typical of Unit B.

Possibly more of the quartz (up to two thirds of the quartz in the rock) is in undulant, fretted aggregates in Unit B than in Unit A; but otherwise the quartz in the two rocks is identical.

Potash feldspar is both twinned and untwinned as in Unit A. It forms highly complex intergrowths with the plagioclase and also poikilitically includes small grains of all other minerals in the rock. Its average diameter is about one millimeter, and it ranges up to eight millimeters in length.

Only one type of plagioclase is common in Unit B. It has a composition of An_{10} to An_{05} and is almost invariably associated with potash feldspar in the complex intergrowths which also characterize Unit A. A few of the larger grains are slightly zoned, the center having a composition of about An_{20}. All of the grains have well developed albite twinning, and some grains show bent twin lamellae and undulant extinction. Perthite contains plagioclase of the same composition as the larger grains. Many of the plagioclase grains contain small inclusions of quartz, which show no optical or morphologic

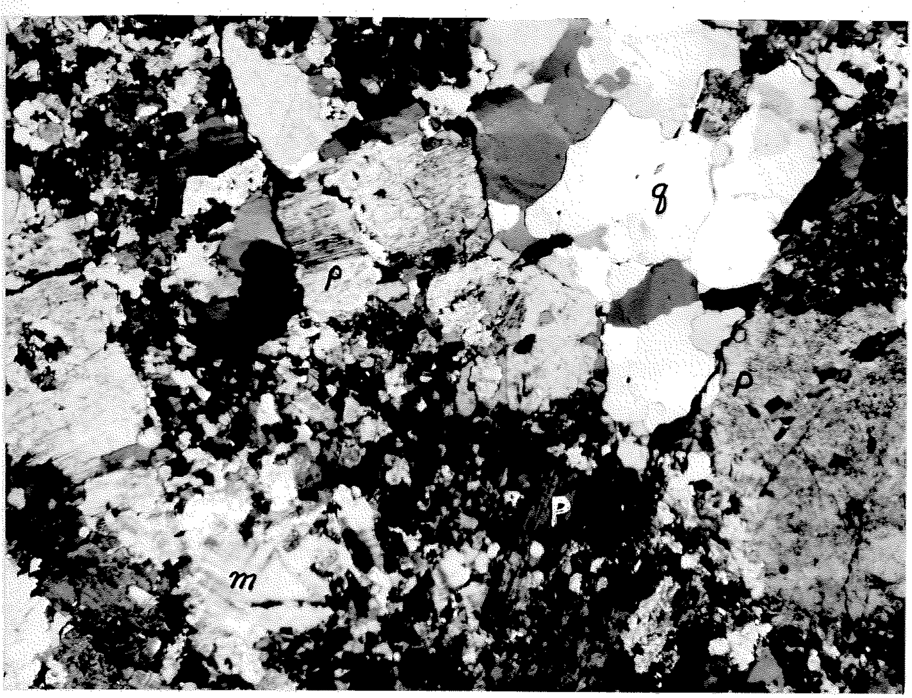


Fig. 11. Sample 363 of Unit B of Palms quartz monzonite southwest of Forty Nine Palms. Major minerals are quartz (q), plagioclase (p), and microcline (m). Crossed nicols, X25.

orientation. There are no relations which indicate a paragenesis between plagioclase and potash feldspar, and the complex intergrowths of the two minerals may signify simultaneous growth.

Biotite forms very small flakes which are pleochroic from yellow to greenish brown. These flakes generally occur in clusters but are not associated with the accessory minerals as they are in Unit A. Unit B contains no hornblende.

Accessory minerals are epidote, sphene, magnetite, and rarely apatite. Some of the epidote is probably an alteration product of plagioclase. The accessory minerals either form aggregates or are scattered throughout the rock.

Sericite occurs in veinlets and as an alteration product of plagioclase. Kaolin is an alteration product of plagioclase and, rarely, of potash feldspar.

In summary, the principal differences between Units A and B of the Palms quartz monzonite are the following:

Unit A	Unit B
1. average plagioclase composition of An_{20}	1. average plagioclase composition of An_{10}
2. several types of plagioclase ranging from An_{30} to pure albite	2. one type of plagioclase
3. 5% biotite	3. 1% biotite
4. approximately half of the quartz in aggregates	4. approximately two thirds of the quartz in aggregates
5. accessories in aggregates with biotite	5. accessories not with biotite
6. apatite a common accessory	6. apatite rare

Although Units A and B both contain the same amount of free quartz, Unit B is clearly more acidic than Unit A.

As was indicated in the discussion of Unit A, the textural relations between plagioclase and potash feldspar seem to be controlled, in large part, by composition; the more sodic plagioclase tends more strongly to form complex intergrowths with potash feldspar. It is to be expected that if the intergrowths had formed by replacement of plagioclase by potash feldspar, the more calcic plagioclase would be more readily attacked, and the majority of the intergrowths would involve calcic plagioclase and potash feldspar. It is difficult to prove that the intergrowths have not formed by replacement of potash feldspar by sodic plagioclase, but as discussed in the section on Unit A, the most reasonable interpretation of the origin of this texture seems to be simultaneous crystallization of the two feldspars.

3. Fine grained quartz monzonite (Unit C):

In Queen Valley and in the western part of Lost Horse Valley is an equigranular quartz monzonite which is clearly older than the White Tank quartz monzonite (as is shown by dikes and other contact features). Unit C intrudes and sends dikes into the gneiss on the west side of Lost Horse Valley, where the contact is quite abrupt (gradational through about an inch). Although unconnected, the two bodies of Unit C are very similar and are almost certainly the same formation. Their correlation with Units A and B of the Palms quartz monzonite is based on rather tenuous evidence:

(1.) Unit C grades into Unit B in the eastern part of Queen Valley.

(2.) As nearly as can be determined, Unit C is the same age as Units A and B.

Much of the contact between Units B and C is along the mountain face on the north side of Queen Valley. The straightness of this face, the difference in the rocks on either side, and the abrupt change in elevation without other apparent cause suggest that this mountain front may be a fault or fault-line scarp.

Modal analyses of three samples of Unit C are given below (samples 129 and 200 are from Queen Valley, and sample 296 is from Lost Horse Valley).

	129	200	296
quartz	34.2%	26.8%	29.7%
potash feldspar	23.7	31.9	25.7
plagioclase	37.0	30.6	40.6
biotite	1.2	7.0	3.8
accessory	0.3	----	0.4
total points	1208	1089	1098

Section 129 (Fig. 12) is typical of Unit C.

The most characteristic feature of Unit C is its marked equigranularity. Quartz and both feldspars average 0.3 to 0.5 millimeter in diameter. Biotite is 0.25 millimeter long. All minerals are evenly distributed throughout the rock, in distinction to Units A and B, in which aggregates of quartz and mafic minerals are common. Quartz shows a slight tendency to form aggregates in Unit C, but most quartz is in individual grains. Quartz and potash feldspar are anhedral, but plagioclase is subhedral and forms lath-shaped crystals. Hand specimens are light brown, fine grained, equigranular, and generally massive, but, in some places, show a faint foliation.

Fig. 12. Sample 129 of Unit C of Palms quartz monzonite in Queen Valley. Major minerals are quartz (q), plagioclase (p), and microcline (m). Crossed nicols, X25.

Some quartz grains have a slight undulant extinction. In some sections isolated grains have identical optical orientations within areas up to five millimeters in diameter.

In samples whose plagioclase is highly sodic (An_{05} or less), all of the potash feldspar shows grid twinning. In most of Unit C, however, both twinned and untwinned grains occur in the same section.

The composition of the plagioclase is different in different parts of Unit C. The rock in the eastern part of Queen Valley contains plagioclase laths having a composition of An_{10} to An_{05}. These laths are twinned but generally unzoned. In addition, this rock may contain untwinned, irregular, partly myrmekitic, small grains of approximately pure albite around the borders of potash feldspar grains. Some of the plagioclase laths contain small, round, unoriented inclusions of quartz.

Most of the rock in Queen Valley and all of the rock in Lost Horse Valley contains plagioclase somewhat more calcic than that in the eastern part of Queen Valley. In general, the more westerly plagioclase is more calcic. Compositions of the subhedral laths range from An_{20} to An_{30}. Up to ten percent of the plagioclase is pure albite, as small, partly myrmekitic, grains scattered throughout the rock and rarely, as sodic rims on the plagioclase laths. Some of the larger plagioclase laths (up to three millimeters long) show a normal zoning over a compositional range of about An_{05}. All plagioclase is twinned. In some sections from the western part of Lost Horse Valley, the calcic plagioclase laths form irregular, oriented intergrowths with potash feldspar and may be myrmekitic. Plagioclase in the rare rod and vein perthite has a composition in the albite range.

Biotite forms very ragged flakes, pleochroic from yellow to dark brown. It is intensely chloritized and, in places, altered to a reddish material with tiny white opaque needles.

Magnetite is the most common accessory mineral. Zircon forms pleochroic haloes in some biotite. Apatite is rare, and sphene, which characterizes the other units of the Palms quartz monzonite, is absent.

Plagioclase is moderately sericitized, but some of the white mica seems to have formed by alteration of biotite or, possibly, by primary crystallization. Kaolin forms a light dusting on both feldspars.

Unit C differs from Units A and B in several important respects. Most of Unit C lacks the extremely complex intergrowths of potash feldspar and plagioclase which characterize Units A and B. Unit C is equigranular, but Units A and B are markedly inequigranular. The minerals in Unit C are evenly distributed throughout the rock, whereas in Units A and B clusters of quartz and mafic minerals are common. Unit C lacks sphene, a characteristic accessory mineral in the other units, and contains no hornblende. On the basis of this evidence, it might be argued that Unit C formed under entirely different conditions from the rest of the Palms quartz monzonite and has no relation to it. But for the reasons listed on page 57, it seems most reasonable to consider Unit C as a part of the Palms quartz monzonite, although the correlation with the type rock is not definite.

4. Dikes of Palms quartz monzonite:

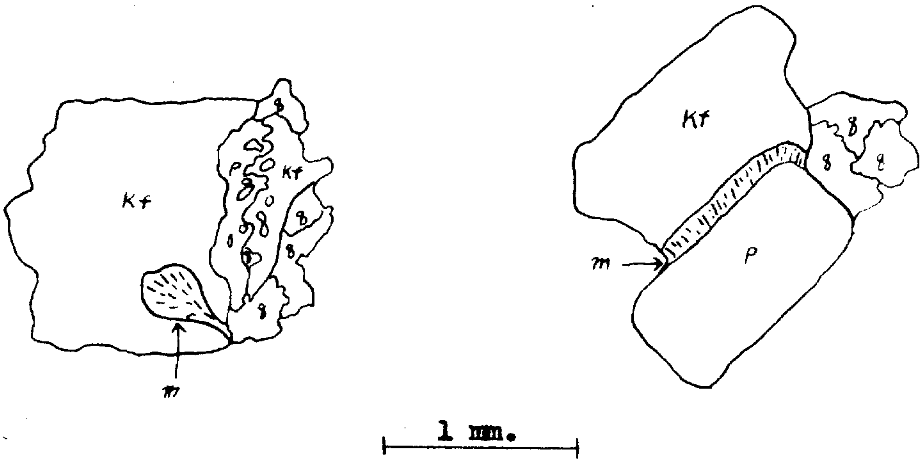
Dikes of quartz monzonite cut the monzonitic porphyry in several places along the contact north and west of Forty Nine Palms; they are most abundant north of Indian Cove. Inasmuch as these dikes extend in straight lines through the porphyry and across contacts and have very sharp borders with their wall rocks, they presumably represent injection of fluid material.

Compositionally the dikes are very similar to Unit A of the quartz monzonite. Plagioclase in the dikes is commonly a little more sodic (An_{15} to An_{10}) than in Unit A, but in some dikes the plagioclase laths are An_{25}. Dikes with the more calcic plagioclase laths (An_{25}) also contain a sodic phase which forms rims and small grains as in Unit A. Dikes with sodic plagioclase (An_{10}) contain only one plagioclase phase, but in contact with potash feldspar grains, this plagioclase may be slightly (normally) zoned. The accessory minerals characteristic of Unit A (magnetite, sphene, epidote, apatite, and allanite) are present in all dikes. Highly altered flakes of biotite are as abundant as in Unit A.

Texturally the dikes differ somewhat from Unit A. Except for the mafic and accessory minerals, which show a very slight tendency to form clusters, all minerals are evenly distributed. Quartz occurs as individual grains rather than in aggregates. The feldspars in the dikes are not as complexly intergrown as in Unit A. Myrmekite may have either of two forms (illustrated in Fig. 13). Rod perthite generally has the same composition as the associated plagioclase

Fig. 13

Diagrammatic sketches showing two types of myrmekite in dikes of Palms quartz monzonite



1 mm.

Kf = potash feldspar
p = plagioclase
q = quartz
m = myrmekite

laths, and antiperthite occurs in some of the larger plagioclase laths. Small veinlets of quartz cut some of the feldspars. Section 339, Fig. 14, is typical of these dikes.

Characteristically, the grain size of all minerals in the dikes is smaller than in Unit A, and the size range is also smaller. The small dikes are generally equigranular with regard to quartz and the feldspars, the quartz being slightly larger in some sections. Most grains have a diameter of 0.25 to 0.5 millimeter. One dike about six feet wide (slightly larger than average) has a fine grained, equigranular border and a central portion of the same composition but with quartz and both feldspars seriate from the groundmass up to phenocrysts as large as in Unit A. The central portion of this dike also has the complex intergrowths of feldspars and aggregates of quartz characteristic of Unit A, but it has only one plagioclase phase.

The dikes described above indicate that the Palms quartz monzonite was, at least at one time, mobile enough to be intruded as a fluid. The fineness of grain in the small dikes and the zoning in the larger dikes indicate that this injection occurred before the quartz monzonite had crystallized to the coarse grain size characteristic of Unit A (for the dikes and Unit A have approximately the same composition).

A dike cutting Unit C north of Hidden Valley contains approximately five percent garnet. The garnet grains are up to two millimeters in diameter, show many crystal faces and edges but are highly irregular on other surfaces, have a slight birefringence (biaxial positive), and are polysynthetically twinned. The garnet is yellowish in section,

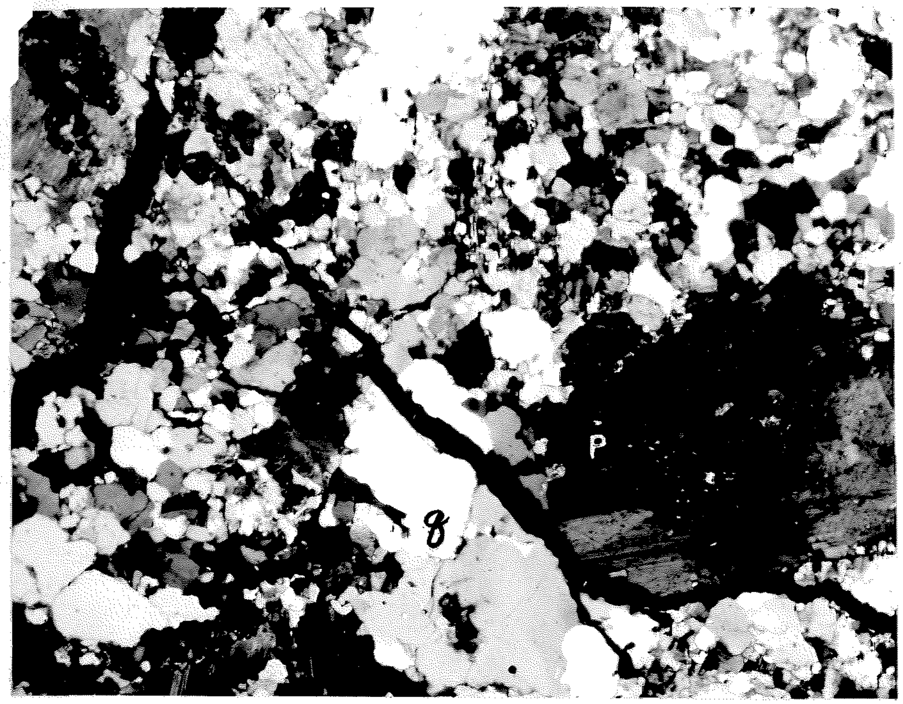


Fig. 14. Sample 339 of a dike of Palms quartz monzonite in monzonitic porphyry east of Indian Cove. Phenocryst of plagioclase (p) and quartzose aggregate (q) in groundmass of plagioclase, quartz, and potash feldspar. Crossed nicols, X25.

but the color is very dull and not distinctive. This garnet is tentatively identified as andradite. About two thirds of the dike is composed of subhedral, twinned to untwinned, unzoned laths of apparently pure albite with an average length of 0.5 millimeter. Small grains of quartz are scattered through the rock. Large irregular grains of potash feldspar (up to two millimeters in diameter), poikilitically include much of the plagioclase and some of the quartz. Both quartz and potash feldspar appear interstitial to the albite. Biotite, sphene, magnetite, and epidote are minor constituents. The plagioclase is intensely kaolinized, and the biotite is altered to ferruginous material.

The origin of this dike is uncertain. Its content of sphene and garnet is not characteristic of Unit C, the rock which it intrudes. In the remainder of the quartz monzonite, albite certainly does not crystallize before potash feldspar and quartz and generally crystallizes apparently simultaneously with either mineral. Thus, it is unusual to find both quartz and potash feldspar interstitial to laths of approximately pure albite. Perhaps the early crystallization of the albite in the dike was caused by its extremely high concentration (75% of the final rock). There is no evidence that the albite formed by replacement of more calcic plagioclase.

B. <u>Contacts between Palms Quartz Monzonite and Pinto Gneiss</u>:

Contacts between the Palms quartz monzonite and the Pinto gneiss range from very abrupt to broadly gradational. Examples of three parts of this range, plus one example of apparently broad gradation, are discussed below.

1. Abrupt contact:

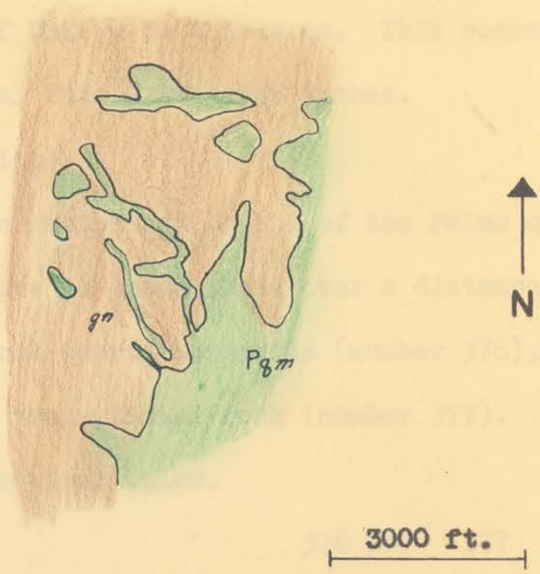
The contact between Unit C of the Palms quartz monzonite and the biotitic gneiss along the western edge of Lost Horse Valley is generally gradational over about an inch. In some places, however, a zone about five feet wide is essentially identical to the quartz monzonite except that it contains about ten percent biotite (more than normal in Unit C). Contacts between these two rocks are nowhere knife-edged, as are some of the contacts of the White Tank quartz monzonite. Fig. 15 shows a group of dikes of Unit C cutting the gneiss northwest of Hidden Valley.

Except for a zone slightly higher in biotite, the quartz monzonite shows absolutely no textural or compositional variation at the contacts from the rest of Unit C. The contact between this biotitic zone and the rest of Unit C is generally fairly abrupt (gradational over less than an inch), which may indicate that the ingested gneiss affected only the narrow zone near the contact. Thus, the effect of assimilation of the wall rock extended over no more than a few feet into the intrusive at the time of final consolidation of the melt.

At one place along one contact between Unit C and the zone of ingested biotitic rock is a slight development of a partly chilled and partly pegmatitic contact. Next to the biotitic rock is a fine grained rim about one centimeter wide and consisting of an estimated 25% quartz, 40% potash feldspar, 35% plagioclase (An_{30}), two percent biotite, and rare magnetite. All minerals are anhedral, evenly distributed, and have an average diameter of 0.5 millimeter. Isolated

Fig. 15

Map showing dikes of Unit C of Palms quartz monzonite in biotitic gneiss northwest of Hidden Valley



Unit C of Palms quartz monzonite.

Gneiss.

quartz grains may have identical optical orientations within an area five millimeters in diameter. Perthite, antiperthite, and other intergrowths between potash feldspar and plagioclase are common. Myrmekite is abundant. Further into the quartz monzonite from the fine grained rim is a zone of coarse grained quartz aggregates, potash feldspar up to eight millimeters long, and plagioclase (An_{30}) up to five millimeters long. The composition of the plagioclase is identical to that in the rest of Unit C in this area. This coarse grained zone grades into the rest of Unit C in a few inches.

2. Slight gradation:

A contact between gneiss and Unit A of the Palms quartz monzonite northeast of Indian Cove is gradational over a distance of ten feet. Figs. 16-18 show typical quartz monzonite (number 376), typical gneiss (number 378), and the transitional rock (number 377). Modal analyses of the three rocks are given below.

	376	377	378
quartz	21.9%	36.0%	34.2%
potash feldspar	27.4	41.0	25.6
plagioclase	43.5	15.2	24.3
biotite and hornblende	6.1	7.2	15.7
accessory	1.3	0.6	0.1
total points	1056	1143	1120

The most notable compositional changes are the following:

(1.) The percentage of biotite increases from quartz monzonite to gneiss. Hornblende occurs only in the quartz monzonite.

(2.) The amount of accessory minerals decreases toward the gneiss.

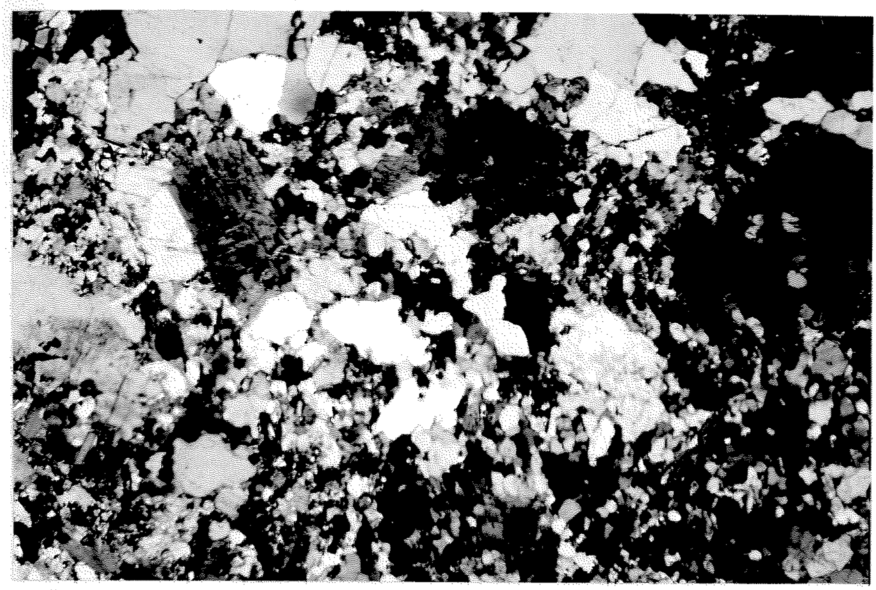
(3.) The composition of plagioclase laths is An_{25} in gneiss, transitional rock, and quartz monzonite. Laths are about one millimeter

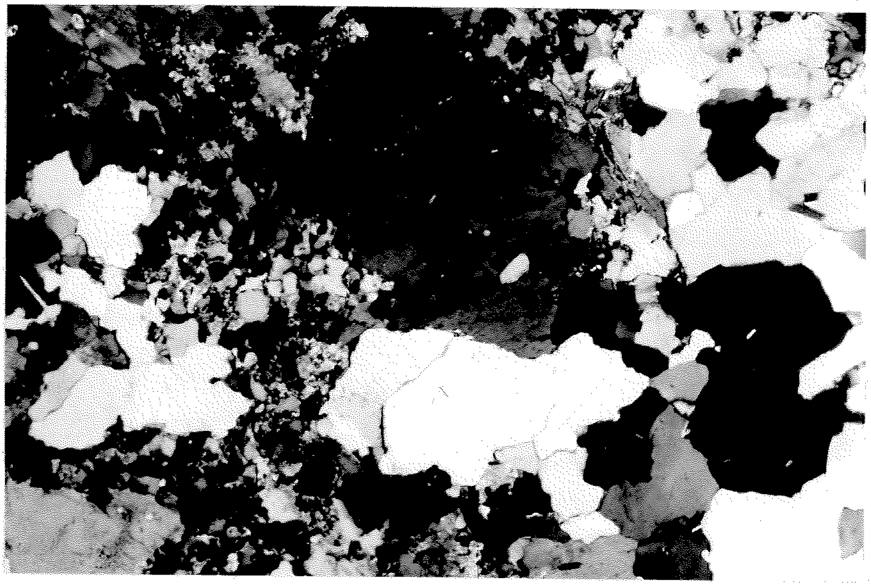
Figs. 16-18. Samples 376 (quartz monzonite), 377 (transitional rock), and 378 (gneiss), across contact between gneiss and Unit A of Palms quartz monzonite northeast of Indian Cove. Samples 376 and 378 are ten feet apart along a line normal to the contact. All pictures with crossed nicols, X25.

Fig. 16. Sample 376.

Fig. 17. Sample 377.

Fig. 18. Sample 378.





long in the quartz monzonite and one half millimeter in the gneiss. The total percentage of laths is higher in the intrusive than in the gneiss.

(4.) Part of all sections is a fine grained matrix consisting of about equal parts of potash feldspar and plagioclase (An_{20}), and subordinate quartz. The amount of this groundmass increases toward the quartz monzonite.

(5.) Quartz is more abundant in the gneiss and transitional rock than in the quartz monzonite.

(6.) Potash feldspar is relatively concentrated in the transitional rock. This concentration also occurs in the broad transitional zone between Unit C and the feldspathic gneiss in the Lost Horse Mountains (see page 77).

Textures common to all three rocks are the aggregates of quartz and ferromagnesian minerals and the poikilitic nature of most of the potash feldspar. Antiperthite occurs in all plagioclase laths. Myrmekite and irregular intergrowths of plagioclase and potash feldspar are commonly restricted to the fine grained matrix and are thus more abundant in the quartz monzonite than in the gneiss. Foliation decreases in quality from the gneiss to the quartz monzonite, and is essentially absent in the igneous rock. The contact parallels the foliation.

Apparently the principal effect which the quartz monzonite had on the gneiss is the conversion of some of the biotite to potash feldspar and the addition of a little more potash. Possibly the decrease in biotite content from gneiss to quartz monzonite merely represents the addition of non-biotitic material to the gneiss. Plagioclase may have been removed selectively by addition of potash, but evidence for the removal is insufficient. Quartz seems to be relatively insensitive to contact effects. Some albite may have been added to the wall rock. The totally different compositions of quartz monzonite and transitional rock and the sharp break in the percentage of quartz between the quartz monzonite and the transitional rock indicate, to the writer, that the contact described above is a slight zone of ingestion around a fluid intrusive into the gneiss. This conclusion does not imply that all of the Palms quartz monzonite crystallized from a fluid, but it does imply that there was a sharp junction between wall rock and intrusive at this point.

In this transitional zone is a band about six inches wide in which coarse crystals of potash feldspar have developed. The rock is very similar to the monzonitic porphyry.

3. Apparent broad gradation:

Along the contact between quartz monzonite and gneiss east of Queen Mountain is a zone 50 to 2000 feet wide of a rock apparently transitional between gneiss and Unit B of the quartz monzonite. The foliation, caused by alignment of biotite in some portions and by orientation of elongate quartz aggregates in others, is intermediate between that of the gneiss and that of the intrusive.

The quartzose patches comprise 25 to 50 percent of the rock and consist of undulant, fretted grains approximately one millimeter in diameter. Outside of these aggregates, the rock contains about equal amounts of individual quartz grains, potash feldspar, and plagioclase, and minor amounts of biotite, magnetite, epidote, and apatite. Sphene, characteristic of Units A and B of the quartz monzonite, is absent. Section 421 (Fig. 19) is typical of this transitional rock.

Quartz grains have a diameter of 0.25 millimeter outside of the aggregates and one millimeter in them.

Potash feldspar forms anhedral grains with an average size of 0.25 millimeter. Some of the grains show grid twinning. Plagioclase in the rod perthite has the same composition as the large plagioclase grains.

Plagioclase forms subhedral grains about 0.25 millimeter in diameter. Most of the grains are twinned and unzoned and have a composition of An_{15}. Rims of more sodic plagioclase (An_{10}) surround the larger grains where they contact potash feldspar, but no distinct grains of albite are present (in distinction to Units A and B of the quartz monzonite). Small, round inclusions of quartz occur in plagioclase grains of either composition where they contact potash feldspar. Antiperthite is absent except for some grains with typical rod exsolution texture and a modal composition of $Or_{50}(Ab_{85}An_{15})_{50}$.

The complex intergrowths of potash feldspar and plagioclase are not as abundant as in Unit B. Their place may be taken by the perthite, which is far more abundant than in Unit B.

In many places, especially along the southern portion of the contact, the rock described above is so similar to Unit B of the

Fig. 19. Sample 421 of recrystallized gneissic wall rock of Unit B of Palms quartz monzonite. Sample is 200 feet from Unit B. Small grains of plagioclase (p) and microcline (m) have formed in the quartzose gneiss. Crossed nicols, X25.

Palms quartz monzonite that no definite contact can be mapped between the two rocks. In such places the contact appears broadly gradational. But in other places the transition between gneiss and quartz monzonite is complete within ten feet.

If the rock described above were completely gradational between gneiss and Unit B, it should show the following gradual changes in texture and composition toward the quartz monzonite: 1, the percentage of quartz should decrease; 2, the amount of complex intergrowth between potash feldspar and plagioclase should increase; 3, the amount of minerals (such as sphene) characteristic of Unit B should increase; 4, the degree of foliation should decrease. With the exception of number 4, none of these expected gradual changes are observed except along the southern portion of the contact.

Thus, the relatively sharp contacts in some places, plus the fact that the apparently transitional rock does not have a texture and composition truly gradational between gneiss and quartz monzonite (except possibly in the south), indicate that the "transitional rock" is not a product of broad reaction between quartz monzonite and wall rock. Rather, the transitional rock is more reasonably interpreted as a recrystallized gneiss which has undergone slight metasomatic alteration. The actual transition into the quartz monzonite takes place in a zone approximately ten feet wide in most places.

The amount of material which has been added to the gneiss to form the "transitional rock" is unknown, but the quartzose nature of the transitional rock suggests little addition. Possibly the rims of sodic feldspar around the other plagioclase grains indicate addition of soda, and some of the potash may have been introduced. But most of the mineralogy of the "transitional rock" may be explained by recrystallization of material already present in the gneiss.

4. Broad gradation:

Unit C of the Palms quartz monzonite shows an indetectable border with light colored, feldspathic gneiss on the northeastern flank of the Lost Horse Mountains. There is complete gradation over an interval of 1000 feet between gneiss and quartz monzonite. Foliation in the transitional rock (shown by orientation of the few biotite flakes in the rock) is less well developed than in the gneiss; the quartz monzonite is not foliated.

Compositionally both the gneiss and Unit C are very similar. Plagioclase in some of the gneiss has a composition of An_{25}, but much is more sodic. Plagioclase in the intrusive rock has a composition of An_{10} to An_{15}. In the transitional rock the principal plagioclase, which makes up about 25 percent of the rock, is An_{25}; it may be slightly, normally, zoned, and there is abundant albite in rims and small grains. Irregular myrmekite occurs in both types of plagioclase near the potash feldspar. Patch perthite seems to have a composition close to that of the more sodic plagioclase. Owing to the sodic nature of the plagioclase in some parts of the gneiss, it is not certain how much of the albitic material has been introduced by the quartz monzonite. It is significant, however, that the principal plagioclase grains in the transitional rock have about the same size as they do in the nearby gneiss.

Quartz makes up about 30 percent of the transitional rock. It is commonly in aggregates, but the number of individual grains increases toward the quartz monzonite (in which none of the grains are in aggregates).

Potash feldspar comprises about 40 percent of the transitional rock, which is a higher percentage than in either gneiss or quartz monzonite. Anhedral, roughly rectangular grains up to six millimeters long are scattered throughout the rock apparently without orientation. Most of the potash feldspar is untwinned, but some grid twinning is present in patches in some grains. The grain borders are very irregular in detail, and potash feldspar may contain inclusions of all other minerals.

Small flakes of biotite make up a few percent of the rock. All are highly altered to a reddish material and small white opaque needles. Some of the biotite may be replaced by muscovite.

Magnetite, apatite, allanite, and epidote are common accessory minerals. Some of the epidote may be an alteration product of plagioclase.

Some plagioclase is thoroughly altered to sericite. Chlorite is an uncommon alteration product of biotite. Kaolin forms a light dust on both feldspars.

The evidence from this one contact (and a similar one in the western part of Lost Horse Valley) is not sufficient to determine exactly the origin of the transitional rock. It may be hypothesized that both potash feldspar and sodic plagioclase (or at least potash and soda) have been added to the gneiss by the quartz monzonite, but the gneiss varies internally so much that the exact nature of the parent rock for any given sample of transitional rock is indeterminate. The addition of both feldspars, and especially the concentration of potash feldspar, is likely, however, in view of the proposed origin of the monzonitic porphyry (see pages 118-120).

C. General Description of Monzonitic Porphyry:

The monzonitic porphyry occurs in three patches around the northeastern, northern, and northwestern periphery of Units A and B of the Palms quartz monzonite. In some places the porphyry appears to cut sharply through the quartz monzonite as a later intrusion, but in other places the two rocks grade into each other. Similarly, the porphyry is gradational into the Pinto gneiss along most contacts but cuts sharply through the gneiss in other places.

The typical monzonitic porphyry (Fig. 20) is characterized by 25 to 50 percent coarse, pink to gray, subhedral crystals of potash feldspar. Some of the larger crystals show Carlsbad twinning. Orientation of potash feldspar grains gives the porphyry a planar structure (indicated on Plate I by the symbol for foliation) parallel to some contacts with the gneiss, whether or not these contacts are parallel to the gneissic foliation. Most of the porphyry away from the contacts is massive.

The contact between porphyry and gneiss east of Lone Palm cuts the gneissic foliation. Here, the planar structure in the porphyry is parallel to the contact, but potash feldspar grains in the rock

Fig. 20. Typical monzonitic porphyry east of Lone Palm. Glasses are for scale.

mapped as gneiss are parallel to the gneissic foliation. This change in orientation of the potash feldspar grains across the contact may imply some movement in the partly fluid porphyry at this place.

Field measurements of the size of potash feldspar grains in four typical samples of porphyry are as follows:

	size
252	15.7 millimeters
256	14.8
308	13.6
332	18.0

Samples 252 and 256 are from the outcrop north of Forty Nine Palms, sample 308 is from the porphyry east of Lone Palm, and sample 332 is from the porphyry east of Indian Cove. The monzonitic porphyry east of Indian Cove is, in general, coarser grained than the rock in the other two bodies.

Most of the potash feldspar shows grid twinning, but parts of some grains are entirely untwinned. The most characteristic feature of the large feldspar crystals is their abundance of included grains. Most grains enclose an average of 10 to 20 percent of other minerals, and one crystal (section 309, Fig. 21) east of Lone Palm held 50 percent inclusions by micrometric measurement. The types of minerals and their proportions in the inclusions are identical to those in the rest of the porphyry (see Table 5), but minerals in the inclusions are of smaller size than in the rest of the rock. Inclusions commonly occur in clusters rather than scattered randomly through the host feldspar, but these clusters rarely show morphologic orientation. The borders

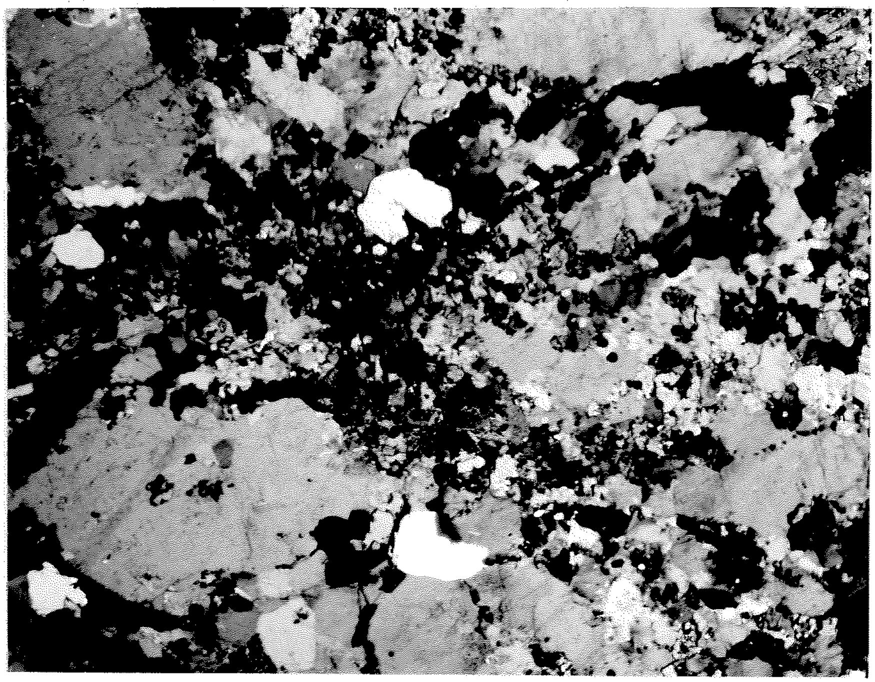


Fig. 21. Sample 309 of a single crystal of potash feldspar from monzonitic porphyry east of Lone Palm. Inclusions make up 50 percent of the crystal. Crossed nicols, X25.

Table 5. Comparison of Bulk Composition of the Monzonitic Porphyry and the Composition of Inclusions in a Single Large Crystal of Potash Feldspar:

	308	309
	bulk composition of typical porphyry	composition of inclusions in single crystal of potash feldspar
quartz	18.7%	24%
potash feldspar	7.0	20
plagioclase	50.5	51
biotite and hornblende	7.9	5
accessory	1.7	0.5
groundmass	14.7	indistinguishable

Note that unoriented grains of potash feldspar also occur as inclusions in the large crystal.

of the potash feldspar grains are highly irregular in detail, although apparently straight megascopically, and are wrapped around grains of other minerals. Most of the potash feldspar grains contain up to 20 percent plagioclase (An_{15}) as rod perthite.

Plagioclase forms laths with an average length of two to three millimeters and a maximum of ten. The borders are slightly irregular but much more even than those of the potash feldspar. There is a rough inverse relation between twinning and zoning, the zoned grains showing little albite twinning and vice versa. All of the twinned grains show albite twinning, and some show pericline twinning also. There is apparently no constant difference in grain size between the twinned and zoned grains. Zoning is invariably normal with some oscillation, and a common range is An_{25} to An_{15}. In distinction to the potash feldspar, the plagioclase contains few inclusions. Irregular or rod antiperthite occurs in a few plagioclase grains (either twinned or untwinned). Irregular myrmekite occurs in some portions of the large plagioclase grains near potash feldspar. In summary, the plagioclase in the monzonitic porphyry is very similar to the plagioclase in the Palms quartz monzonite.

Quartz forms aggregates of undulant, fretted grains with an average grain size of one millimeter.

Biotite commonly forms clusters of flakes. Individual flakes have an average length of 0.25 millimeter, are very ragged, and are pleochroic from yellow to olive green. Biotite in the quartz monzonite is more reddish, insofar as color may be determined for the altered grains.

The ratio between biotite and hornblende varies erratically throughout the porphyry. Most sections contain hornblende (in distinction to the quartz monzonite, in which hornblende is uncommon). The optical properties of hornblende in both porphyry and quartz monzonite are the same and are the following: $X =$ yellow, $Y =$ light bluish green to olive green, $Z =$ dark green, $Z \wedge c = 24^{\circ}$, birefringence $= 0.2$. Hornblende needles average about 0.5 millimeter long and range up to six millimeters. Hornblende forms solitary crystals except where it is included in clusters with biotite.

In sections of the porphyry which contain almost no hornblende, clusters of biotite and accessory minerals are common. Small grains of hornblende (relics?) in these clusters suggest that the biotite and accessory minerals formed by alteration of the amphibole, but the boundary relations between hornblende and biotite do not provide a clear picture of paragenesis.

Accessory minerals in the porphyry are identical to those in the Palms quartz monzonite. Magnetite, apatite, sphene, allanite, and epidote are common. The accessory minerals commonly occur in clusters with biotite.

All of the monzonitic porphyry contains a groundmass of fine grained quartz and feldspar which makes up 10 to 20 percent of the rock. Average size of most grains is about 1/25 millimeter.

In most sections about 50 percent of the groundmass is composed of equant, anhedral grains of untwinned, unzoned plagioclase. Their small size and high degree of alteration prevent exact determination of their composition, but indices seem to range from those of sodic oligoclase to those of pure albite. Some of the small plagioclase inclusions in potash feldspar are surrounded by irregular rims of more sodic plagioclase. Myrmekite, characterized by very irregularly shaped and oriented blebs of quartz, is abundant. Inclusions of plagioclase grains in potash feldspar may follow fairly straight bands through the crystal.

Small irregular stringers of potash feldspar are also common in the groundmass. They may poikilitically include the quartz and plagioclase. In some places it is not possible to distinguish the groundmass from irregular intergrowths of large crystals of potash feldspar and plagioclase.

Quartz occurs in the groundmass in most sections. It generally forms small grains scattered randomly through the matrix, but in some sections almost all of the quartz is included in myrmekite.

All of the plagioclase, both in large crystals and groundmass, is intensely altered. Most of the feldspars are thoroughly kaolinized and also slightly sericitized. Some of the biotite is altered to chlorite. Ferruginous staining is common in some sections. Some epidote has formed by alteration of plagioclase. Some of the small plagioclase grains in the groundmass have interiors which are more altered than the rims, possibly indicating a zoning which is not otherwise visible.

Some small streaks (never more than six inches wide) in the porphyry show the effects of shearing and reduction of grain size caused by granulation.

Although the potash feldspar grains are too coarse to be measured accurately by micrometric methods, modal analyses of three thin sections of typical porphyry given below show the general proportions of the other minerals (the measured percentage of potash feldspar is included in order to bring the total percentage to 100). Sections 252 and 256 are from the outcrop north of Forty Nine Palms, and section 308 is from the large body east of Lone Palm.

	252	256	308
quartz	16.5%	8.2%	18.7%
potash feldspar	14.7	30.1	7.0
plagioclase	42.3	49.6	50.5
hornblende and biotite	9.7	1.9	7.9
accessory	1.4	2.6	1.7
groundmass	15.8	7.8	14.7
total points	1066	1011	1081

Section 318 (Fig. 22) is typical of the porphyry.

On the basis of the petrographic character of the monzonitic porphyry, several important conclusions can be drawn concerning its origin. The different types of plagioclase and their range in compositions indicate that equilibrium was not maintained throughout the formation of the rock. Apparently (based on compositions) the large, more calcic crystals of plagioclase grew before most of the groundmass. The fine grained inclusions of all minerals, including those in the groundmass, in the large crystals of potash feldspar indicate that the potash feldspar grew during the formation and growth of all other minerals in the rock; i. e., its period of growth spanned the time of formation of all, or nearly all, of the porphyry. It is not known why some of the potash feldspar formed large grains while a minor portion formed small grains in the groundmass. The clusters of mafic and accessory minerals in some sections may have formed by alteration of hornblende.

D. <u>Contacts between Palms Quartz Monzonite and Monzonitic Porphyry</u>:

Most contacts between the Palms quartz monzonite and the monzonitic porphyry are slightly gradational, and it is believed that this gradation supports the mineralogic evidence that the two rocks are intimately related. A few very sharp contacts may be explained as a result of movement of the partially solid porphyry. The various types of contact are described below.

1. Gradational:

Gradation between quartz monzonite and porphyry is invariably complete within 200 feet and commonly in a shorter distance. The most broadly gradational contacts are associated with the body of porphyry just north of Forty Nine Palms. The principal changes which take place upon passing from the porphyry into the quartz monzonite are the following:

(1.) A very large decrease in the size of potash feldspar grains.

(2.) A slight decrease in the size of plagioclase grains.

(3.) Possibly a slight decrease in the size of quartz grains.

(4.) Possibly an increase in the percentage of quartz.

(5.) Possibly a decrease in the percentage of hornblende with respect to biotite.

(6.) Change from reddish to greenish biotite. (The change is generally near, but not necessarily at, the border between the two rocks.)

(7.) Change from a porphyritic texture to an inequigranular seriate one.

(8.) Increase in the amount of complex intergrowth between potash feldspar and plagioclase. (The intergrowths are most common in the groundmass of the porphyry but are characteristic of all grains in the quartz monzonite.)

Features common to both quartz monzonite and porphyry are these:

(1.) Quartz in aggregates.

(2.) Type of accessory minerals.

(3.) Approximate similarity in bulk composition.

(4.) Composition and types of plagioclase.

(5.) Type of hornblende.

Commonly both the porphyry and the quartz monzonite are massive near the contact, but east of Lone Palm the porphyry shows a very strongly developed planar structure parallel to the contact.* The contact east of Lone Palm is not well exposed, but there is apparent interlayering of the porphyry and quartz monzonite over a zone approximately 100 feet wide; actual contacts between the two rocks are generally gradational over less than a foot and some are knife-edged.

Small dikes of pegmatite and/or aplite cut the contact in several places, but they are not obviously related to one or the other of the rocks, nor are they at all numerous.

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* This portion of the porphyry is also foliated parallel to its contact with the gneiss, although the contact cuts across the gneissic foliation. Perhaps the whole mass of porphyry east of Lone Palm has undergone movement after nearly complete crystallization.

A summary of the relations across three contacts between porphyry and quartz monzonite north of Forty Nine Palms is given in Table 6. Figs. 22-24 are photomicrographs of three thin sections from one of these contact zones.

In addition to normal experimental errors, four other errors affect the data in Table 6. They are these:

(1.) Percentage and grain size of potash feldspar measured in the field might vary markedly from similar measurements made in thin section, even if such measurements could be made in a normal section. Thus, correlation between laboratory and field data is tentative.

(2.) The composition of the groundmass affects the percentage of both feldspars and quartz in the porphyry, whereas such an effect is not present in the quartz monzonite, which has no measured groundmass. Thus, compositions of the two rocks are compared on the basis that the groundmass is about 50 percent plagioclase, 25 percent potash feldspar, and 25 percent quartz.

(3.) In rocks intermediate between porphyry and quartz monzonite, the distinction of "groundmass" is very subjective, and its stated percentage may be greatly in error.

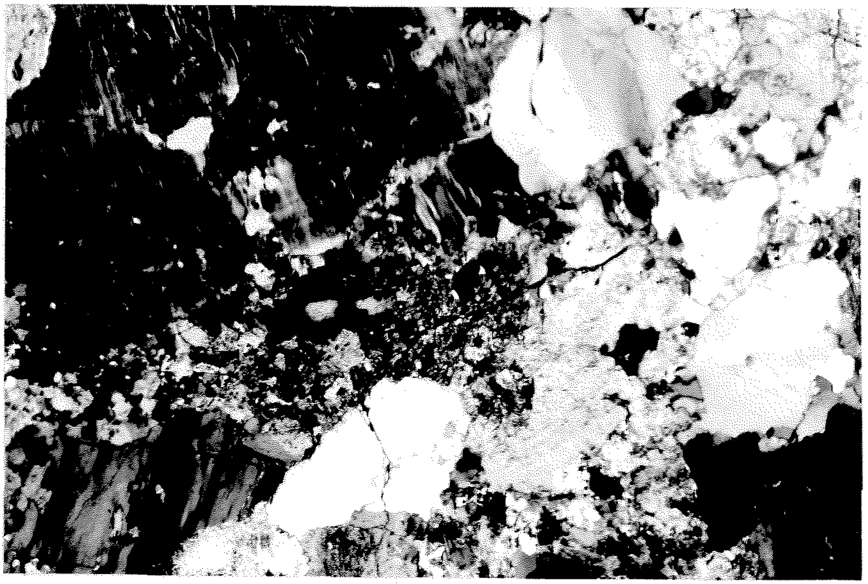
(4.) Measurements of the percentage of potash feldspar made in the field must be corrected for the amount of inclusions in the feldspar and the amount of potash feldspar in the groundmass. These corrections are only approximate at best. The fact that feldspar in the porphyry is commonly more perthitic than feldspar in the quartz monzonite also adds error to the measurements.

Fig. 22. Sample 318.

Fig. 23. Sample 319.

Fig. 24. Sample 322.

Figs. 22-24. Samples 318 (porphyry), 319 (transitional rock), and 322 (quartz monzonite), across contact between monzonitic porphyry and Unit A of Palms quartz monzonite northwest of Forty Nine Palms. Samples 318 and 322 are 50 feet apart along a line normal to the contact. All pictures with crossed nicols, X25.



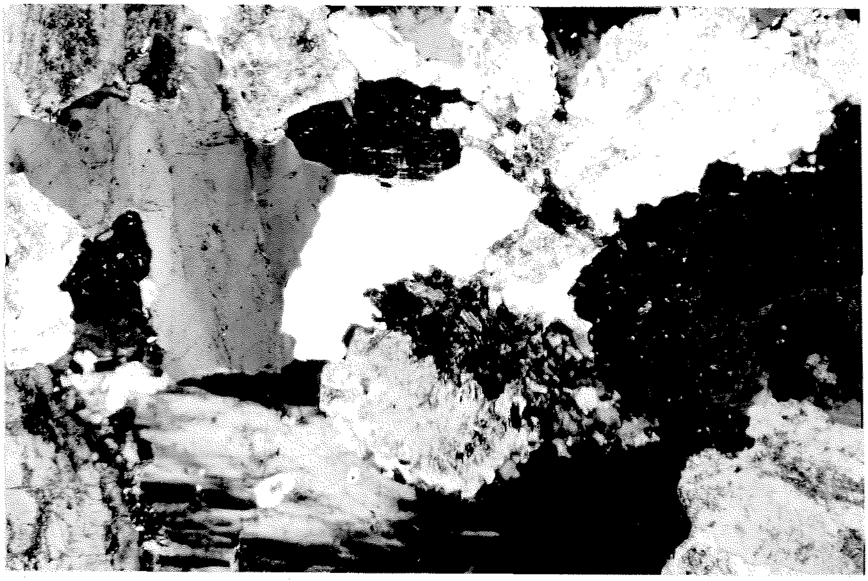


Table 6. Transition between Palms Quartz Monzonite and Monzonitic Porphyry North of 49 Palms:

Sample	Distance	% potash feldspar	size potash feldspar	size quartz	size plagioclase	micrometric measurements: quartz	plagioclase	biotite and hornblende	accessory	gmass
318	50 ft.	30% (f)	9.6 mm. (f)	1.1 mm.	1.9 mm.	11.0%	33.0%	2.7%	1.4%	15.2%
"		37.0 (l)								
319	25	23.7 (l)	3.0 (l)	0.9	1.9	17.3	28.5	3.1	1.0	26.5
322	0	28.4 (l)	1.3 (l)	1.1	1.4	15.4	47.0	7.0	1.9	
323	60	30 (f)	9.9 (f)	1.1	2.1	21.7	46.2	1.7	1.6	11.0
"		17.0 (l)								
324	25	30 (f)	8.9 (f)	1.2	1.9	12.0	50.2	4.9	1.7	13.4
"		18.0 (l)								
325	0	30.4 (l)	1.3 (l)	1.1	1.2	31.1	32.0	4.9	1.8	
---	225	30 (f)	13.0 (f)							
342	150	30 (f)	9.1 (f)	0.7	2.0					
343	75	35 (l)	2.1 (l)	0.6	1.9					
344	0	35 (l)	1.4 (l)	0.6	1.4					
252	normal	35 (f)	15.7 (f)	1.2	2.5	16.5	42.3	9.7	1.4	15.8
"	monz.	14.7 (l)								
256	porph.	35 (f)	14.8 (f)	0.7	2.2	8.2	49.6	1.9	2.6	7.8
"		30.1 (l)								
316	normal	21.3 (l)	0.9 (l)	0.5	1.0	28.4	42.0	7.7	0.6	
354	qtz.monz.	25.2 (l)	1.4 (l)	0.6	1.6	28.1	40.5	4.3	1.7	

All distances are measured from a point in the quartz monzonite designated as 0 ft. The transition into typical monzonitic porphyry is complete in the interval measured in each example.
Sizes and percentages measured in the field are labeled (f), those measured in the laboratory in thin section are labeled (l). Percentages and sizes of all minerals except potash feldspar were all obtained from thin section.
"gmass" refers to the groundmass in the monzonitic porphyry.

All of the gradational contacts mentioned in Table 6 are from the large body of porphyry north of Forty Nine Palms, and in general its contacts are far more gradational than those of the other two bodies. Gradation is complete within a foot between porphyry and quartz monzonite east of Lone Palm, and the outcrops west of Forty Nine Palms invariably have knife-edged contacts against the quartz monzonite. The reasons for these differences in contacts in different masses of porphyry are unknown.

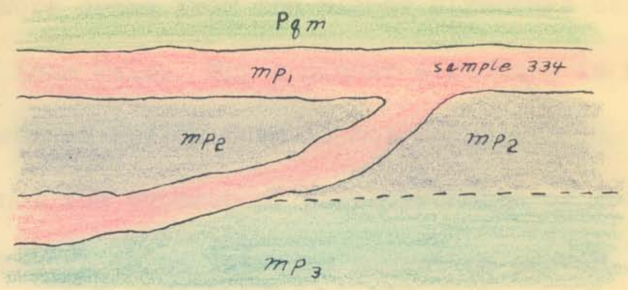
2. Abrupt:

As mentioned in the last section, the porphyry west of Forty Nine Palms has sharp contacts against the quartz monzonite wherever the exact contact can be found. There is absolutely no difference in grain size of potash feldspar a few inches from the contact from grain size in the rest of the porphyry. The rock is massive at the contact. The monzonitic porphyry west of Forty Nine Palms is slightly coarser grained than the other units, the average grain size of potash feldspar being 20 millimeters as opposed to 15 millimeters for the outcrops north and northeast of Forty Nine Palms. In all other respects, such as mineralogy and other textures, however, the porphyry in all three masses is identical.

One contact between porphyry and quartz monzonite east of Indian Cove is illustrated in Fig. 25. The contact is knife-edged. Sample 333 may represent a zone of smaller grain size, but there is no gradual decrease in size of potash feldspar into the quartz monzonite as characterizes the contacts north of Forty Nine Palms. The coarse

Fig. 25

Sketch of abrupt contact between monzonitic porphyry and Unit A of Palms quartz monzonite east of Indian Cove



Monzonitic porphyry; pegmatitic ?; 70% potash feldspar with an average length of 25 millimeters.

Monzonitic porphyry; 30% potash feldspar with an average length of 14 millimeters.

Normal monzonitic porphyry; 35% potash feldspar with an average length of 18 millimeters.

Unit A of Palms quartz monzonite.

grained dike shown in the illustration is, except for size and percentage of potash feldspar, identical to the rest of the porphyry in the area. All rocks shown in the illustration are massive.

Contact effects such as are shown in Fig. 25 are not likely to result from the intrusion of quartz monzonite into porphyry; consequently they suggest that at some time the porphyry was sufficiently mobile to intrude the quartz monzonite. Similar conclusions as to the mobility of the porphyry were drawn from the planar structure developed in the porphyry east of Lone Palm. Why a planar structure is not developed in the outcrop east of Indian Cove is not known.

Whether or not the outcrop of porphyry north of Forty Nine Palms was ever mobile enough to be intruded cannot be proven. As mentioned before, there is no textural or mineralogical difference between the rocks in the different large masses of porphyry, with the exception that the potash feldspar in the westernmost one is slightly coarser than in the other two bodies. Presumably, then, the origin of all three masses was approximately the same, and if erosion had not removed part of the mountain front, the separate units might be connected.

E. Contacts between Pinto Gneiss and Monzonitic Porphyry:

Although the different bodies of the monzonitic porphyry have characteristically different contacts with the quartz monzonite, no such systematic difference is noted in their contacts with gneiss. The porphyry grades into the gneiss in almost all locations, the transition being far more gradual than the transition between porphyry and quartz monzonite. The porphyry, however, abruptly cuts the gneiss in a few places. The various types of contacts are described below.

1. Gradational:

Most contacts between porphyry and gneiss are gradational through approximately 500 feet. Only a few examples will be discussed in this section.

One excellent example of gradation is a contact north of Forty Nine Palms. The variation in grain sizes of potash feldspar is summarized below. Distances are measured from a point in the gneiss.

	distance	average size of potash feldspar	percentage of potash feldspar
mapped as gneiss	0 ft.	5.0 mm	20%
mapped as porphyry	10	7.9	30
	25	8.6	30
	250	10.2	30
	400	11.4	30
	1000	10.6	30
	2500	12.4	25

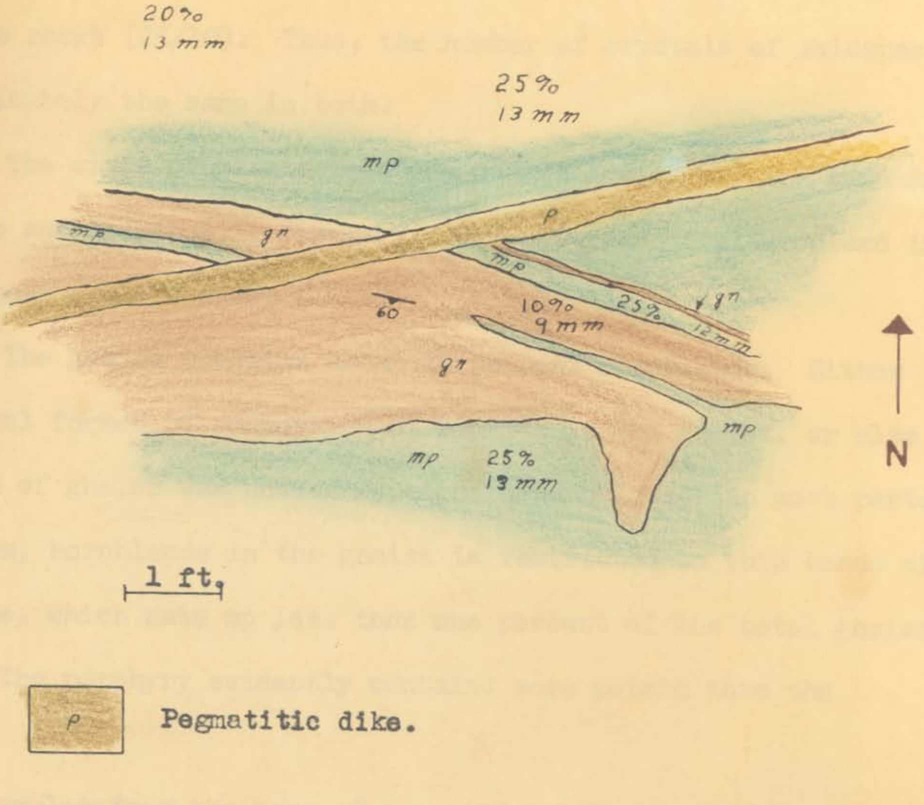
These values of grain size are reproducible to ± 1 millimeter anywhere along zones parallel to the contact (which parallels the foliation in the gneiss). The potash content is approximately constant, for the rock with a high content of biotite (the gneiss) is relatively low in potash feldspar. Near the contact in one place is a dike of very coarse potash feldspar similar to sample 334, page 95 . Also a few pegmatite and aplite dikes cut both the porphyry and gneiss.

The contact sketched in Fig. 26 illustrates gradation between gneiss and porphyry. Actually, this portion of gneiss is separated from the main body by about 600 feet of rock transitional between

Fig. 26

Sketch showing contact between monzonitic porphyry and gneiss northeast of Forty Nine Palms

(Percentages and grain sizes of potash feldspar are indicated at various points throughout the rocks.)



Pegmatitic dike.

Monzonitic porphyry.

Gneiss; amphibolitic.

Strike and dip of foliation.

gneiss and porphyry. The significant features are these:

(1.) The grain size and percentage of potash feldspar in the rock recognizable as gneiss are both less than in the porphyry. Cubing the ratio of linear sizes of grains in the porphyry and gneiss (12.7/9.1) gives approximately the ratio between percentage of potash feldspar in the two rocks (25/10). Thus, the number of crystals of feldspar is approximately the same in both.

(2.) The sizes of plagioclase and quartz grains are the same in the gneiss and neighboring porphyry. Compositions of plagioclase in the two rocks are the same.

(3.) The gneiss contains about 20 percent hornblende. Either this mineral formed by conversion of biotite in the gneiss, or else this patch of gneiss was unusually high in hornblende (in most parts of the area, hornblende in the gneiss is restricted to thin bands of amphibolite, which make up less than one percent of the total gneiss).*

(4.) The porphyry evidently contains more potash than the gneiss.

Two samples from the zone of transition between porphyry and gneiss mentioned just above are very different. Sample 265 (Figs. 27 and 28) contains large grains of potash feldspar lying parallel to the gneissic foliation. These grains have an average length of 4.1 millimeters as measured in the field and a length of 2.2 millimeters measured in thin

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* Hornblende in amphibolitic portions of the gneiss is identical to hornblende in the monzonitic porphyry.

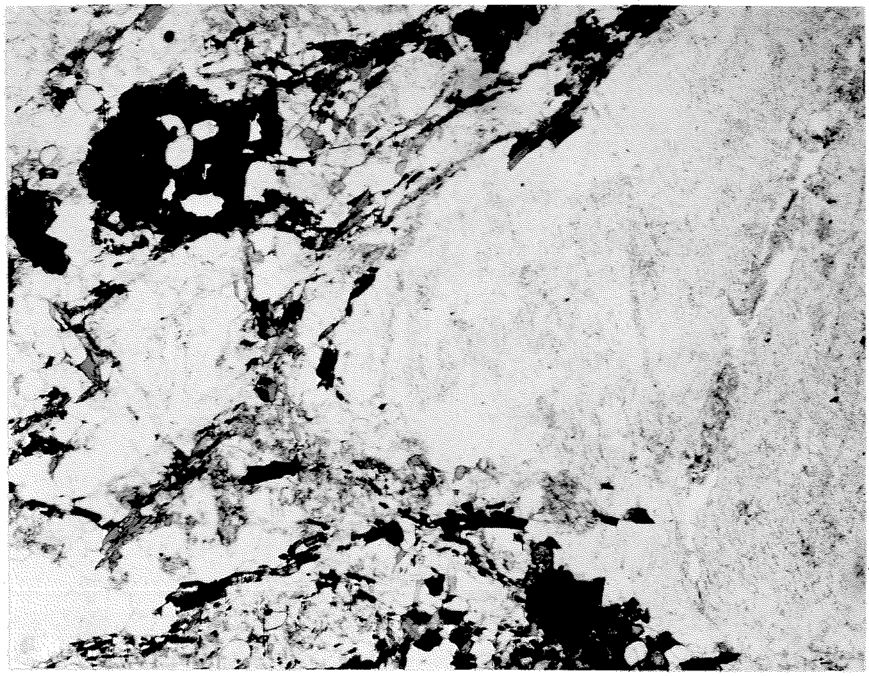

Fig. 27

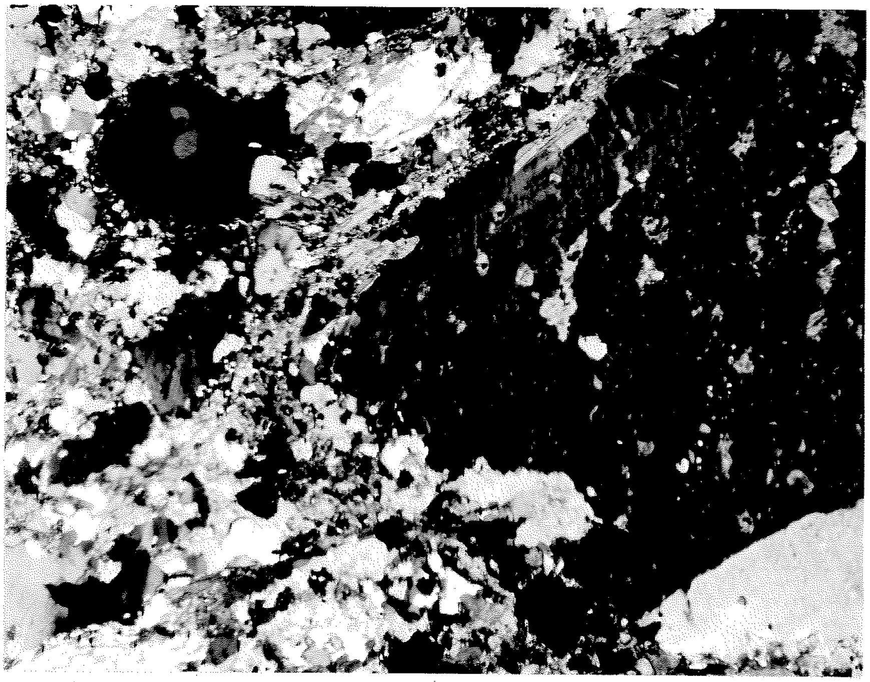

Fig. 28

Sample 265 of rock transitional between monzonitic porphyry and gneiss north of Forty Nine Palms. Large crystal of microcline has grown in partly recrystallized gneiss. Biotite flakes are aligned parallel to rim of microcline crystal. Fig. 27 in plain light, and Fig. 28 under crossed nicols; both X25.

section.* Grains of plagioclase two millimeters long (measured in thin section) and lenses of intergrown quartz and potash feldspar also lie parallel to the foliation and may be mistaken for potash feldspar in hand specimen. Trains of biotite flakes curve around the lenses and the large feldspar crystals. Modal analysis of the rock gave the following result:

	265
quartz	24.4%
potash feldspar	21.9
plagioclase	25.2
biotite	24.4
accessory	4.4
total points	1047

There is no diminution of biotite content in the neighborhood of the lenses or large grains of potash feldspar. For this reason, and because the total potash content is much higher in sample 265 than in any other portion of the gneiss, it appears that potash has been added to the gneiss. Whether other components have been added or removed is not known.

Another rock (sample 263) in this same zone shows the blurred foliation typical of the mixed porphyry and gneiss, but contains no large crystals of potash feldspar. The average size of potash feldspar (measured in thin section) is 1.1 millimeters. Modal analysis of this section gave the following results:

[See next page]

*Inasmuch as coarse potash feldspar crystals are more resistant than the matrix, weathering of the gneiss tends to expose the maximum dimension of the feldspar grains. A single thin section has little chance of intersecting the maximum dimension.

	263
quartz	15.6%
potash feldspar	17.4
plagioclase	46.7
hornblende	13.8
accessory	6.1
total points	1063

Textural features and compositions of the plagioclase (An_{25}) in samples 263 and 265 are identical. Measurements of grain sizes of plagioclase and quartz in the two rocks are shown below.

	263	265
quartz	0.7 mm	0.6 mm
plagioclase	1.6	1.4

These sizes of quartz and plagioclase are intermediate between those of the gneiss (both quartz and plagioclase approximately 0.1 millimeter) and the true monzonitic porphyry (quartz one millimeter and plagioclase 2.5 millimeters). Both samples 263 and 265 contain a small amount of interstitial material similar to the groundmass of the porphyry.

It seems likely that the same amount of potash feldspar (or just potash) has been added to both samples 263 and 265. Possibly sample 263 was originally amphibolitic and not as susceptible to the formation of large crystals of potash feldspar as sample 265*; thus, the gneiss illustrated in Fig. 26 may have resisted feldspathization because of its original amphibole content. As mentioned on page 99, however, nowhere does the gneiss contain as much hornblende as the porphyry and mixed rock north of Forty Nine Palms. Thus, either the development

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* The susceptibility to feldspathization may be determined either by physical or mineralogic properties of the various types of gneiss.

of the porphyry promotes the formation of amphibole (in which case sample 265 should contain hornblende rather than biotite), or the porphyry is restricted to the northern border of the quartz monzonite because the gneiss in this area was originally richer in amphibole (in which case sample 263 should show far more development of coarse potash feldspar grains than sample 265). The unreplaced remnants of gneiss shown in Fig. 26 should be biotitic rather than amphibolitic on the basis of either argument.

Another interesting feature in this zone of mixed rock is the apparent feldspathization of a silexite or coarsely recrystallized quartzite.* The result is the formation of pegmatite by growth of soda and potash feldspar in the quartz rock. Pegmatites in this area commonly contain graphic textures in which quartz blebs of identical optical orientation are enclosed in adjacent feldspar grains of several different orientations. This fact, plus their lack of zoning, indicates that these pegmatites may have formed at least partly by replacement. This evidence, although not conclusive by itself, may be another indication of the addition of potash to surrounding rocks during the formation of the porphyry.

The gradation between gneiss and porphyry is not as well defined along the contact east of Lone Palm as it is north of Forty Nine Palms. The monzonitic porphyry in the area contains potash feldspar grains with an average size of 15 millimeters. In the gneiss the potash feldspar increases from a size of one millimeter (the smallest

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* Similar features were described by Campbell (1937).

measurable in the field) to a size of 15 millimeters in samples near the contact. The contact, however, cuts across the gneissic foliation, and foliation in the porphyry is roughly parallel to the contact. In the rock mapped as porphyry, there seems to be no difference in grain size near the contact from the size in the central, massive part of the outcrop. A complicating factor in the measurement of grain size in the gneiss is the presence of shear zones. Most of these do not seem to enter the porphyry and appear to antedate the formation of large potash feldspar crystals in both the porphyry and gneiss; a few small shear zones, however, postdate the growth of potash feldspar, and in them some of the potash feldspar is crushed to smaller sizes. Those parts of the rock mapped as gneiss which contain the largest crystals of potash feldspar (15 millimeters) also contain crystals of plagioclase up to two millimeters long, aggregates of 0.5- to one-millimeter quartz grains, and a small amount of interstitial material similar to the groundmass in the porphyry. Thus, the gradation between porphyry and gneiss is demonstrated by several textural and compositional features in addition to the potash feldspar.

The few exposed contacts between porphyry and gneiss north of Indian Cove are, for the most part, gradational. The development of slightly porphyritic rock between quartz monzonite and gneiss in this area has been mentioned on page 73. Several sills of monzonitic porphyry follow the foliation in some of the thin outcrops of gneiss in the area. Most of these sills are identical, in composition, grain size, and other textures, to the typical porphyry in the large bodies, but some small sills are fine grained, and a few of the large ones have fine grained borders.

One of these sills is illustrated in Fig. 29. It is distinguished from the typical large masses of porphyry by the very small amount of sodic plagioclase (the plagioclase which comprises much of the groundmass in the typical porphyry) and the absence of sphene and hornblende. Plagioclase forms laths with a composition of An_{25} in both the fine grained borders and the coarser grained interior. Quartz forms both aggregates and individual grains. Biotite occurs as ragged flakes pleochroic from yellow to dark brown. Foliation in the dike is parallel to the foliation in the surrounding gneiss.

2. Abrupt:

A few of the contacts between the large bodies of monzonitic porphyry and Pinto gneiss are very abrupt and dikes generally have knife-edged borders, although some are slightly gradational into the gneiss.

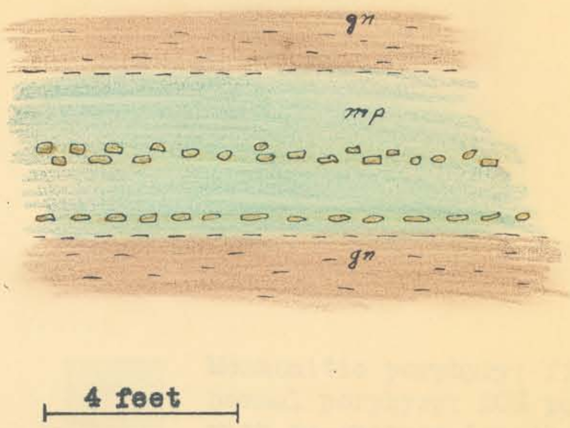
One dike north of Forty Nine Palms is illustrated in Fig. 30. The gneiss near the dike shows little or no difference from typical gneiss in the area except for a zone containing fragments of gneiss in porphyry about one inch wide along the borders of the dike. The dike is similar to typical monzonitic porphyry, except for the following differences:

(1.) The average grain size of potash feldspar is 5.8 millimeters in the dike, compared to 15 millimeters in the large masses of porphyry.

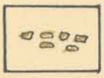
(2.) The large plagioclase crystals are An_{30}, which is more calcic than plagioclase in the large bodies of porphyry.

Fig. 29

Section through dike of monzonitic porphyry in feldspathic gneiss northeast of Indian Cove



Monzonitic porphyry; fine grained, (average grain size of 2 millimeters); no large grains of potash feldspar.

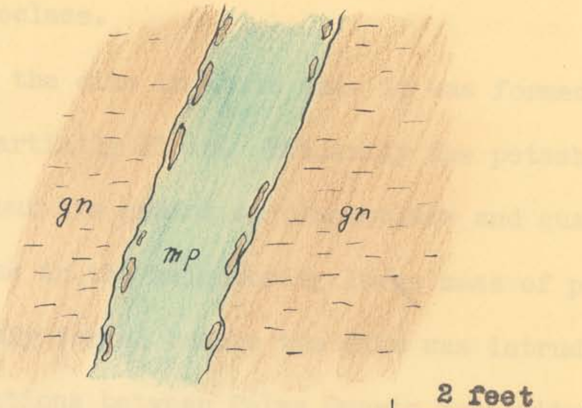


Large crystals of potash feldspar.

Gneiss; feldspathic.

Fig. 30

Sketch showing dike of monzonitic porphyry cutting gneiss north of Forty Nine Palms



Monzonitic porphyry; finer grained than normal porphyry; 20% potash feldspar with an average length of 7 millimeters.

Gneiss.

(3.) Groundmass makes up 25 percent of the dike, which is more than in most of the porphyry. Plagioclase in the groundmass of the dike is median oligoclase (by indices), which is more calcic than a fluid in equilibrium with the larger crystals according to the phase diagram for pure plagioclase.

These features of the dike indicate that it was formed by injection of material at least partially fluid. Evidently the potash feldspar grew after injection, but the grains of plagioclase and quartz are so similar in size to those in the neighboring large mass of porphyry that they were presumably formed before the dike was intruded.

F. Summary of Relations between Palms Quartz Monzonite, Monzonitic Porphyry, and Pinto Gneiss:

The principal relations between quartz monzonite, gneiss, and porphyry may be summarized under three headings: distribution, composition, and grain size.

1. Distribution:

As mentioned on page 43, the monzonitic porphyry is roughly peripheral around the northern portion of the Palms quartz monzonite, and in many places the two rocks grade into each other. Unfortunately, the gneiss which probably exists north of the porphyry is not exposed, and it cannot be stated absolutely that the porphyry is a border between gneiss and quartz monzonite. The porphyry is, however, gradational into the gneiss in many places, and local development of the porphyry at the contact between gneiss and quartz monzonite is found in at least two places (north of Indian Cove and east of Lone Palm). Many petrologists have reported similar porphyritic margins on intrusive rocks throughout the world (see, for example, Engel and Engel [1953], Edwards and Baker [1944], Walker and Mathias* [1946], and Bagchi [1952]). In all cases, the large grains of potash feldspar contain abundant inclusions and appear to have formed after the rest of the rock.

2. Composition:

Table 7 summarizes the compositional differences between quartz monzonite, monzonitic porphyry, gneiss, and rocks transitional between porphyry and gneiss. On the basis of this tabulation and previous descriptions of the various rock types, several conclusions may be drawn concerning the compositional changes involved in the formation of the porphyry by incorporation of gneiss in quartz monzonitic fluid:

(1.) Quartz is most abundant in the gneiss and decreases abruptly in the transitional rock. The quartz monzonite apparently contains more quartz than the porphyry.

(2.) Potash feldspar seems to increase gradually from the gneiss through the transitional rock and porphyry to the quartz monzonite.

(3.) Plagioclase is more abundant in the porphyry than in either the gneiss or the quartz monzonite. The composition of the central portion of the plagioclase laths (An_{30}) is roughly constant in all rocks; but the normal zoning of the laths and the additional phase of sodic oligoclase (An_{15}) in the porphyry and quartz monzonite indicate that the total albite content of the rock increases from the gneiss to the quartz monzonite.

* Walker and Mathias believe that the large feldspar crystals in both the porphyritic zone and the associated granitic rock formed by replacement. Shand (1949), however, described a single crystal from the granitic rock and concluded that the large feldspar crystals in the granite were magmatic in origin.

Table 7. Summary of Compositional Differences between Palms Quartz Monzonite, Monzonitic Porphyry, and Gneiss (All Figures in Percent):

	gneiss				transitional rock				porphyry			qtz.monz.	
	130	167	228	246	263	265	299	300	252	256	308	316	354
quartz	31.7	53.8	46.2	35.0	15.6	24.4	6.8	14.4	20.5	10.2	22.4	28.4	28.1
potash feldspar	12.2	15.3	11.9	29.6	17.4	21.9	36.2	32.8	18.7	32.1	10.7	21.3	25.2
plagioclase	22.8	23.0	24.1	30.9	46.7	25.2	51.7	41.2	50.2	53.4	57.9	42.0	40.5
biotite and hornblende	30.8	4.8	17.7	4.6	13.8	24.4	4.1	10.3	9.7	1.9	7.9	7.7	4.3
accessory	2.8	0.1	0.1	0.2	6.1	4.4	2.1	1.4	1.4	2.6	1.7	0.6	1.7
% anorthite in plagioclase laths	40	05	25	25	25	25	30	30	25	20	20	25	15

Samples in which the percentage of groundmass was measured (263, 299, 300, 252, 256, and 308) are tabulated above as follows: 50% of the groundmass is added to the amount of measured plagioclase, 25% to potash feldspar, and 25% to quartz.

Miller, 1938, reported the following average modal compositions:

	non-foliated Palms granite
quartz	28%
microcline	17
microperthite	11.3
oligoclase	36
biotite	4.3
epidote	1.3
magnetite	0.7
sericite	0.4
garnet	0.6
other	1.4

	monzonitic porphyry
microcline (somewhat perthitic)	20%
albite and oligoclase-andesine	39
quartz	17
hornblende	16
biotite	3
magnetite	2
epidote	1.5
titanite	1
other	0.5

(4.) Biotite and hornblende are so irregularly distributed in all four rock types that no definite conclusions are drawn concerning their distribution. Possibly the amount of mafic minerals decreases from the gneiss through the transitional rock and porphyry to the quartz monzonite.

(5.) Accessory minerals are most abundant in the porphyry and transitional rock.

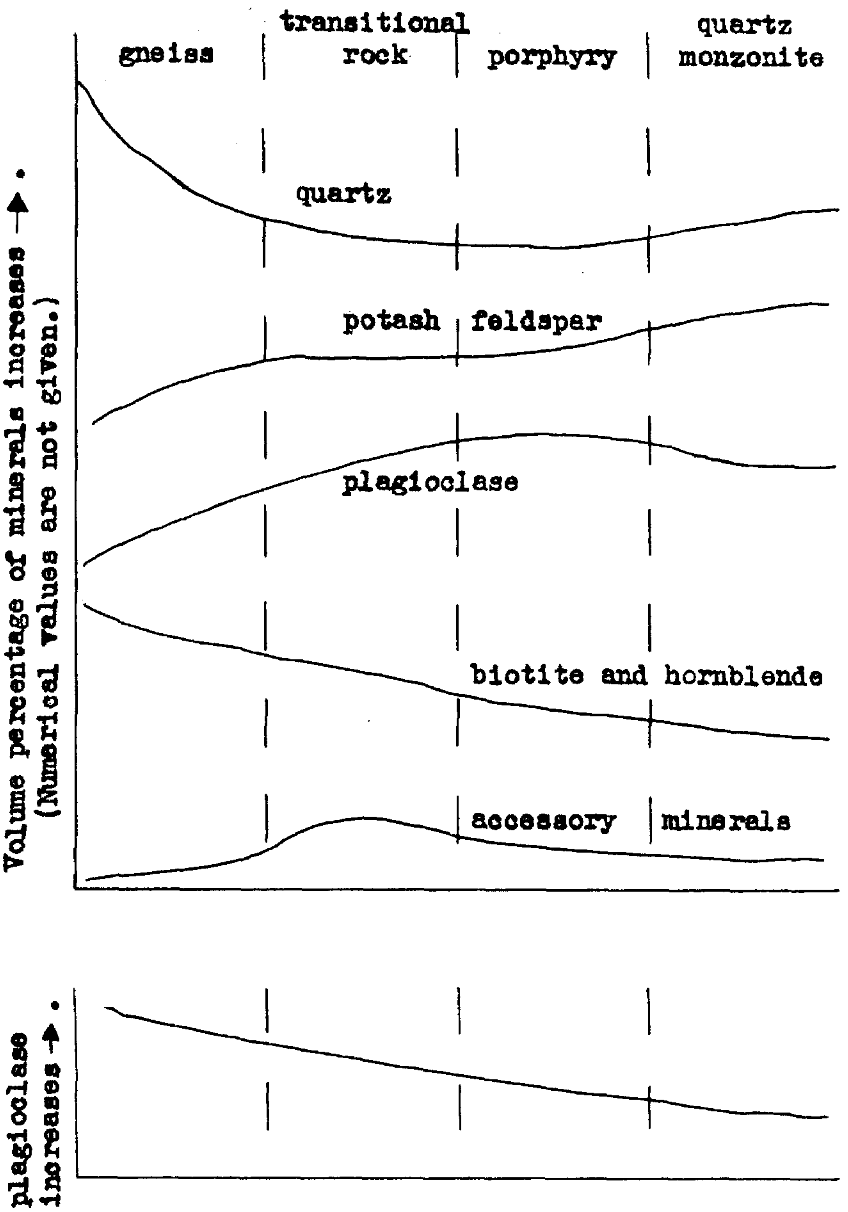
These relations are summarized in the curves shown in Fig. 31. The curves are qualitative and do not purport to show absolute values.

Apparently the most significant chemical change in the formation of porphyry from gneiss and quartz monzonite melt is the addition of potash feldspar and sodic plagioclase (or potash and soda) by the quartz monzonite, and concomitant decrease in the percentage of quartz and, perhaps, mafic minerals originally in the gneiss. Evidence is insufficient to determine whether or not the hornblende in the porphyry was incorporated from the gneiss, or was formed from other dark minerals in the gneiss, or was simply introduced by the quartz monzonite. The addition of sodic plagioclase to the gneiss accounts for the normally zoned plagioclase laths and the irregularly shaped grains of sodic oligoclase present in the porphyry and quartz monzonite but absent from the gneiss. The composition of the introduced plagioclase is unknown but was probably between An_{15} and An_{00}.

Although there are compositional differences between the quartz monzonite and the monzonitic porphyry, the mineralogic similarity and spatial relations are definite indications of a genetic relationship

Fig. 31

Generalized curves showing mineralogical relations between gneiss, transitional rock, monzonitic porphyry, and quartz monzonite



between the two rocks; both rocks contain the same suite of accessory minerals, hornblende of identical optical properties, and similar types of plagioclase.

3. Grain size:

The curves shown in Figs. 32-35 summarize the distribution of grain sizes of each mineral (quartz, potash feldspar, and plagioclase*) in different thin sections of quartz monzonite, porphyry, and rock transitional between gneiss and porphyry. The maximum dimensions of 25 grains of each mineral were measured in each section, and the number of grains in each group were plotted as the ordinate in the distribution curves. It is practically impossible to convert from megascopic to microscopic measurements of grain size, as would be necessary in plotting the size distribution of potash feldspar grains in the monzonitic porphyry. An abundance of small grains, in addition to the 25 measured ones, of all three minerals causes a rise in the distribution curves toward the small end of the size scale, but the lack of quantitative data about these small grains makes it impossible to determine whether or not there is a peak in the distribution curve in the small sizes. Fig. 35 shows a plot of grain size vs. volume percentage of each mineral.

The writer does not know whether a plot of grain volumes would show the same distribution as the plot of the maximum dimensions of the grains as measured in thin section. So long as the shapes of the large and small grains are approximately the same, however, the

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* All types of plagioclase (laths, irregularly shaped grains, and grains of all different compositions) are included in these measurements.

Fig. 32

Curves showing distribution of grain sizes of quartz, plagioclase, and potash feldspar in rocks transitional between gneiss and monzonitic porphyry

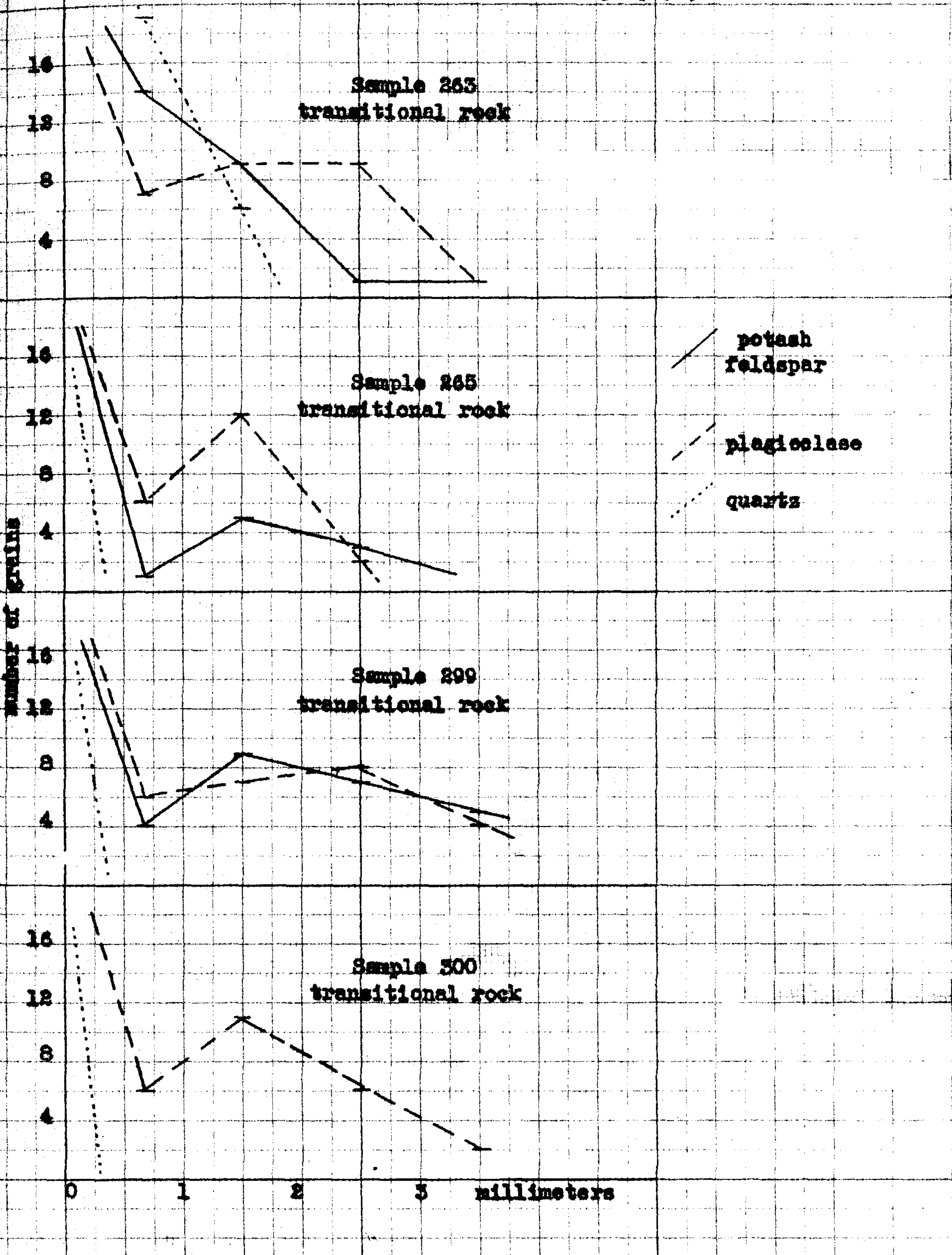


Fig. 33

Curves showing distribution of grain sizes of quartz and plagioclase in monzonitic porphyry and mylonitized porphyry

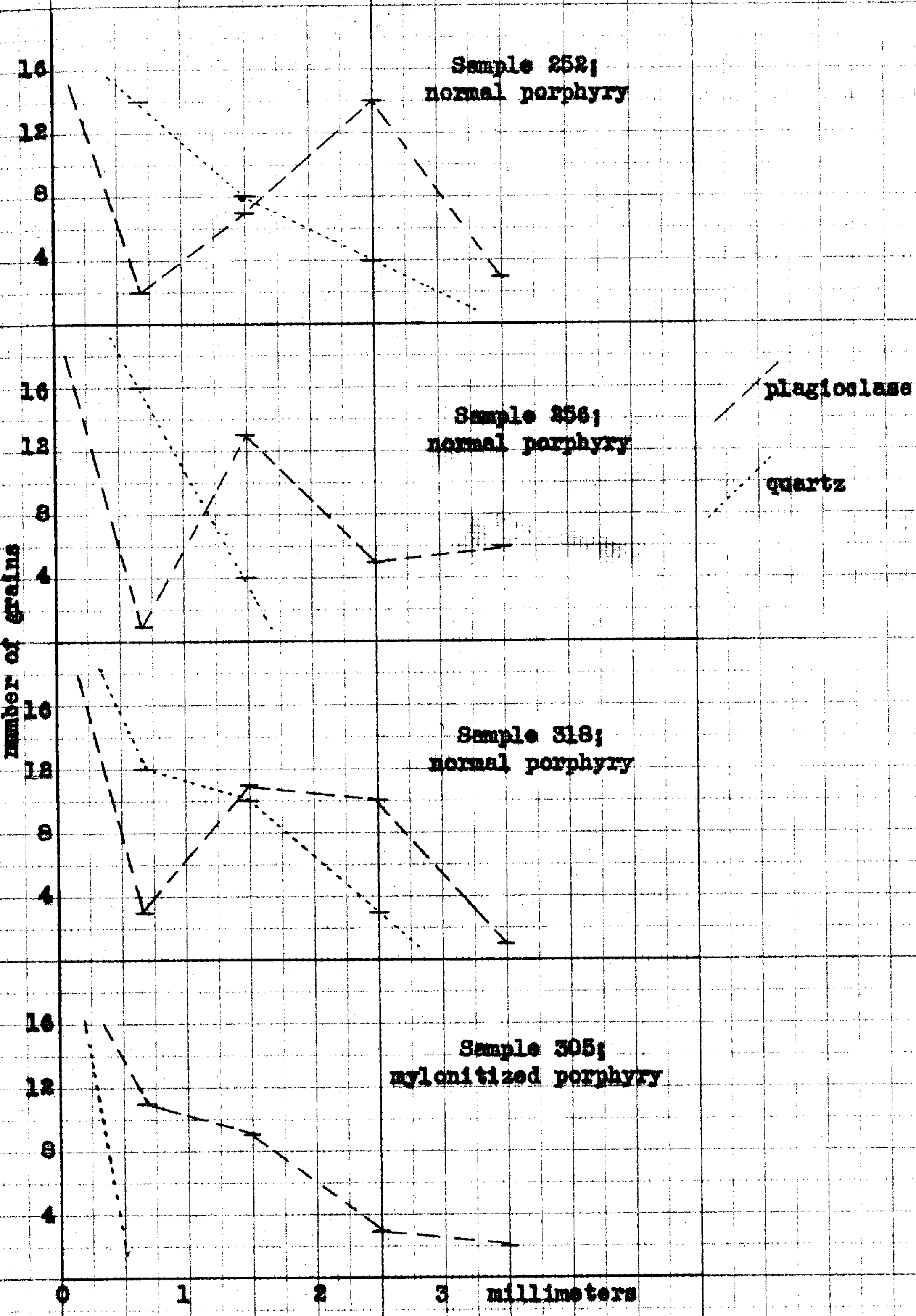


Fig. 34

Curves showing distribution of grain sizes of quartz, plagioclase, and potash feldspar in Palms quartz monzonite

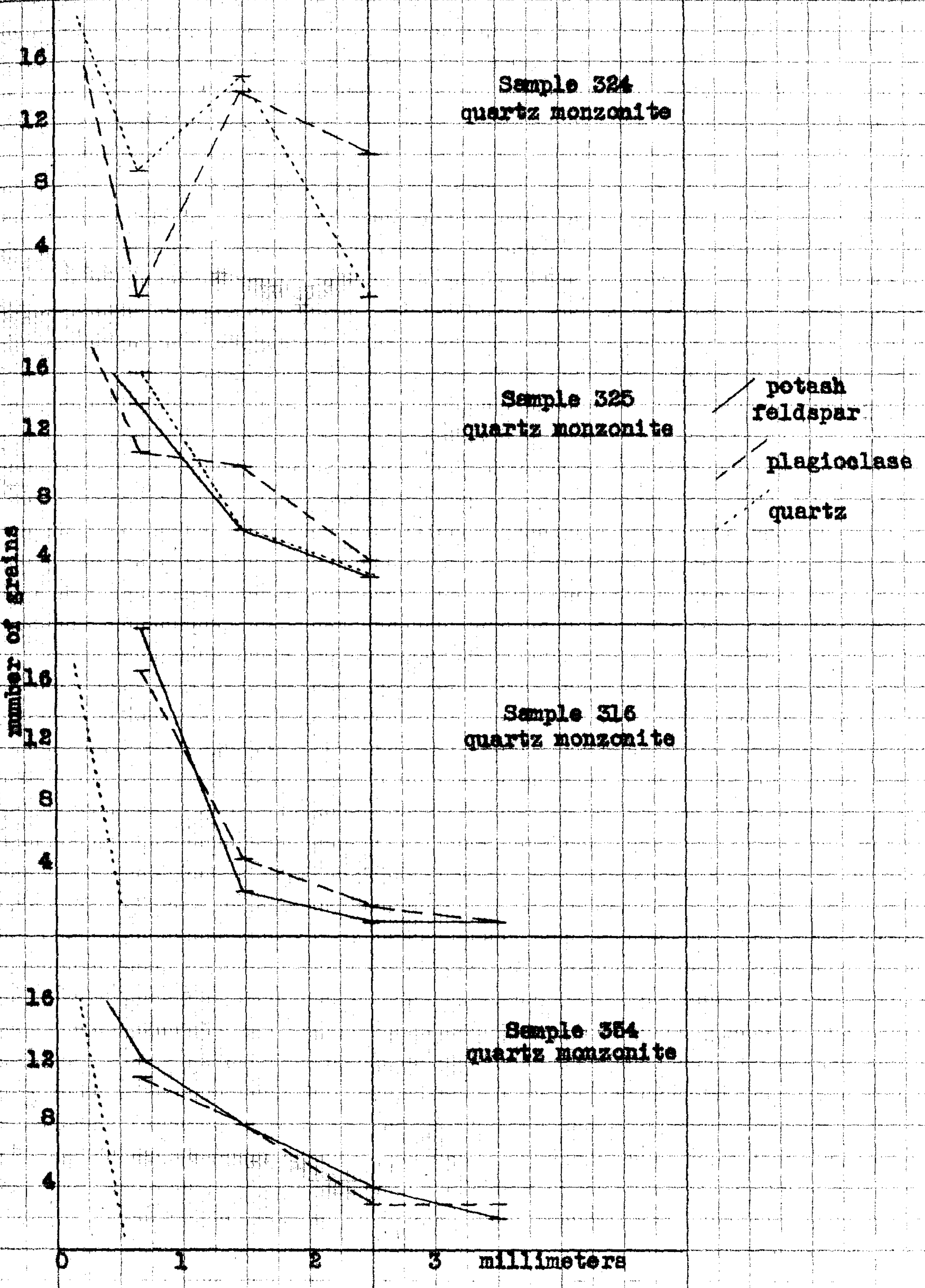
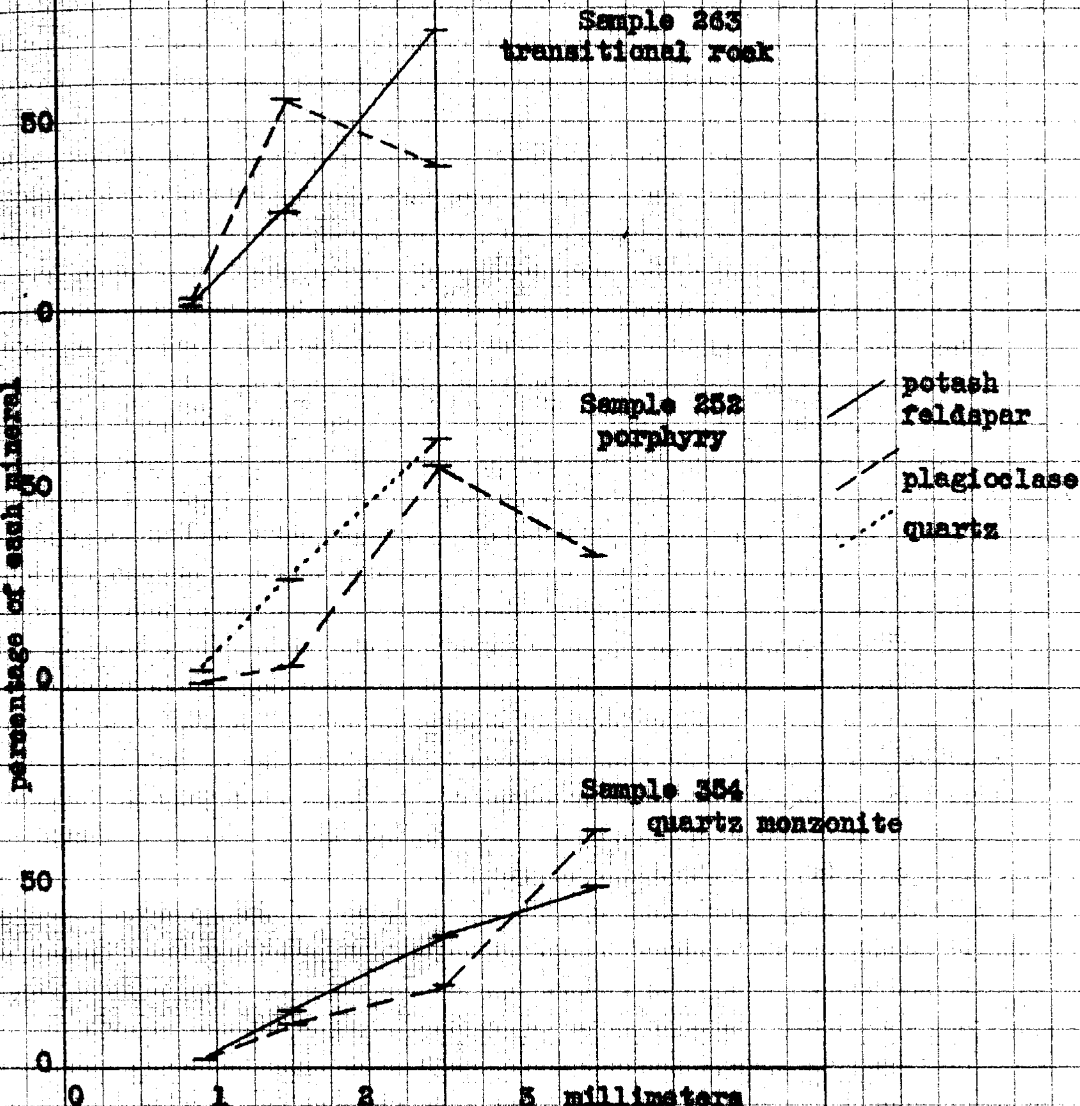


Fig. 35

Curves showing distribution of grain sizes of quartz, potash feldspar, and plagioclase in transitional rock, monzonitic porphyry, and quartz monzonite



The relative percentage of a mineral in a given grain size was determined by cubing the grain size, (the maximum dimension), and multiplying by the number of grains of the given size. Total percentage was then recomputed to 100%.

writer feels that the type of measurement used in this work would give the same general form of distribution curve as the measurement of actual grain volumes.

Regardless of the distribution in the very small sizes, it is apparent from Figs. 32-34 that the distribution curves for quartz monzonite are very different from those for porphyry and rock transitional between gneiss and porphyry. Both the porphyry and the transitional rock show a peak in the large sizes for all minerals, whereas the distribution curves of grain sizes in quartz monzonite rise steadily toward the smaller sizes, except for sample 354. Possibly the different shapes in the distribution curves for the quartz monzonite and monzonitic porphyry indicate a fundamental difference in the mode of formation of the two rocks. The distribution curves for sample 306 show the effect of mylonitization of a portion of the transitional rock.

IV. Origin:

The Palms quartz monzonite and the monzonitic porphyry are believed to be related in origin. Their similar mineralogy, the gradation between the two rocks in some places, and the distribution of the porphyry peripheral to the quartz monzonite all indicate a genetic relationship between the two rocks.

The writer hypothesizes that the monzonitic porphyry was formed by reaction between the quartz monzonite and the surrounding gneiss. Sharp contacts between porphyry and both gneiss and quartz monzonite in places, indicate that, at least locally, the porphyry was sufficiently mobile to intrude the other rocks. Actually, the planar structure near some contacts where the porphyry has undergone movement suggests that only a small portion of the porphyry was liquid at the time of movement; at least 75 percent (by volume) of the minerals in the porphyry are oriented and, thus, were probably solid during movement of the rock.

The evidence in favor of formation of the porphyry by reaction of quartz monzonite melt with gneiss may be summarized as follows:

1. Complete gradation of porphyry into gneiss along most contacts. This gradation is demonstrated by the size and percentage of potash feldspar grains; the size, percentage, and composition of the various forms of plagioclase; the size and percentage of quartz; the percentage of groundmass; the percentage and type of accessory minerals; and possibly by the percentage and type of mafic minerals.

2. The genetic relationship between the porphyry and the quartz monzonite as mentioned in the first paragraph of this section.

3. The fact that the porphyry is compositionally intermediate to the gneiss and quartz monzonite. Potash feldspar and the albite/anorthite ratio in the rocks increase steadily from gneiss through porphyry to quartz monzonite; quartz and possibly mafic minerals decrease in the same direction. Plagioclase is most concentrated in the porphyry because of the contribution from the gneiss and the addition of sodic material from the quartz monzonite. It is not known why accessory minerals should be most abundant in the porphyry.

Thus, it appears that the intrusion of quartz monzonite supplied potash feldspar and sodic plagioclase (An_{15} to An_{00}) to the gneiss and also supplied the heat necessary for the reconstitution of the gneiss to the monzonitic porphyry. There are, however, two major objections to such a theory:

1. Inasmuch as the monzonitic porphyry makes up the rims of the mountains south of Twentynine Palms, its contact away from the quartz monzonite (which makes up the center of the mountains) is generally not exposed. Thus, it is impossible to demonstrate a large scale gradation from quartz monzonite to porphyry to gneiss.

2. Many contacts between Palms quartz monzonite and gneiss show no development of porphyry. A typical contact is the one southeast of Queen Mountain, where the quartz monzonite grades into gneiss along much of the contact without an intermediate porphyry.

If it is assumed that the porphyry did form by reaction between quartz monzonite and gneiss, four major problems remain unanswered or only partially answered. These are:

1. What was the order of formation of the new minerals (principally the feldspars) in the porphyry? On textural appearance, it seems that the laths of plagioclase formed partly before the large potash feldspar grains. Possibly the potash feldspar grew throughout the entire period of formation of the rock.

2. What causes the formation of large crystals of potash feldspar in the porphyry, especially where finer grained potash feldspar is also present in the groundmass? A possible answer was given by Stöber in 1931, when he demonstrated that sodium nitrate formed much larger crystals if grown in a matrix of fine grained quartz

sand than if grown from a pure solution. There is, of course, a great difference between the conditions of his experiment and the conditions of formation of the monzonitic porphyry, but it may be hypothesized that the presence of solid material generally favors the formation of large crystals.

3. Why are inclusions abundant in the potash feldspar but rare in large plagioclase grains?

4. Is the hornblende in the porphyry all derived from hornblende in the gneiss, or does it represent conversion of other material such as biotite?

The exact mode of formation of the Palms quartz monzonite is also in doubt. For the following reasons it is proposed, however, that the quartz monzonite crystallized from an intruded melt:

1. Although there is complete gradation between quartz monzonite and both gneiss and porphyry in many places, the transitions are generally accomplished in a few feet. Some features, such as content of quartz, may show an abrupt break between transitional rock and quartz monzonite. It appears easier to explain this phenomenon by reaction between a fluid quartz monzonite and a solid wall rock than by replacement in the solid state.

2. Dikes of quartz monzonite in both porphyry and gneiss indicate that parts of the quartz monzonite were mobile during at least part of its period of formation.

3. If the quartz monzonite had formed in the same manner as the porphyry (i.e., by partial incorporation of the surrounding rocks),

one would not expect the grain sizes of both potash feldspar and plagioclase to be maximum in the porphyritic rims and less in the center of the area of replacement; rather, the grain sizes should increase from the rim toward the center of the quartz monzonite. This argument, of course, assumes a genetic relationship between the quartz monzonite and the porphyry.

It may be that the Palms quartz monzonite is partially the product of injection and crystallization of fluid material and partially the product of solid-state replacement, with the percentage of rock formed by each process unknown.

If the quartz monzonite did form by crystallization of a melt, it appears that crystallization of a fluid may produce an inequigranular seriate texture concomitant with the formation of a porphyritic texture in the partially replaced wall rock. Possibly the differences in the size distribution curves of the porphyry and quartz monzonite reflect the differences in origin.

WHITE TANK QUARTZ MONZONITE

I. Introduction:

The White Tank quartz monzonite was originally named the White Tank monzonite by W. J. Miller in 1938, although Miller recognized that an average sample contained approximately 30 percent quartz. The present writer has changed the name merely to place the rock more accurately in modern petrologic classifications. The formation crops out in four principal masses within the area: 1, a roughly circular mass south of Queen Mountain; 2, along the eastern side of Lost Horse Valley; 3, in an upfaulted block south of Forty Nine Palms; and 4, in a few small outcrops near the Anaconda Mine. The White Tank quartz monzonite is the youngest major plutonic rock in the area.

Direct evidence of the absolute age of the White Tank quartz monzonite is lacking. According to Dr. D. F. Hewett (personal communication), however, the White Tank quartz monzonite may be the same age as similar rocks elsewhere in the Mojave Desert. A pegmatite in the Cactus quartz monzonite (a possible correlative) has been dated by Hewett and Glass (1953) as approximately 150 million years old, thus presumably Jurassic.

II. Structure:

Almost no megascopic structure, with the exception of the widespread jointing, is to be found in the White Tank quartz monzonite. Most of the rock is massive, and no simple pattern has been discerned from the isolated patches that show a poorly developed foliation. The massive nature of the rock obtains even a few feet from the contacts.

Joints, however, are a characteristic feature of the quartz monzonite (Fig. 36). Some comments concerning the joint pattern are these:

1. Joints appear to have formed synchronously. No joint offsets any other.

2. In Lost Horse Valley and the north part of Queen Valley, joints in the White Tank quartz monzonite have an identical pattern to those in the Palms quartz monzonite. Many individual joints cross the contact with no deflection.

3. Both radial and concentric patterns are present in the quartz monzonite near contacts with the gneiss.

4. The gneiss is generally unjointed even near the quartz monzonite.

Pegmatite, aplite, and other dikes which cut the quartz monzonite bear no relation either to the joint pattern or to individual joints.

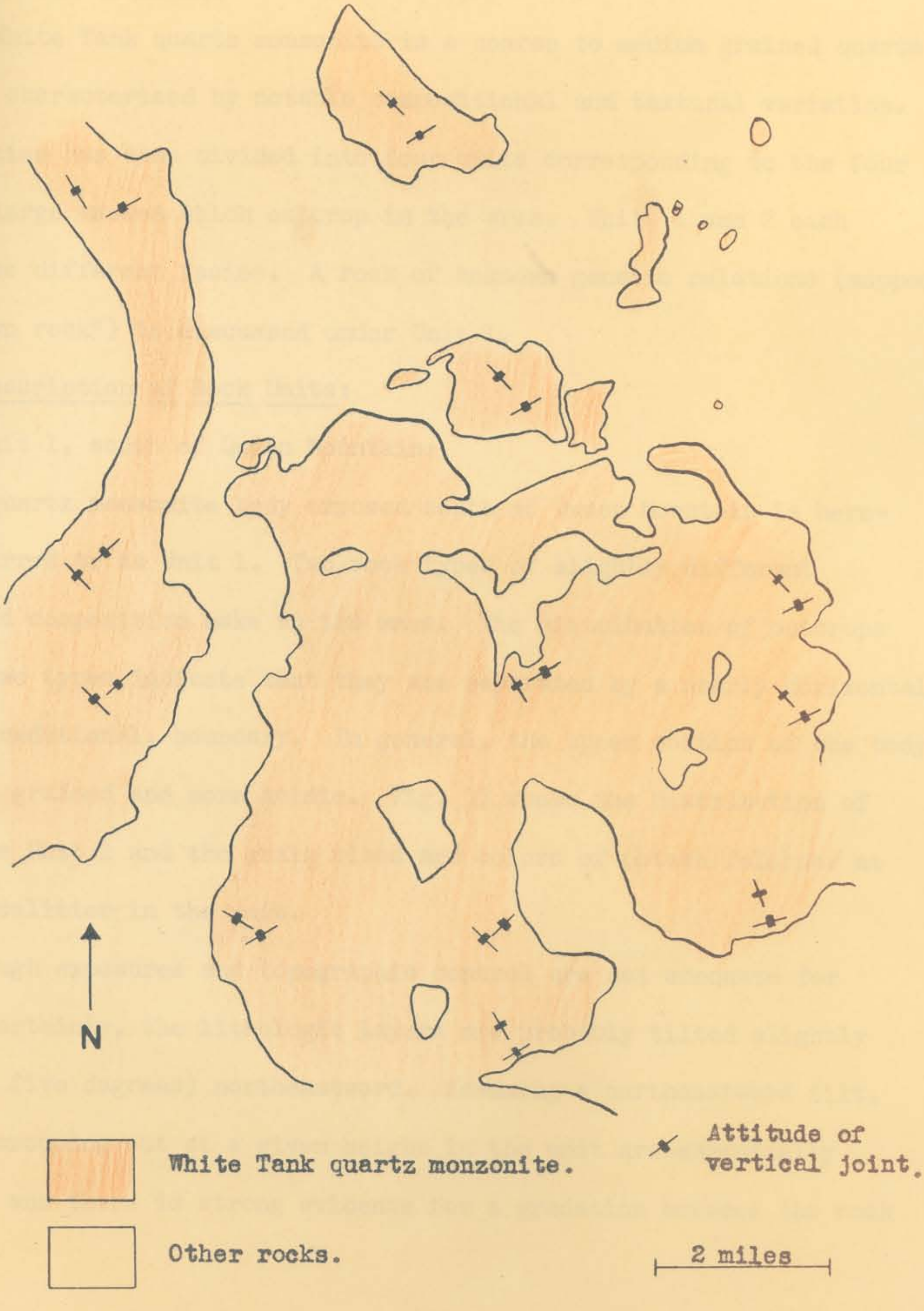
An adequate analysis of the jointing would require a statistical study of the joint pattern in many different parts of the quartz monzonite and adjacent rocks--a study outside the scope of the present investigation. Conclusions as to the origin of these joints must, therefore, be considered tentative.

The lack of relation between dikes and the joints plus the extension of the joints across contacts with other rocks indicates that the joints formed during or after the latest stages of igneous activity associated with the White Tank quartz monzonite. The absence of joints in the gneiss and the joint patterns associated with the intrusive contacts may be explained by assuming that the massive quartz monzonite was susceptible to the formation of joints, whereas the foliated gneiss

Fig. 36

Outline map of White Tank quartz monzonite showing attitude of vertical joints

(Horizontal joints are ubiquitous but are not shown below.)



was not. Possibly the joint pattern formed as a consequence of cooling of the intrusive bodies and was imposed on the overlying granitoid rocks.

III. Composition and Texture:

A. General Statement:

The White Tank quartz monzonite is a coarse to medium grained quartz monzonite characterized by notable compositional and textural variation. The formation has been divided into four units corresponding to the four separate large masses which outcrop in the area. Units 1 and 2 each contain two different facies. A rock of unknown genetic relations (mapped as "unknown rock") is discussed under Unit 1.

B. Description of Rock Units:

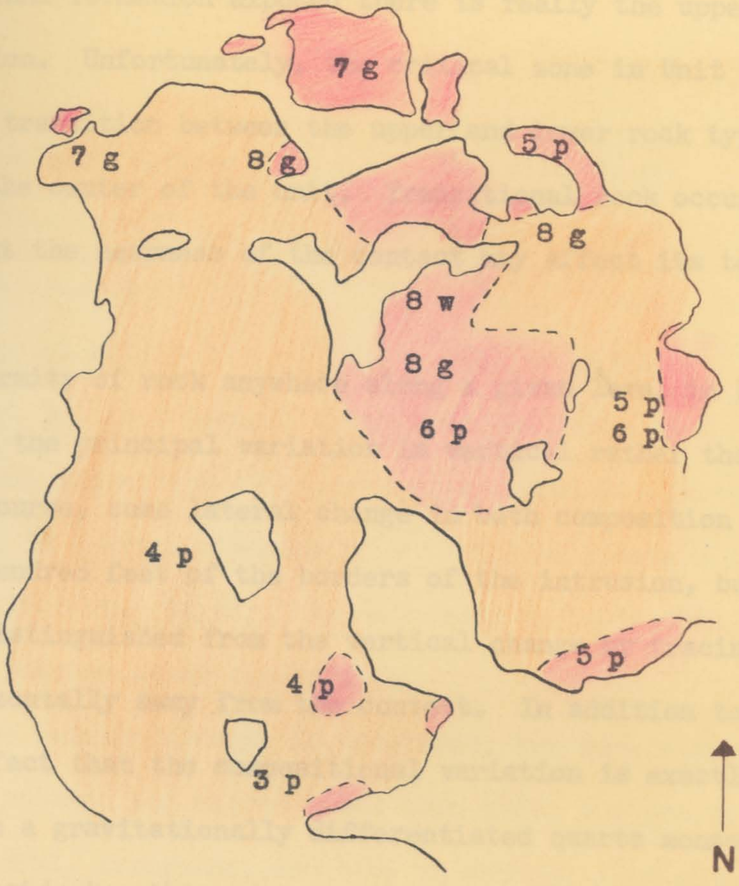
1. Unit 1, south of Queen Mountain:

The quartz monzonite body exposed south of Queen Mountain is hereafter referred to as Unit 1. Two rock types of slightly different texture and composition make up the mass. The distribution of outcrops of these two types indicate that they are separated by a nearly horizontal, probably gradational, boundary. In general, the upper portion of the body is coarser grained and more acidic. Fig. 37 shows the distribution of outcrops in Unit 1 and the grain sizes and colors of potash feldspar at various localities in the unit.

Although exposures and topographic control are not adequate for absolute certainty, the lithologic layers are probably tilted slightly (less than five degrees) northeastward. Assuming a northeastward tilt, all rocks cropping out at a given height in the unit are essentially identical, and there is strong evidence for a gradation between the rock

Fig. 37

Outline map of Unit 1 of White Tank quartz monzonite showing colors and grain sizes of potash feldspar and quality of outcrops



White Tank quartz monzonite; well exposed.

White Tank quartz monzonite; poorly exposed.

Other rocks

2 miles

All sizes shown above are in millimeters.

Color designations are: p = pink, w = white, g = gray.

exposed near Squaw Tank (the base of the exposed rock) and the facies in the upper part of Unit 1 (in Queen Valley). Scattered patches of roof rock (Palms quartz monzonite) in Queen Valley indicate that the portion of the White Tank formation exposed there is really the uppermost part of the intrusion. Unfortunately, the critical zone in Unit 1 (the one of most rapid transition between the upper and lower rock types) is unexposed in the center of the unit. Transitional rock occurs near White Tank, but the nearness of the contact may affect its texture and composition.

The uniformity of rock anywhere along a given level in Unit 1 indicates that the principal variation is vertical rather than lateral. There is, of course, some lateral change in both composition and texture within a few hundred feet of the borders of the intrusion, but this can generally be distinguished from the vertical change by tracing the variation horizontally away from the contact. In addition to the field evidence, the fact that the compositional variation is exactly what one would expect in a gravitationally differentiated quartz monzonite argues in favor of considering the major textural variation to be also vertical.

The three-dimensional shape of the intrusive is unknown. No floor is visible even at the lowest exposed rock (in the Squaw Tank area). Dr. J. A. Noble has suggested (personal communication) that the unit may, however, be a floored body; his argument is based partly on the fact that most large, unfloored, plutonic bodies generally do not show a vertical variation.

The two facies of Unit 1 (upper and lower) are described below. The descriptions are a composite of several different samples from each type.

a. Squaw Tank area, lowest exposed rock in the unit:

Megascopically the rock is light brown to light gray, massive, medium to coarse grained, and equigranular. Modal analyses of three samples gave the following compositions:

	43	224	506
quartz	16.7%	23.4%	22.8%
potash feldspar	25.6	23.0	15.8
plagioclase	48.4	45.3	50.3
biotite	8.2	7.8	10.2
hornblende	0.2	trace	---
accessory	0.8	0.4	0.9
total points	938	1350	1091

Section 43, Fig. 38, is a typical example of the lower part of Unit 1.

Quartz forms aggregates of a dozen or so undulant, fretted grains, each grain with an average diameter of 1 to 1.5 millimeters and some as large as 6 millimeters. Rarely, quartz occurs as individual, interstitial grains between other minerals.

Most of the potash feldspar is untwinned, but some microcline twinning forms patches and narrow bands throughout the grains. All grains are anhedral, irregular, and have an average dimension of 2.3 millimeters and a maximum of 10. Vein and rod perthite are present but uncommon. Some of the larger grains are poikilitic, the common inclusions being plagioclase.

Subhedral laths of plagioclase have an average length of 2 millimeters and a maximum of 10. Most grains are slightly zoned, the composition ranging from An_{35} in the center to An_{20} at the rim and showing some oscillation. Grains which show the strongest zoning are generally untwinned, and conversely, the twinned grains are unzoned. Some grains,

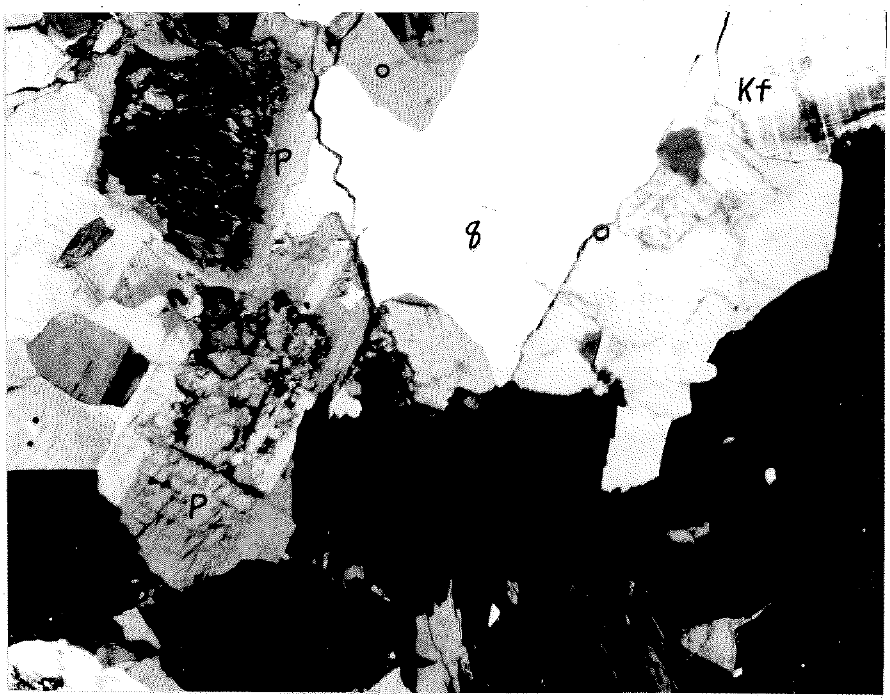


Fig. 38. Sample 43 of lower facies of Unit 1 of White Tank quartz monzonite. Major minerals are quartz (q), plagioclase (p), and potash feldspar (Kf). Crossed nicols, X25.

however, are both twinned and zoned. Twinning generally follows the albite law. A few grains are twinned according to the pericline law, such twins being more common in the lower part of Unit 1 than in other parts of the quartz monzonite.

A few plagioclase grains are surrounded by small rims of albite in optical continuity with the larger grains. These rims are sharply distinct from the rest of the grain and commonly occur only at the border between plagioclase and potash feldspar. Some rims are myrmekitic, the quartz blebs being oriented across the rim and normal to the grain borders. Less commonly, myrmekite occurs in the large laths of plagioclase where they border potash feldspar, and in such cases the quartz blebs do not show any morphologic orientation, although some are optically oriented.

Biotite forms flakes approximately 1 millimeter long. It is pleochroic from yellow to brown, but the chloritization and possibly other alteration make color determination difficult. Commonly the biotite occurs in aggregates of several grains.

The principal accessory mineral is magnetite, but apatite, zircon, and sphene are also present. All of the zircon is included in biotite, where it forms small pleochroic haloes. Magnetite and apatite are also concentrated either as inclusions in the biotite or associated as separate grains with the biotitic aggregates. Sphene, however, is scattered randomly through the rock. The accessory minerals are invariably euhedral and much smaller than the essential minerals.

Some sections from this lowermost part of Unit 1 contain a few small grains of hornblende, pleochroic from yellow to blue green.

The optical properties are the following: length slow, birefringence 0.2, extinction angle 25°. The mineral is best identified as common hornblende.

The plagioclase, especially the centers of zoned grains, has been altered to sericite* and epidote, and perhaps some calcite. Some irregularly shaped epidote grains scattered through the rock do not seem to have formed by alteration of plagioclase and may be primary. Kaolin is lightly scattered over both types of feldspar.

b. Queen Valley, uppermost rock in the unit:

Megascopically the White Tank quartz monzonite here is gray, massive, coarse grained, and very inequigranular. It is characterized by an average of 30 to 40 percent gray, subhedral crystals of potash feldspar with an average maximum dimension of 8 millimeters. Some grains of potash feldspar show several zones, the outer one commonly being white.

Modal analyses of two rocks in Queen Valley are below.

	127	85
quartz	19.6%	17.6%
potash feldspar	38.3	13.1
plagioclase	35.6	57.2
biotite	5.8	1.8
epidote	---	6.5
accessory	0.7	3.8
total points	1116	1169

Section 127, Fig. 39, is a typical example of the upper part of Unit 1.

* In this thesis, the word "sericite" will designate a fine grained white mica formed by alteration of some other mineral. "Muscovite" will designate a coarse grained white mica formed by any process. The two types may have the same composition, or they may be different. Stains used to determine the percentage of potash feldspar in some sections also showed the presence of potassium in sericite, but the sericite may be partly illitic and/or paragonitic.

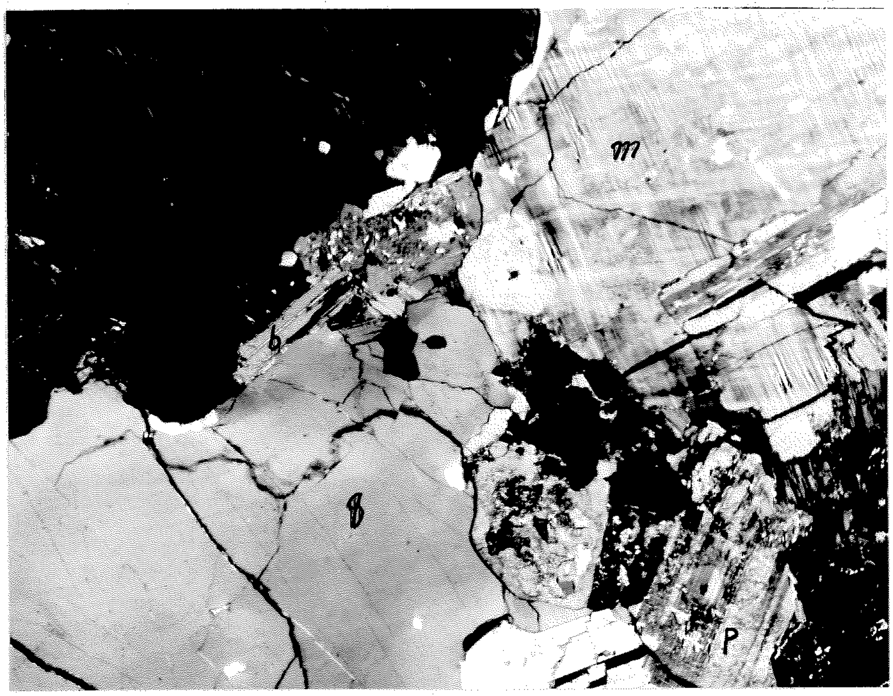


Fig. 39. Sample 127 of upper facies of Unit 1 of White Tank quartz monzonite. Major minerals are quartz (q), plagioclase (p), microcline (m), and biotite (b). Crossed nicols, X25.

The variation between the two modes indicates, as is evident also from the nature of the rock, that the rock in this area is really too coarse grained to give accurate micrometric results. The percentage of microcline measured depends largely on whether or not the section cuts one of the large crystals. Similarly, the biotite, which is obviously less than 5 percent in hand specimen, occurs in clusters which, locally, give an anomalously high percentage in thin section. The true content of microcline in the upper part of Unit 1 was measured in the field by the rough point count method described previously (page 9), and averages 30 to 40 percent.

Nearly all of the quartz forms aggregates of undulant, fretted, two-millimeter grains. A few individual, interstitial grains are also present, and rarely a stringer of quartz appears to penetrate a feldspar grain or to follow the border between optically-continuous, intergrown grains of plagioclase and microcline. This may indicate that quartz completed its crystallization after at least part of the microcline had formed.

The most characteristic textural feature of the feldspars is the irregular, optically-oriented intergrowths between microcline and sodic plagioclase (Fig. 40). Many of the large gray phenocrysts consist of approximately one fourth albite and the rest potash feldspar. The border between the two minerals is commonly very irregular in detail, and many isolated patches of plagioclase with the same orientation as the large grains occur throughout the microcline. The twin directions in these separate grains are parallel to each other, but individual

Fig. 40. Intergrowth of microcline and sodic plagioclase in sample 72 of upper facies of Unit 1 of White Tank quartz monzonite. Crossed nicols, X25.

albite twin lamellae can rarely be traced from one patch to the adjacent one, as should be possible if the separation had resulted by replacement of single plagioclase crystals by microcline.

In addition to the oriented intergrowths, microcline may contain small inclusions of plagioclase which, though bearing the same orientation with respect to each other, show no constant relation to the orientation of the potash feldspar. One grain of microcline in section 86 contains a zone of these inclusions parallel to the rim and about one half millimeter from it. In this same section, some microcline grains show successive zones of potash feldspar with slightly different optical orientations from each other.

The plagioclase in the oriented intergrowths or zonally arranged inclusions is unzoned, twinned on the albite law, and has a composition of An_{10} to An_{05} (measured by the Michel-Levy method). There is no myrmekite in this type of plagioclase. Plagioclase in the vein type of perthite which characterizes some of the microcline in this facies seems to have the same composition as plagioclase in the intergrowths, but lack of twinning in some veins makes accurate determination difficult. Unlike the potash feldspar in the lower portion of Unit 1, the microcline in the upper portion contains no rod perthite.

Two other types of plagioclase occur in addition to the type discussed above. The most common of these is about equal in abundance to that of the intergrowths. It forms anhedral to subhedral, 1- to 2-millimeter, laths occurring either as distinct grains or as unoriented inclusions in the microcline. Some grains show a slight normal zoning, and most grains are twinned. The average composition is An_{15}.

The least abundant variety of plagioclase (about five percent of the total) is apparently pure albite. It forms distinct, oriented rims around the more calcic laths or occurs as small, irregular grains next to microcline. The albitic rims invariably occur next to potash feldspar. Myrmekite is common in both types of albite, the quartz blebs in the rims being oriented normal to the rims, and the blebs in the irregular grains showing no apparent orientation.

Biotite in this portion of the quartz monzonite forms small (0.25 millimeter long), ragged flakes pleochroic from yellow to brown. Parts are chloritized.

Accessory minerals consist of magnetite (altered to ferric oxide), apatite, sphene, zircon (which forms pleochroic haloes in the biotite), and allanite. The biotite and accessory minerals, with the exception of sphene, commonly form aggregates.

In some sections much of the plagioclase has been altered to epidote. The epidote forms anhedral grains having an average length of 0.25 millimeter. Many grains bear no obvious relation to plagioclase and may be primary.

Sericitic alteration is ubiquitous in all plagioclase containing any anorthite but varies markedly from grain to grain. Kaolin forms a light dusting on both feldspars.

Section 205 is from the lower portion of the upper facies of Unit 1. It contains pink microcline phenocrysts having an average maximum dimension of 6 millimeters, as opposed to gray, 8-millimeter crystals higher in the body. The composition of the plagioclase laths is An_{16}, which is not measurably different from the plagioclase (An_{15}) higher in the quartz monzonite. A modal analysis gave the following composition:

	205
quartz	20.9%
microcline	43.3
plagioclase	31.2
biotite	4.1
accessory	0.5
total points	1000

Based on estimates made in the field, biotite may be somewhat more abundant in the rock represented by section 205 than higher in Unit 1.

In addition to the rocks described above, another variety of White Tank quartz monzonite crops out in Queen Valley. It is restricted to a small hill (Fig. 41) about two miles south of Queen Mountain. Inasmuch as patches of roof rock overlie the quartz monzonite with intrusive contact in the valley below, the facies of quartz monzonite on the hill may be a cupola formed above the main intrusion. For two reasons it is believed that the hill is not the result of faulting:

(1.) No evidence of shear zones is found around its base.

(2.) The rock on the hill is slightly different from the rest of the quartz monzonite in Queen Valley and presumably represents a more extreme product of differentiation.

Megascopically the rock is gray, massive, very coarse grained, and inequigranular. Potash feldspar phenocrysts average 8 to 9 millimeters in maximum dimension. Two modal analyses of the rock gave the following results:

[See page 140]

Fig. 41. Hill in Queen Valley on which is exposed rock from a cupola in White Tank quartz monzonite.

	197	212
quartz	11.2%	43.3%
microcline	48.4	26.1
plagioclase	36.3	29.2
biotite	3.9	1.4
accessory	0.2	0.4
total points	1256	1120

The large difference between the two modal analyses given above again shows the sampling error in analyzing such a coarse grained rock. As measured in the field, the potash feldspar content is about 50 percent, the quartz and plagioclase 25 percent each, and the biotite 1 to 2 percent.

The quartz is similar to quartz in the rest of the rock in Queen Valley. It forms aggregates of undulant, fretted grains each 2 to 2.5 millimeters in diameter.

The potash feldspar is entirely microcline. Intergrowths with plagioclase are common and identical to those described on page 134. The grains are subhedral to anhedral. Rod perthite is absent or rare. The outer portions of some grains show a graphic texture with quartz of 0.25-millimeter diameter. A few of the quartzose aggregates contain anhedral microcline grains.

Plagioclase occurs in several different habits identical to those described for the rest of the White Tank quartz monzonite in Queen Valley. The anhedral to subhedral laths have an average length of 1.5 millimeters and a composition of An_{15}. They are twinned and unzoned. Distinct rims of albite surround the plagioclase laths where they border microcline, and small, untwinned grains of albite are scattered throughout the rock. The irregular albite grains are generally in contact with microcline, but some are completely surrounded by quartz. Plagioclase intergrown with microcline has a composition of An_{10} or more sodic. Sericitization is intense on all but the pure albite.

Biotite forms ragged flakes from 0.5 to 1 millimeter long. Most flakes are almost entirely altered to muscovite and red iron oxide.

Accessory minerals are uncommon, those noted being magnetite, apatite, and zircon. A few epidote grains may be either primary or secondary.

Staining by ferruginous material or iron-stained clay is common in the cupola. Possibly this is due to iron-enrichment in the upper parts of the quartz monzonite during its crystallization.

Two lines of evidence favor the opinion that a gradation exists between the upper and lower facies of Unit 1:

(1). The rock near White Tank is intermediate in both composition and texture to the upper and lower facies. It contains about 30 percent pink grains of potash feldspar with a grain size of 6 millimeters, and the composition of its plagioclase is An_{20}; both features are intermediate between rocks typical of the upper and lower facies. If the lithologic layers in Unit 1 are tilted approximately 3 degrees northeastward, the rock near White Tank is in a zone between the upper and lower facies. This intermediate rock is found up to two miles from the wall-rock contact, although outcrops are more common near the contact. It does not seem reasonable that contact effects should influence the rock to such a distance.

(2.) In the lower facies the potash feldspar tends to become coarser upward but maintains its pink color throughout the facies.

In the upper facies the typical large gray crystals of microcline become a dark pink downward and appear to decrease in size. Thus, the trends in both rocks are toward a common intermediate which is much like the rock near White Tank.

c. Unknown rock, possibly part of Unit 1:

A rock that is possibly related to the White Tank quartz monzonite crops out in an area south of Jumbo Rocks and north of the Hexie Mountains. Megascopically it is white to light gray, massive, medium to coarse grained, inequigranular. Some portions of the rock contain white phenocrysts of plagioclase up to 10 millimeters long.

A modal analysis of this rock gave the following composition:

	435
quartz	27.5%
potash feldspar	11.3
plagioclase	48.0
biotite	9.4
hornblende	2.7
accessory	1.0
total points	1051

Approximately half of the quartz occurs in aggregates of undulant, fretted, 1-millimeter grains; the remainder forms individual, interstitial grains with an average size of 0.5 millimeter.

Most of the potash feldspar exhibits grid twinning and forms anhedral grains having an average size of 0.5 millimeter (measured in thin section). Perthite is absent.

Plagioclase forms subhedral laths having an average length of 1.3 millimeter. Laths are twinned and/or normally zoned and have a compositional range from An_{40} in the center of the grain to An_{30} at the edge. Albitic borders are very rare. Myrmekite is absent.

Biotite is pleochroic from yellow to dark brown. It forms ragged flakes having an average length of 1 millimeter. Hornblende occurs as prisms, having an average length of 0.5 millimeter, pleochroic from yellow green to blue green.

The accessory minerals are magnetite, apatite, sphene, and zircon, all of which form small euhedral grains.

Most of the plagioclase is intensely altered to sericite, and both feldspars are lightly coated by kaolin. Some of the biotite is chloritized.

Approximately one third of the rock can be considered a groundmass of 0.25- to 0.5-millimeter grains of all minerals in the rock. This groundmass consists of individual quartz grains, plagioclase laths (An_{40} to An_{30}), and microcline, in about the same proportions as they are in the rock as a whole. The grains of all three of these minerals are completely seriate from the groundmass crystals up to the largest grains.

This rock has roughly the composition of the lower facies of Unit 1, but texturally there seems to be little relation between the two rocks. All of Unit 1 is coarser grained, has more of its quartz in aggregates, and lacks the distinct groundmass of the unknown rock. The only portion of any unit of the White Tank quartz monzonite which is texturally at all similar to this unknown rock is in a relatively fine grained (apparently chilled) zone within one hundred feet of the eastern border of Unit 1. The unknown rock is not related to a border of the quartz monzonite.

Thus, it may be concluded that the unknown rock may have been derived from the same magma source as the White Tank quartz monzonite but probably was intruded at a different time. Possibly the unknown rock is a large dike injected soon after the crystallization of Unit 1. If the unknown rock and the quartz monzonite near Squaw Tank are differentiates of the same injection (which seems unlikely), then there is no complete gradation between the upper and lower facies of Unit 1, for outcrops of the unknown rock and the upper facies of Unit 1 may be found within 25 feet of each other and with no evidence of gradation between the two rocks.

2. Unit 2, in Lost Horse Valley:

The quartz monzonite hereafter referred to as Unit 2 crops out in Lost Horse Valley. It shows far less textural and compositional variation than Unit 1. Throughout the entire vertical distance from Indian Cove to Cap Rock (about 1000 feet) there is almost no variation. Only in the uppermost part of the unit, next to the Palms quartz monzonite on the eastern edge of Lost Horse Valley, is there any difference in texture; and this may, in large part, be the result of horizontal variation away from the wall rock rather than a vertical change. Unit 2 may be subdivided into two different facies, which are described below.

a. Indian Cove and Cap Rock areas, bulk of unit:

As seen in hand specimen, the rock is brown, medium grained, equigranular, and massive. The potash feldspar is pink as in the lower part of Unit 1.

Modal analysis of Unit 2 is presumably more accurate than analysis of Unit 1 because of the much smaller grain size of Unit 2. Analyses of three samples are given below; sample 6 is from the rock south of Indian Cove, sample 13 was taken east of Hidden Valley, and sample 83 was taken east of Cap Rock.

	6	13	83
quartz	39.4%	26.3%	33.1%
potash feldspar	20.2	32.1	26.4
plagioclase	38.0	40.7	36.3
biotite	2.3	0.7	3.7
accessory	0.3	0.2	1.0
total points	1082	1215	1285

Sample 6 (Fig. 42) is a typical example of Unit 2.

Quartz occurs in aggregates of undulant, fretted, 1- to 2-millimeter grains. Some individual, interstitial grains fill spaces between feldspars. In some potash feldspar grains, thin quartz stringers follow cleavages or cut randomly across the grains; some stringers are in optical continuity with an adjoining quartz grain.

Most of the potash feldspar is untwinned, but some borders and thin zones through the grain show grid twinning. Both vein and rod perthite are present but uncommon. The grains are anhedral to subhedral and have an average length of 5 to 6 millimeters. Inclusions of quartz in potash feldspar have an average diameter of 0.25 millimeter (which is

Fig. 42. Sample 6 of Unit 2 of White Tank quartz monzonite south of Indian Cove. Major minerals are quartz (q), plagioclase (p), and microcline (m). Crossed nicols, X25.

smaller than quartz grains in the rest of the rock), whereas inclusions of plagioclase average 1.5 millimeters long (the average size for plagioclase laths in the whole rock).

Most of the plagioclase forms subhedral laths 1.5 millimeters long. Many grains are zoned, the composition ranging from An_{30} in the center to An_{20} at the rim. Albite twinning is present except on the most strongly zoned grains. Some zoned grains are twinned on the edges but not in the center. Some of the plagioclase laths are bordered by rims of albite where they are in contact with potash feldspar; small, irregular grains of albite are scattered throughout the rock, commonly near potash feldspar. Inclusions of quartz in potash feldspar may be surrounded by rims of albite (Fig. 43).

Myrmekite is identical to the types in Unit 1. Most myrmekitic growth is restricted to albitic rims around plagioclase laths, but some of the laths are also myrmekitic.

Biotite forms flakes about 0.5 to 1 millimeter long. It is pleochroic from yellow to dark brown, some slightly greenish flakes owing their color, perhaps, to slight alteration.

Magnetite, zircon, and sphene are accessory minerals. Zircon is generally included in the biotite, where it causes small pleochroic haloes. Magnetite and biotite are commonly clustered together in aggregates of several grains.

Sericitization is intense in all plagioclase except albite and is especially concentrated in the more calcic portions of the zoned grains. Some large flakes of white mica may be primary. Kaolin is lightly

Fig. 43. Albitic rim (ab) around inclusion of quartz (q) in potash feldspar. Sample 13 of Unit 2 of White Tank quartz monzonite east of Hidden Valley. Crossed nicols, X65.

scattered over both feldspars. A little chlorite penetrates biotite in patches parallel to its cleavage, and some unidentified reddish alteration product is present on a few flakes of biotite.

b. Rim along eastern contact of Unit 2 south of Rattlesnake Valley:

A thin rim up to 200 feet wide along part of the eastern margin of Unit 2 differs from the rest of Unit 2 in its content of muscovite and garnet and the albitic composition of its plagioclase laths. This facies is found only along the uppermost portion of the contact (at the head of Rattlesnake Valley and southward), and is absent at the mouth of Rattlesnake Valley (1000 feet lower). This micaceous facies grades horizontally into quartz monzonite typical of the rest of Unit 2 within 200 feet of the contact, and its location, therefore, is not solely controlled by elevation.

Megascopically the quartz monzonite in this rim is tan to light gray, massive, medium grained, and equigranular. It is easily recognized by the flakes of muscovite (up to 5 millimeters in diameter) which make up about one percent of the rock. Some portions of the rock contain a few red garnets which range from a fraction of a millimeter up to 5 millimeters in diameter. A modal analysis of the rock in this rim gave the following composition:

	170
quartz	29.9%
potash feldspar	24.2
plagioclase	45.1
biotite	0.4
muscovite	0.4
accessory	---
total points	1272

Section 170, Fig. 44, is typical of the rock in this rim.

Fig. 44. Sample 170 of micaceous eastern rim of Unit 2 of White Tank quartz monzonite. Major minerals are quartz (q), plagioclase (p), and microcline (m). Crossed nicols, X25. Muscovite is not present in this photograph.

As in most of the White Tank quartz monzonite, quartz occurs primarily in aggregates of undulant, fretted grains, each 1 to 2 millimeters in diameter. Some quartz forms individual, interstitial grains about 0.5 millimeter long.

Most of the potash feldspar is untwinned, but small areas in some grains show microcline twinning. The feldspar contains rare vein perthite and no other type. Individual grains of potash feldspar are anhedral, roughly equant, and have an average diameter of 5 to 6 millimeters.

Plagioclase forms subhedral laths having an average length of 1.5 to 2 millimeters. All grains are twinned on the albite law, and a few show a very faint, normal (?) zoning. As determined by the Michel-Levy method, the composition is An_{10} to An_{15}. In addition to these large plagioclase grains, small rims of albite form textures identical to those in the rest of Unit 2.

Biotite forms very ragged flakes from 0.5 to 1 millimeter long. Most of the grains are thoroughly altered to one or more of the following:

(1.) Muscovite.

(2.) Chlorite.

(3.) Red, ferruginous material containing scattered small, opaque needles of an unidentified mineral. The needles are white in reflected light.

Magnetite, sphene, and possibly some epidote make up the accessory minerals. Garnet is so rare that it is unlikely to occur in thin section, but it can be identified in hand specimen. The garnet is deep red to orange, has an index of 1.81, and apparently has a unit cell dimension of 11.6 Å (from powder pattern). These data, plus its alteration to a black powder (manganese oxide?), indicate that the garnet is a spessartite.

Except for the pure albite, plagioclase is intensely altered to sericite or muscovite, some of which forms flakes up to 0.5 millimeter long. Most books of white mica, however, bear no relation to other minerals and seem to be primary. Kaolin is lightly scattered over both feldspars.

3. Unit 3, in up-faulted wedge north of Queen Mountain:

The White Tank quartz monzonite between Forty Nine Palms and Queen Mountain is hereafter referred to as Unit 3. The rock in Unit 3 is very similar to the micaceous eastern rim of Unit 2 but contains more muscovite and garnet and a more highly sodic plagioclase than the rim. Apparently the rock does not vary over the entire area of the wedge except for slight changes near the southern contact with the Palms quartz monzonite. The lack of relief in the area of exposure, however, prevents looking for a vertical variation.

Megascopically the rock is gray to white, massive, medium grained, and equigranular. It is characterized by books of muscovite, scattered red garnets, and white potash feldspar.* Modal analyses of two samples gave the following results:

[See next page]

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* In all other units of the White Tank quartz monzonite, potash feldspar is colored (either pink or gray).

	356	359
quartz	39.8%	30.8%
microcline	21.5	22.7
plagioclase	31.4	40.6
muscovite	6.7	5.7
biotite	0.2	---
garnet	0.5	0.3
total points	1129	1172

Section 356 (Fig. 45) is typical of Unit 3.

The aggregates of quartz grains which characterize most of the quartz monzonite are absent from this unit. All quartz forms individual, interstitial grains with an average diameter of 1.5 millimeters. The grains are slightly undulant and are fretted in contact with other quartz grains but not against feldspar.

All of the potash feldspar is twinned microcline. It occurs as anhedral, somewhat equant grains which are too small to measure accurately in the field. In section, the average maximum dimension is 2 millimeters. Rod perthite is absent, but a little vein perthite occurs in most grains.

Plagioclase forms anhedral, lath-shaped grains with an average length of 1.5 millimeters. It is twinned on the albite law, unzoned, and has a composition of An_{03} by Michel-Levy measurement. No rims or small grains of albite are present, in distinction to the rest of the quartz monzonite. Myrmekite is absent.

Muscovite forms flakes having an average length of 1 millimeter. A small amount seems to have formed by alteration of plagioclase, but most occurs as large flakes showing no relation to plagioclase and is almost certainly primary. A brown alteration product has formed along some cleavage planes.

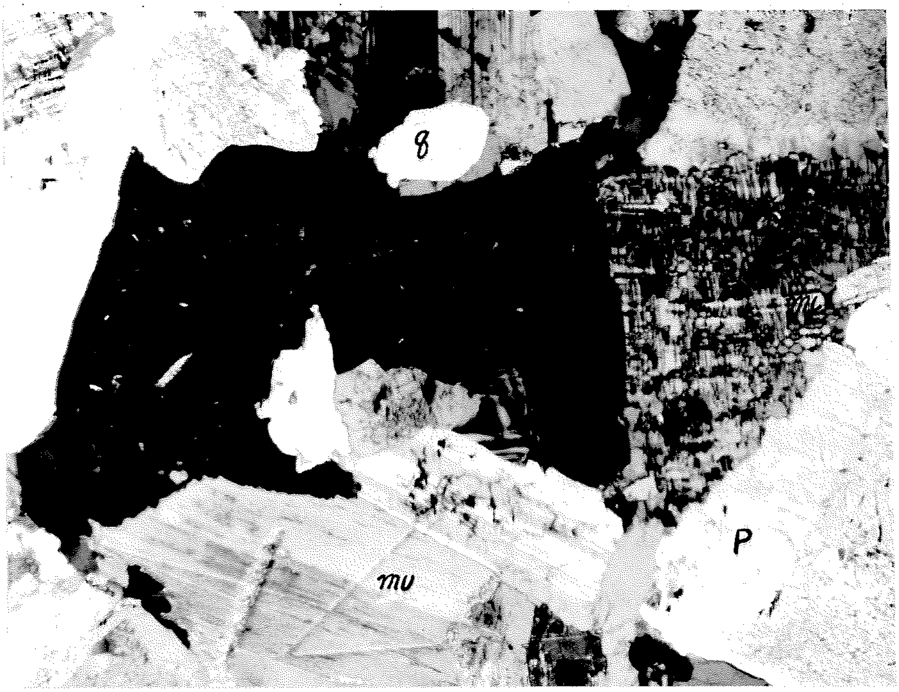


Fig. 45. Sample 356 of Unit 3 of White Tank quartz monzonite south of Forty Nine Palms. Major minerals are quartz (q), plagioclase (p), microcline (mi), and muscovite (mu). Crossed nicols, X25.

Garnet forms euhedral, equant grains with an average diameter of 0.5 millimeter. Magnetite and apatite are very rare; some small grains included in muscovite may be magnetite.

Both feldspars are lightly dusted by kaolin.

4. Unit 4, small outcrops near Anaconda Mine:

The quartz monzonite in the small outcrops near the Anaconda Mine is hereafter referred to as Unit 4. The rock is generally gray, massive, and very inequigranular. On the basis of its content of 50 percent gray potash feldspar crystals with an average length of 10 millimeters, it appears to be closely related to the upper facies of Unit 1.

Although the large grain size of the rock precludes accuracy of micrometric measurement, a modal analysis of one thin section is given below.

	78
quartz	36.2%
potash feldspar	38.4
plagioclase	24.1
biotite	1.4
accessory	0.1
total points	1139

Section 78, Fig. 46, is typical of Unit 4.

Quartz forms aggregates of undulant, fretted grains, each grain having a diameter of about 2 millimeters. Inclusions of quartz in potash feldspar are much smaller than the grains in these aggregates. Thin bands of fine grained quartz follow the border between some feldspar crystals.

Most potash feldspar grains are twinned in some portions and untwinned in others. Grains are roughly equant and anhedral. Vein perthite is abundant, but rod perthite is absent.

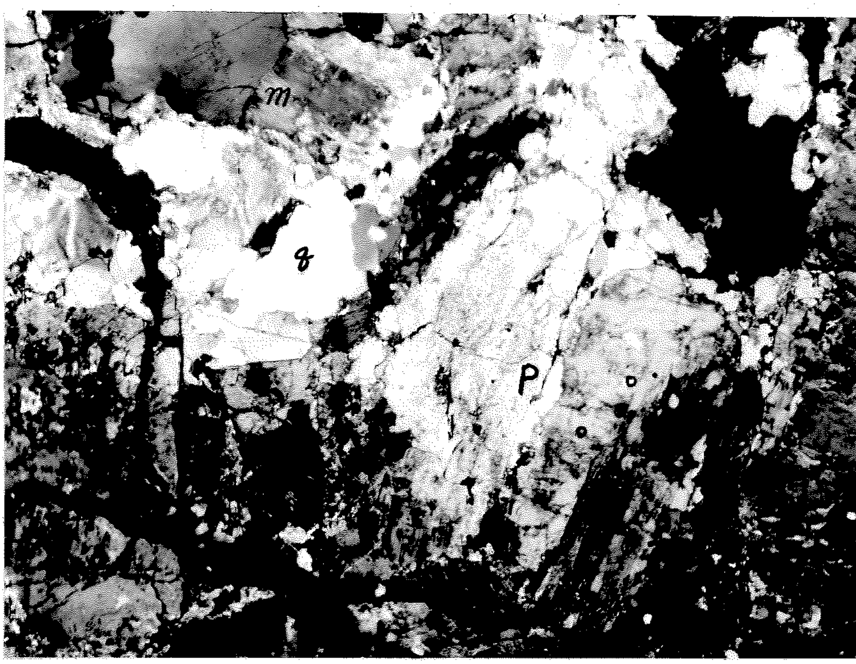


Fig. 46. Sample 78 of Unit 4 of White Tank quartz monzonite west of Anaconda Mine. Large grains are quartz (q), plagioclase (p), and microcline (m) in a groundmass of the same minerals. Crossed nicols, X25.

Plagioclase forms subhedral laths having an average length of 1.5 millimeters. All grains are twinned on the albite law and unzoned (or very faintly zoned), and have a composition of An_{25}. On the basis of relative relief, plagioclase in the perthite seems to have the same composition. In one section is an intergrowth between plagioclase (apparently An_{25}) and microcline similar to the intergrowths in the upper facies of Unit 1.

Albitic rims around the plagioclase laths are most common near potash feldspar and are best developed on inclusions in the microcline. Some rims are myrmekitic. Small irregular grains of albite are also mixed with the fine grained quartz along some intergranular borders. Albite is more abundant in Unit 4 than in the portions of Unit 1 containing plagioclase laths with a composition of An_{25}.

Biotite forms very ragged flakes, pleochroic from yellow to brown, and highly altered. Some chloritization has occurred, but most alteration products are unidentifiable, the biotite appearing simply somewhat opaque and clouded.

Magnetite, sphene, and zircon are rare accessory minerals.

White mica is an uncommon alteration product of plagioclase and also forms veinlets of tiny flakes in both feldspars; some of this mica may be primary. Kaolin forms a light dusting on both feldspars.

The fine grained quartz and albite (and a small amount of the potash feldspar) in Unit 4 comprise a groundmass which makes up approximately one fifth of the rock. This groundmass is absent from all but the border zones of other units of the quartz monzonite.

C. Summary of Major Variations:

The principal lithologic types of the White Tank quartz monzonite are distinguished by variations in mineralogical composition, trace element content of the potash feldspar, grain size, and special textures. Each of these variations is discussed below.

1. Mineralogical composition:

The most striking vertical compositional changes in Unit 1 are the following:

(1.) Increase in percentage of albite in plagioclase toward the top; concurrent increase in discrete grains and rims of albite.

(2.) Decrease in amount of mafic minerals toward the top; hornblende only in lowermost outcrops.

(3.) Increase in percentage of potash feldspar toward the top. The amount of quartz and the total amount of plagioclase remain essentially unchanged.

Unit 2 shows little vertical variation in composition or texture. A thin zone along the upper portion of the eastern contact with the Palms quartz monzonite contains fewer dark minerals and a more sodic plagioclase than the rest of Unit 2. The rim also contains garnet and primary muscovite, which are absent in the rest of the unit.

The average compositions of Units 1 and 2 are about the same.

Unit 3 is similar to the rock along the eastern rim of Unit 2. Owing to its highly albitic plagioclase and almost total lack of dark minerals, Unit 3 is more silicic than any other portion of quartz monzonite in the area. Part of the potash in Unit 3 is held in primary muscovite, and the total amount of potash in both feldspar and muscovite is about the same as in Unit 2 and the lower portion of Unit 1.

Unit 4 has about the same composition as the upper part of Unit 1, although possibly the bulk composition of plagioclase in Unit 4 is more calcic.

These variations are summarized in Figs. 47-49, showing the distribution of potash feldspar and biotite and the variation in the composition of plagioclase. All of the cross-sections are diagrammatic and not to scale.

2. Content of trace elements in potash feldspar:

By methods discussed on pages 11-19, the distribution of trace elements in potash feldspar has been determined. The variations are summarized in Figs. 51-55. Table 8 gives the results of all analyses. Fig. 50 shows the location of all samples. All of the cross-sections are diagrammatic and not to scale.

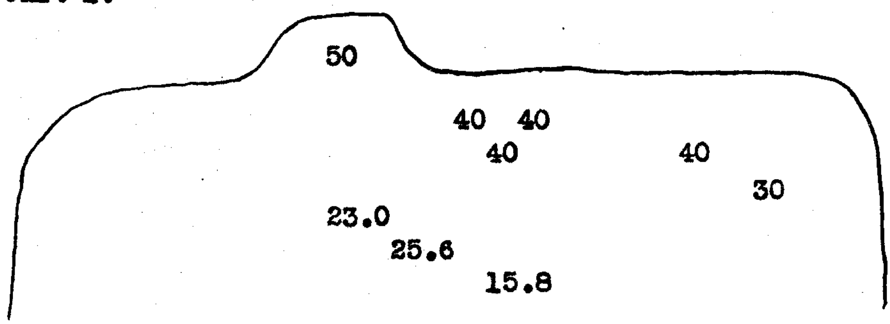
Much of the calcium in the analyzed samples may come from the plagioclase in the perthite or from contamination by large grains of plagioclase. As shown in Fig. 51, the calcium content varies erratically through the rock. The potash feldspar in Unit 3 may be low in calcium, as is the plagioclase in the same rock, but otherwise there is no noticeable pattern to the distribution of calcium. The variation between different parts of a hand specimen is generally larger than between different parts of one of the large units.

The concentration of rubidium is approximately constant through the quartz monzonite. Units 2 and 3 may contain slightly more rubidium than Unit 1, but there is no perceptible variation within one unit.

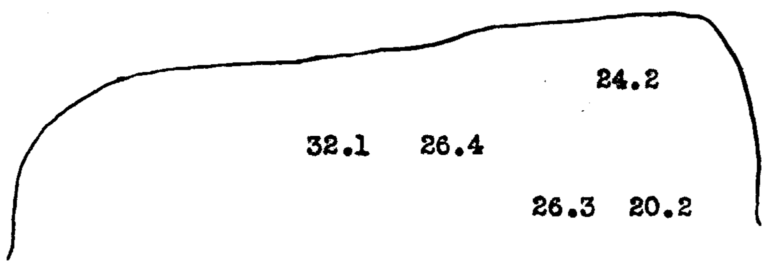
Fig. 47

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing distribution of potash feldspar

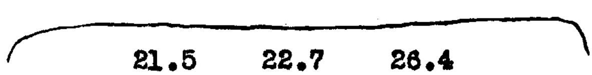
Unit 1.



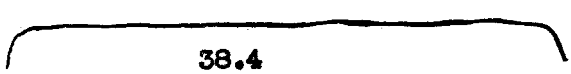
Unit 2.



Unit 3.



Unit 4.

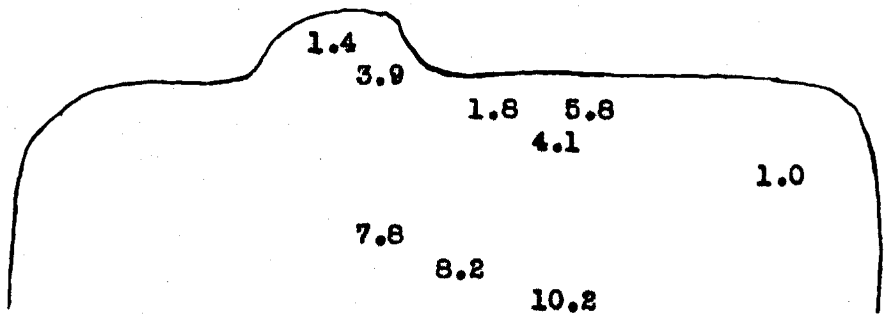


All values shown above are in percent.

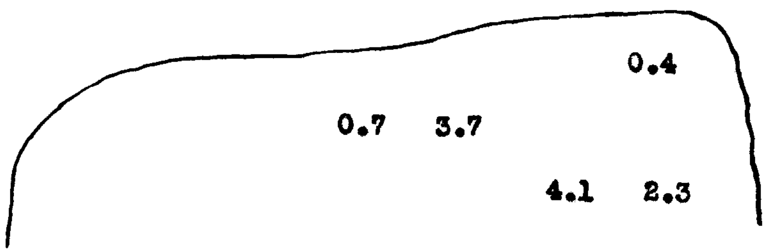
Fig. 48

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing distribution of biotite

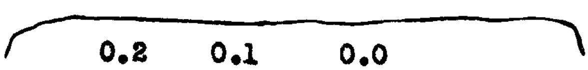
Unit 1.



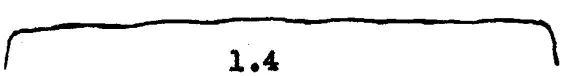
Unit 2.



Unit 3.



Unit 4.

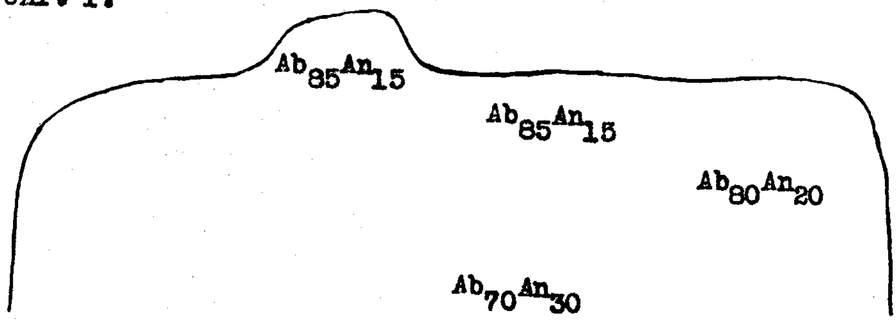


All values shown above are in percent.

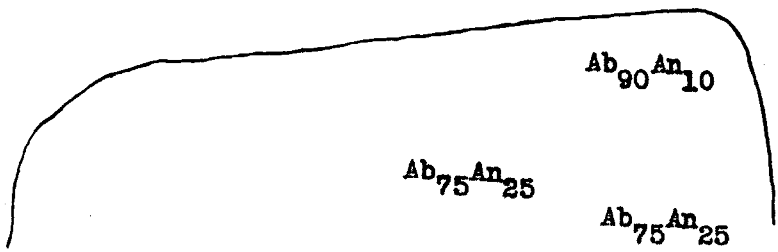
Fig. 49

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing variation in the composition of plagioclase

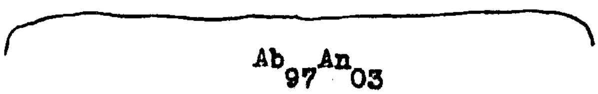
Unit 1.



Unit 2.



Unit 3.



Unit 4.

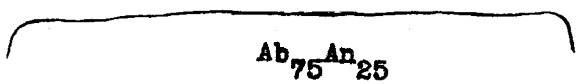
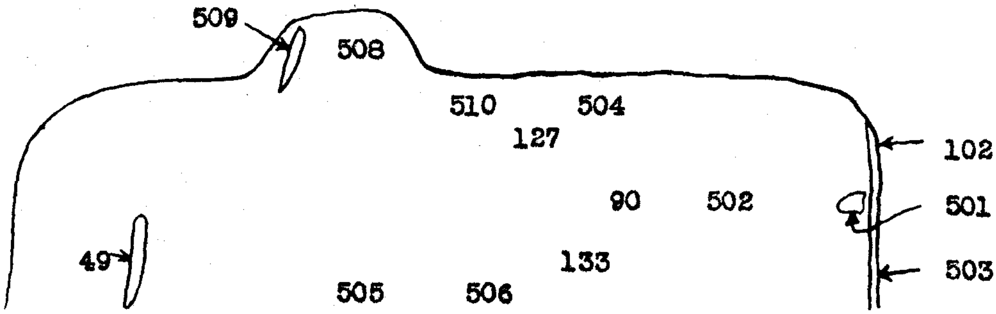


Fig. 50

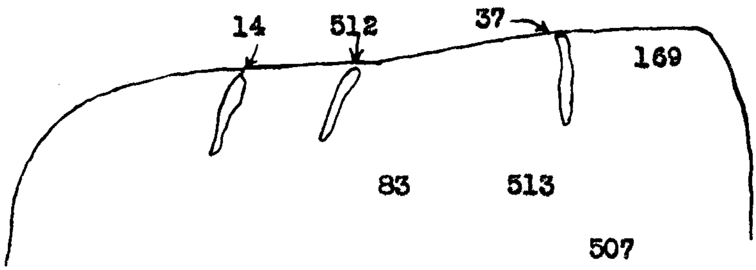
Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing locations of samples taken for spectrochemical analysis

Unit 1.



#102 and #503 are from the fine grained border.
#501 is from a pegmatitic segregation two feet from the border.
#508 is from the cupola.
#509 is from a red dike in the cupola.
#49 is from a pegmatite low in the pluton.
#510, #504, #127, #90, #502, #133, #505, and #506 are normal rock.

Unit 2.



#14 and #512 are from aplites.
#37 is from a pegmatite.
#169 is from the slightly micaceous rim.
#83, #513, and #507 are normal rock.

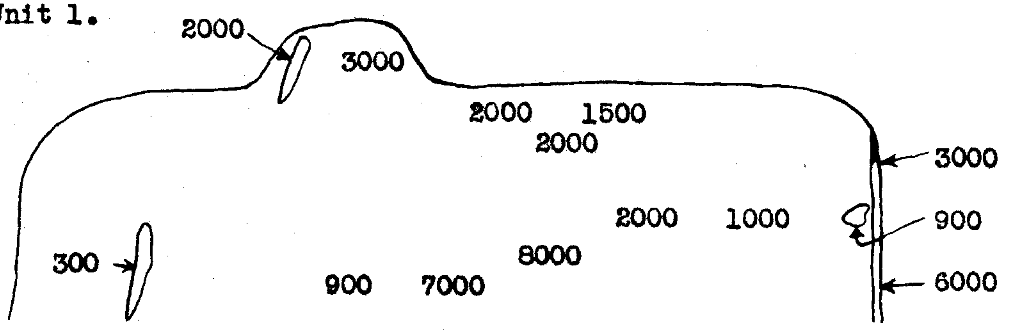
Unit 3.

#388 is from a pegmatite.
#356 and #358 are normal rock.

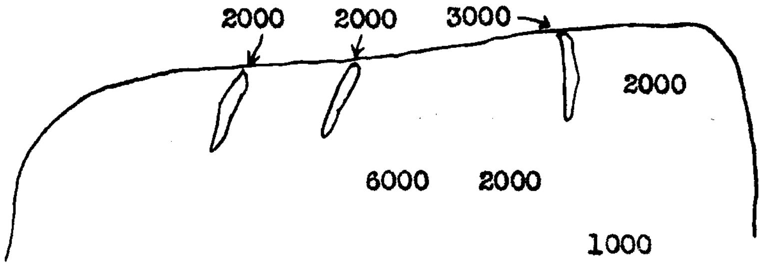
Fig. 51

Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing distribution of calcium in potash feldspar

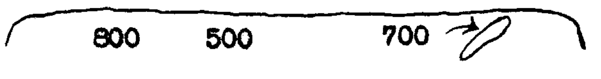
Unit 1.



Unit 2.



Unit 3.

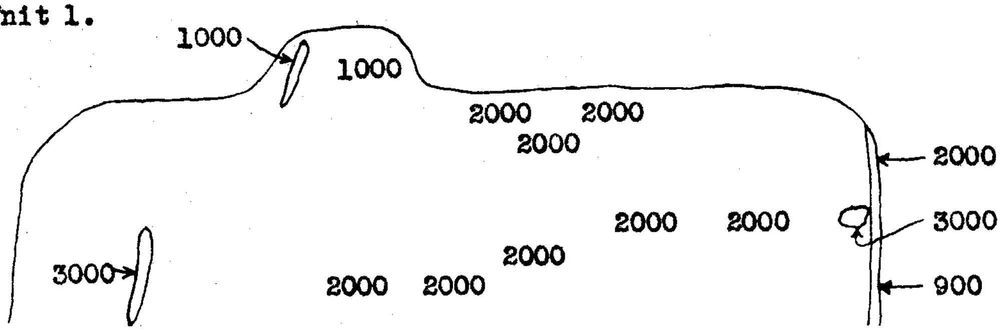


All values shown above are in parts per million.

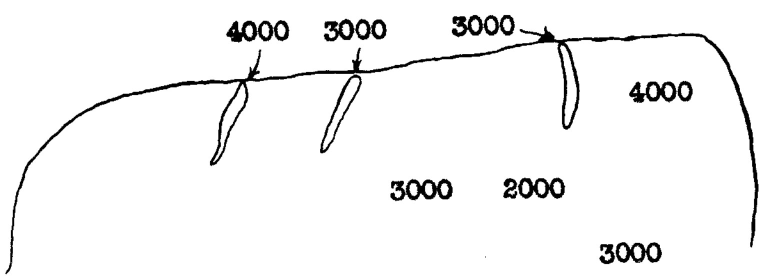
Fig. 52

Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing distribution of rubidium in potash feldspar

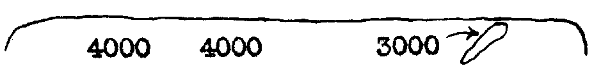
Unit 1.



Unit 2.



Unit 3.

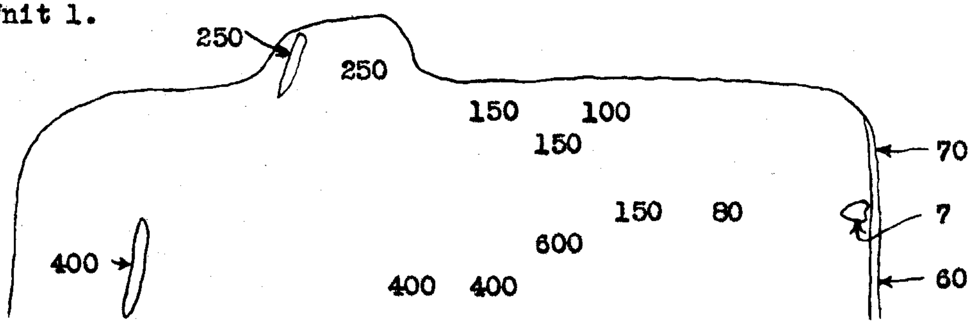


All values shown above are in parts per million.

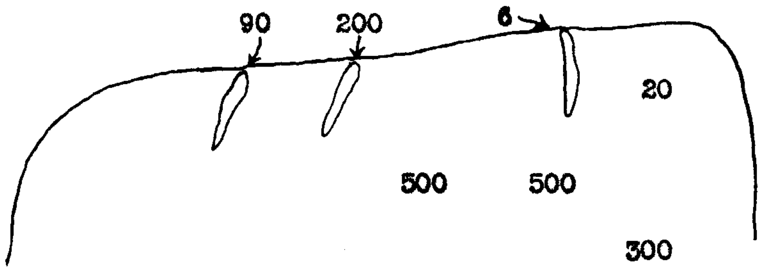
Fig. 53

Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing distribution of strontium in potash feldspar

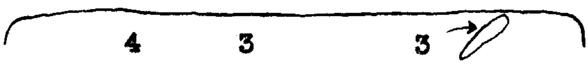
Unit 1.



Unit 2.



Unit 3.

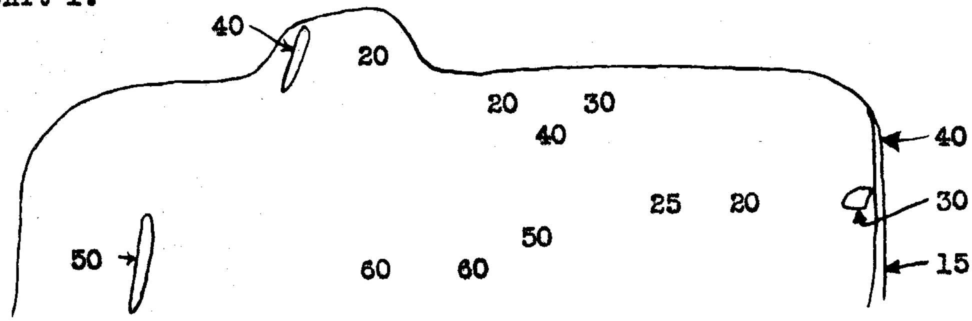


All values shown above are in parts per million.

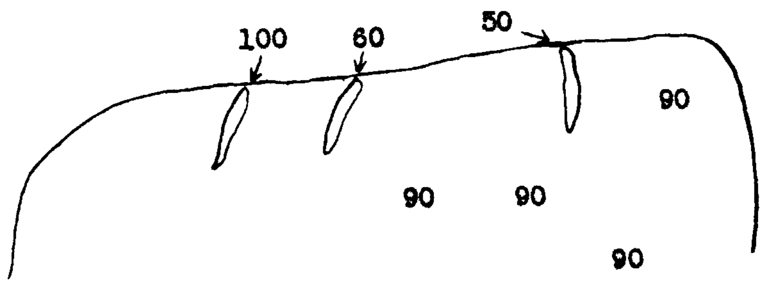
Fig. 54

Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing distribution of lead in potash feldspar

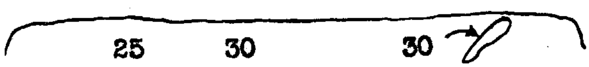
Unit 1.



Unit 2.



Unit 3.

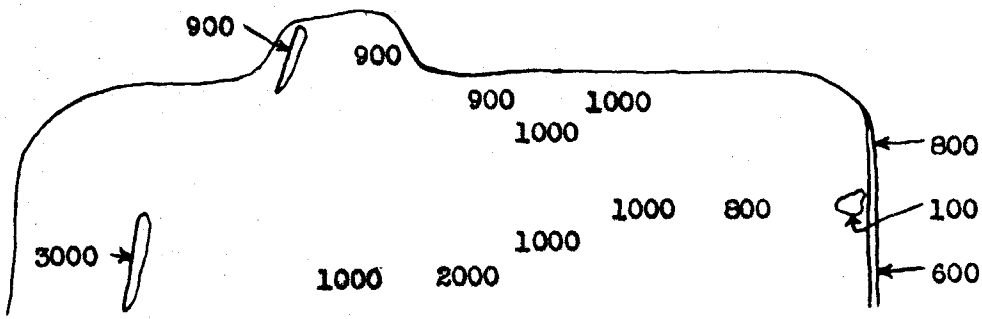


All values shown above are in parts per million.

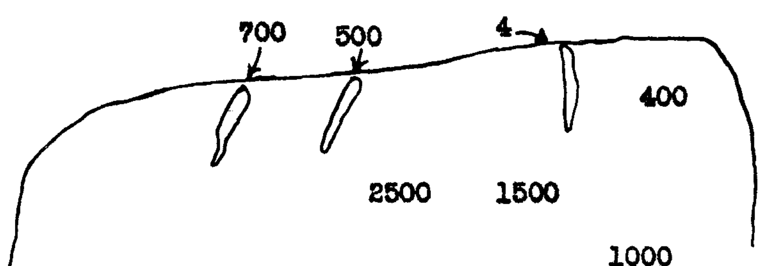
Fig. 55

Diagrammatic cross-sections of three plutons of White Tank quartz monzonite showing distribution of barium in potash feldspar

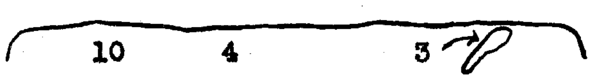
Unit 1.



Unit 2.



Unit 3.



All values shown above are in parts per million.

Table 8. Results of Spectrochemical Determinations on Samples of White Tank Quartz Monzonite:

Sample	Ba	Ca	Cu	Ga	Li	Mn	Pb	Rb	Sr	Ti	V	Y	Yb	Zr
14	700	2000	---	7	2	30	100	4000	90	60	---	---	---	15
37	4	3000	10	20	3	20	50	3000	6	20	6	---	---	---
49	3000	300	---	6	2	1	50	3000	400	20	---	---	---	---
83	2500	6000	10	8	30	10	90	3000	500	50	7	---	---	25
90	1000	2000	15	7	2	5	25	2000	150	60	7	---	---	---
102	800	3000	---	5	2	20	40	2000	70	80	---	---	trace	90
127	1000	2000	15	9	2	4	40	2000	150	70	10	---	---	---
133	1000	8000	5	8	2	8	50	2000	600	70	3	---	---	25
169	400	2000	---	7	5	30	90	4000	20	60	---	---	---	trace
356	10	800	---	8	4	30	25	4000	4	50	---	---	---	15
358	4	500	---	8	20	40	30	4000	3	40	---	---	---	10
388	3	700	---	10	3	70	30	3000	3	40	---	---	---	25
501	100	900	---	10	2	3	30	3000	7	30	---	---	---	---
502	800	1000	---	5	2	20	20	2000	80	50	---	---	---	---
503	600	6000	---	7	2	10	15	900	60	90	---	150	10	---
504	1000	1500	---	7	2	4	30	2000	100	80	---	---	---	trace
505	1000	900	---	5	2	5	60	2000	400	80	---	---	---	---
506	2000	7000	---	4	2	8	60	2000	400	80	---	---	---	---
507	1000	1000	---	6	25	20	90	3000	300	40	---	---	---	---
508	900	3000	---	6	2	2	20	1000	250	100	---	---	---	trace
509	900	2000	---	6	2	2	40	1000	250	100	---	---	---	trace
510	900	2000	---	6	2	3	20	2000	150	80	---	---	---	---
512	500	2000	---	10	3	80	60	3000	200	20	---	---	---	5
513	1500	2000	---	6	10	30	90	2000	500	60	---	---	---	trace

All values are in parts per million.
Elements looked for but not found include Ag, As, Bi, Cd, Co, Cr, Ge, In, Mo, Nb, Ni, Sb, Sc, Sn, Ta, Tl, U, W, Zn. A faintly noticeable trace of beryllium was present in some samples.

Lithium is essentially absent from Unit 1 and is erratically distributed in the other units.

The reproducibility of measurements made on gallium is so low that no conclusions may be drawn from its distribution.

Strontium is probably distributed between potash feldspar and plagioclase in the perthite, and some is undoubtedly contained in the fragments of the plagioclase laths which contaminate the samples. The distribution is roughly as follows:

(1.) In Unit 1 strontium is most concentrated in the lower portions (or perhaps a little above the base) and is less abundant near the top and margins. It is extremely rare in the pegmatitic segregation at the eastern margin but relatively abundant in the pegmatite near the base of the unit.

(2.) Strontium may be most concentrated in the central to upper portion of Unit 2 and slightly less abundant in the lowest exposed rock (in Rattlesnake Valley). The strontium concentration is lowest in the eastern rim and in the pegmatites.

(3.) Strontium is very rare in Unit 3.

The concentration of lead in potash feldspar seems to decrease upward in Unit 1 and may also be low in the marginal zone near White Tank. Unit 2 is high and Unit 3 low in lead.

Barium shows little or no vertical variation in Unit 1 except for a slight diminution in the marginal zone. The marginal zone, aplites, and pegmatites in Unit 2 have a low barium content, as does Unit 3. The pegmatite near Squaw Tank (low in Unit 1) is rich in barium.

In attempting to correlate the trace element contents and sequence of formation of potash feldspars, one great difficulty must be recognized: it is not possible to determine the sequence of formation of potash feldspars in different portions of a rock unit from the sequence of formation of minerals associated with the feldspar. Thus, although the calcic plagioclase in the lower part of Unit 1 probably crystallized before the more sodic varieties in the upper part, the potash feldspar in the two facies may have crystallized first in the upper portion and then in the lower part or may have crystallized simultaneously throughout the unit. If, however, the time of formation of potash feldspar is correlative with the time of formation of the associated plagioclase, two sequences of crystallization of potash feldspar may be deduced. Both textural and trace element data indicate that Units 1 and 2 are only remotely related, and they are discussed in separate sequences, as shown below. Unit 3 is believed to be a differentiate of Unit 2.

I. sequence of formation in Unit 1:

oldest: base of Unit 1
↓
top of Unit 1

youngest: cupola above upper facies of Unit 1

II. sequence of formation in Units 2 and 3:

oldest: central portion of Unit 2
↓
eastern rim of Unit 2

youngest:

aplites		Unit 3		aplites
pegmatites	OR	aplites	OR	Unit 3
Unit 3		pegmatites		pegmatites

The pegmatite (sample 49) near the base of Unit 1 is not included in sequence I. It contains potash feldspar with a very different trace element composition than the other pegmatite samples (37 and 512), and is apparently not a late differentiate of Unit 1. Possibly it is an earlier differentiate of the quartz monzonite or is unrelated to the quartz monzonite.

Table 9 shows the variation in trace element content of potash feldspar in relation to sequence of formation (based on the two sequences shown above).

The following general conclusions may be drawn concerning the distribution of trace elements in potash feldspar:

(1.) Lead is enriched in the earlier-crystallizing potash feldspar in both sequences.

(2.) Barium is enriched in the earlier-crystallizing potash feldspar in sequence II and shows little variation in sequence I. Perhaps the relatively low barium content of potash feldspar in the fine grained rim of Unit 1 indicates that the potash feldspar in the rim was formed very late during the crystallization of the unit, which is certainly possible if, as indicated by textural evidence given on pages 205-208, the potash feldspar in this rim formed by replacement of quartz.

(3.) Strontium may be most concentrated during the middle stages of crystallization. It is least abundant in the later-crystallizing potash feldspar in both sequences.

(4.) The concentration of rubidium either does not change throughout either sequence or shows a very slight enrichment in the later phases.

Table 9. Correlation between Trace Element Content and Age of Formation of Potash Feldspar in White Tank Quartz Monzonite:

Sequence I

Age	Sample	Ba	Pb	Rb	Sr
Oldest	505	1000	60	2000	400
	506	2000	60	2000	400
	133	1000	50	2000	600
	90	1000	25	2000	150
	502	800	20	2000	80
	127	1000	40	2000	150
	504	1000	30	2000	100
	510	900	20	2000	150
	508	900	20	1000	250
Youngest	509	900	40	1000	250

Sequence II

Age	Sample	Ba	Pb	Rb	Sr
Oldest	507	1000	90	3000	300
	83	2500	90	3000	500
	513	1500	90	2000	500
	169	400	90	4000	20
youngest; order uncertain — Unit 3	356	10	25	4000	4
	358	4	30	4000	3
	388	3	30	3000	3
Aplite	14	700	100	4000	90
	512	500	60	3000	200
Pegmatite	37	4	50	3000	6

All values of trace element concentration are in parts per million. Samples in adjoining lines are essentially synchronous; a difference in time of formation is indicated by a blank line.

Results obtained in the present study are (with certain exceptions) similar to those obtained in other work on the trace element content of potash feldspar. Nockolds and Mitchell (1948) found that both barium and strontium were most concentrated in the early-crystallizing potash feldspar (perthitic). They also found that the amount of rubidium in potash feldspar was very constant throughout much of the range of crystallization but increased markedly in the later phases; this increase is not noted in the present work. In distinction to the results obtained by the present writer, Nockolds and Mitchell found that the lead content decreased slightly from early to later feldspar but was a maximum in the latest crystals. Nockolds and Allen (1953) attributed the distribution of strontium in rock samples to an interplay between enrichment in the later phases of plagioclase and diminution in the later phases of potash feldspar.

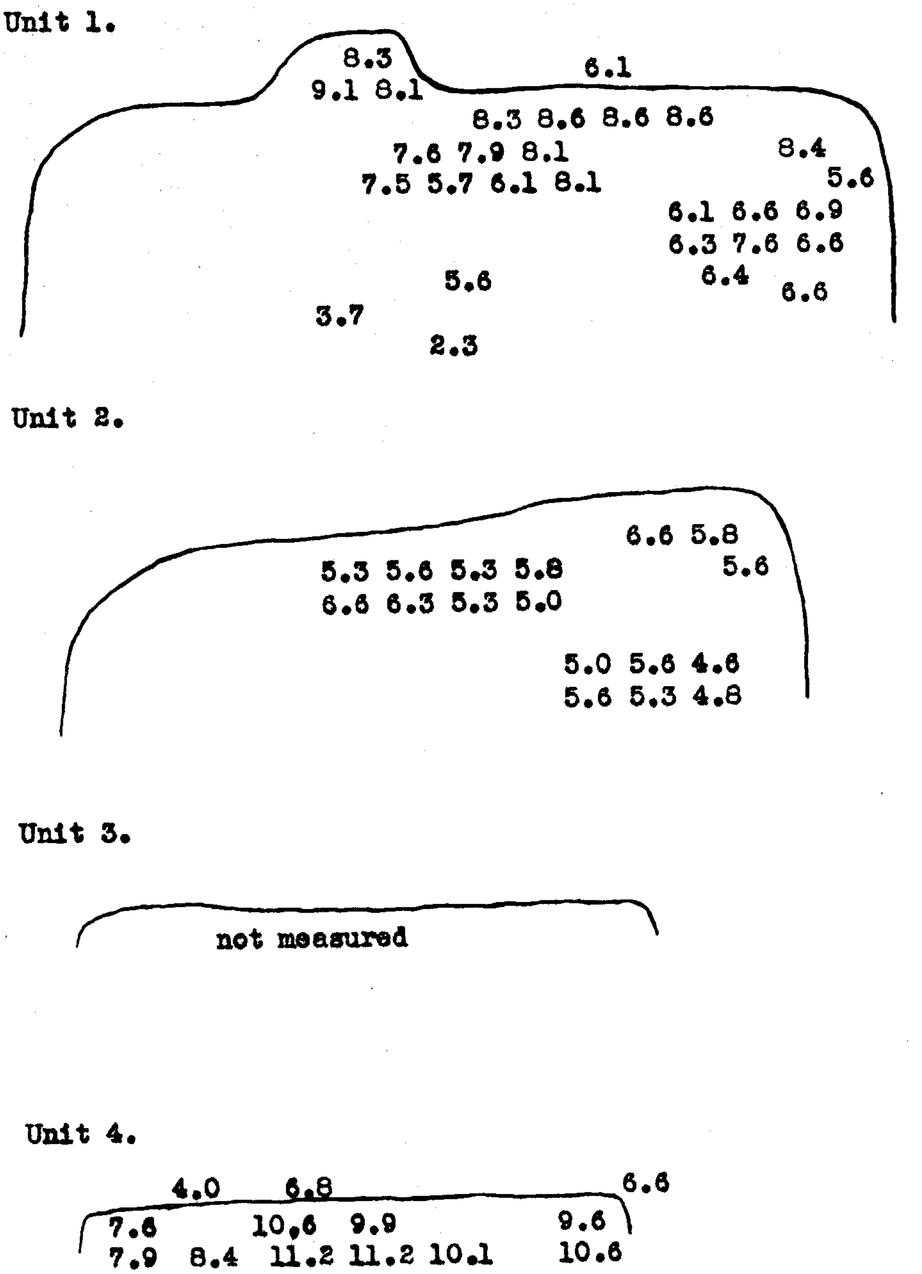
3. Grain sizes:

Figs. 56-58 show the variation in grain sizes of the major minerals in the White Tank quartz monzonite. All cross-sections are diagrammatic and not to scale. As discussed previously (page 11), the "grain size" of a mineral is the average of the maximum dimension of all grains measured in a given rock. Measurements of potash feldspar were made in the field, of quartz and plagioclase in thin section; the two types of measurements are not strictly correlative, for the potash feldspar measured in the field shows a larger grain size than the same mineral measured in thin section.

In Unit 1 the potash feldspar shows an increase in grain size upward and a slight decrease near the margins. The linear dimension

Fig. 56

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing distribution of grain sizes of potash feldspar

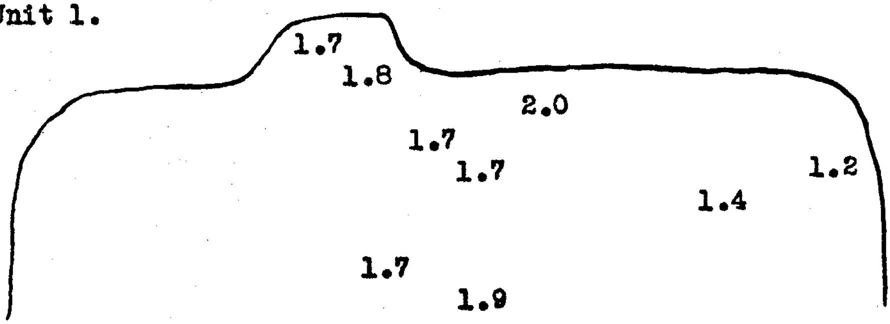


All sizes shown above are in millimeters.
Figures just outside plutons represent grain sizes in ingested rocks.

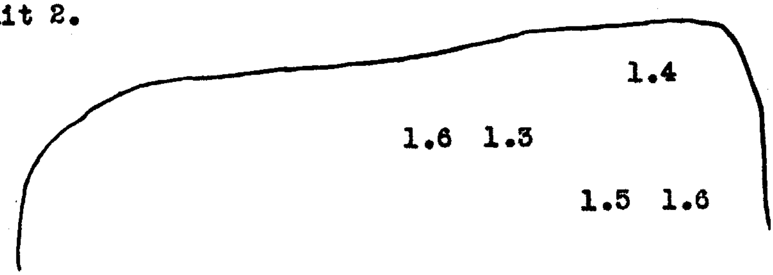
Fig. 57

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing distribution of grain sizes of plagioclase

Unit 1.

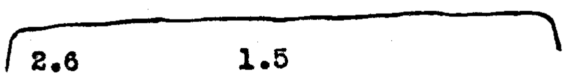


Unit 2.



Unit 3.

Unit 4.

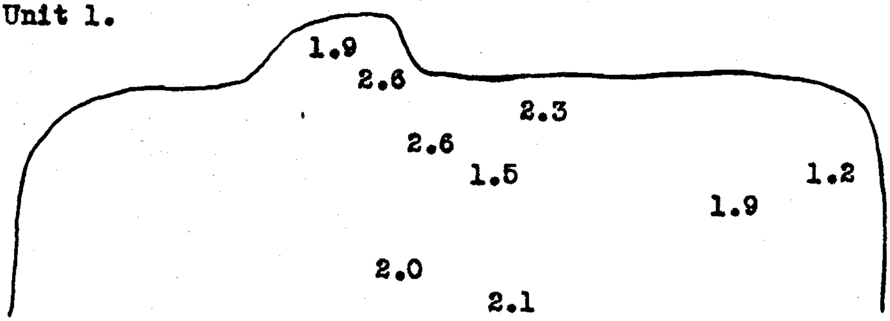


All sizes shown above are in millimeters.

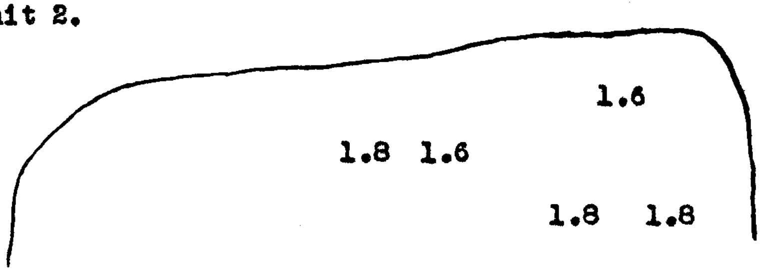
Fig. 58

Diagrammatic cross-sections of four plutons of White Tank quartz monzonite showing distribution of grain sizes of quartz

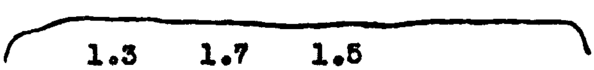
Unit 1.



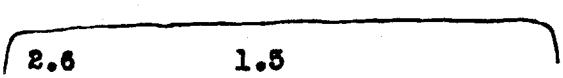
Unit 2.



Unit 3.



Unit 4.



All sizes shown above are in millimeters.

of the grains almost triples from bottom to top (thus multiplying the area of each grain on the outcrop by nine). The percentage of potash feldspar (measured by a point count of the area covered by the mineral on the outcrop) only triples from bottom to top, however, and thus the number of grains of potash feldspar per unit area decreases from bottom to top. This conclusion as to the variation in number of grains is also verified by counts of the number of grains in a given area of outcrop at various places in the unit.

Except in local zones near the contacts, there is no change in the sizes of plagioclase or quartz throughout Unit 1.

The sizes of all minerals in Unit 2 are generally smaller than in Unit 1. Except in very local areas (such as in and around pegmatitic vugs), the grain sizes are constant throughout the unit.

Grain sizes of quartz and plagioclase in Unit 3 are approximately the same as in Unit 2. In Unit 3 the potash feldspar is white (the same color as plagioclase) and fine grained (two millimeters average maximum dimension in thin section); both the lack of color and the small grain size make accurate measurement of the feldspar impossible in the field.

The coarsest potash feldspar occurs in Unit 4, and the grain size may be larger in the center than near the margins. Conversely, the quartz and plagioclase appear to be larger near the margins than in the center of the unit.

4. Special textures:

a. Features related to plagioclase:

In addition to the large, subhedral laths of oligoclase, the White Tank quartz monzonite commonly contains a second plagioclase with the composition of pure albite. This albite never amounts to more than 10 percent of the plagioclase, except in Unit 4, but it forms a distinct phase easily separable from the plagioclase laths. In addition, a third phase, intermediate in composition to the oligoclase and albite, forms irregular intergrowths with microcline in the upper part of Unit 1. Albite is generally unaltered, but the other types of plagioclase are commonly sericitized. The various textures formed by plagioclase are described below.

(1.) Relations between twinned and zoned plagioclase laths:

Many oligoclase grains in the White Tank quartz monzonite are faintly zoned, the centers being more calcic than the rims. A common compositional range is An_{30} to An_{20} with abundant oscillations. The sodic plagioclase in the upper part of Unit 1 shows little zoning, and the nearly pure albite in Unit 3 is unzoned.

The percentage of twinned versus untwinned grains generally is higher for the more sodic plagioclase (with the exception that the fine grained, apparently pure, albite is untwinned). Most twinning is on the albite law, but some of the more calcic grains also show pericline twinning. In some zoned grains, the outer, more sodic zones are twinned, whereas the inner zones are untwinned.

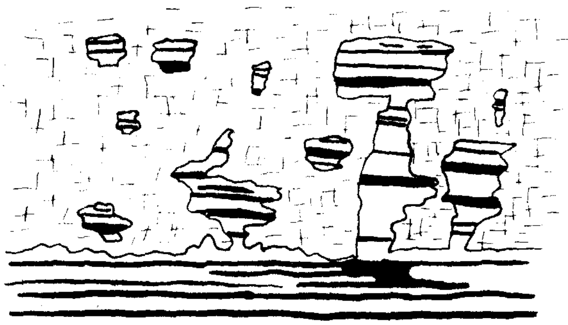
Thus, it appears that twinning and zoning are, to a certain extent, mutually exclusive. This relation was noticed by Emmons (1951), who concluded that twins form as a result of late-stage recrystallization of earlier, magmatic, zoned grains. The present writer feels, however, that such an interpretation requires an inordinately large amount of recrystallization in granitic rocks throughout the world (for twinned plagioclase is very common). It seems more reasonable to interpret twinning as a simple growth feature especially characteristic of the more sodic plagioclase.

(2.) Intergrowths with potash feldspar:

In the upper portion of Unit 1 large microcline crystals characteristically form complex, oriented intergrowths with calcic albite or sodic oligoclase (Fig. 59). Part of the plagioclase may occur as isolated, oriented patches throughout the microcline, although if the third dimension could be seen, these patches might be shown to be connected. Individual twin lamellae cannot be traced from one patch to the next in line. Albitic rims and myrmekite are both absent from this type of plagioclase. The fact that individual twin lamellae are not continuous from one patch to another (over distances within which they are generally continuous in the large plagioclase laths), plus the fact that no plagioclase grains in this portion of the rock are as large as the microcline, indicates that the intergrowths did not form by replacement of plagioclase by microcline. There is no evidence for the replacement of microcline by plagioclase. Thus, it seems logical to assume that the intergrowths formed by simultaneous crystallization of microcline and plagioclase resulting in the formation of the interpenetrating crystals.

Fig. 59

Sketch of oriented intergrowth of microcline and plagioclase



1 mm.

(3.) Perthite:

Rod perthite is uncommon in the White Tank quartz monzonite, the few examples being restricted to Unit 2 or the lower portions of Unit 1. As determined by measurement of relative relief in thin section, the composition of the plagioclase is equal to or more sodic than that of the outer zones of the plagioclase laths with which the perthite is associated. Thus, a typical composition is An_{10}, with some as calcic as An_{20}.

A type of perthite best described as vein perthite in Alling's classification is widespread throughout the quartz monzonite. The plagioclase is untwinned and occurs as very irregular stringers with no apparent orientation within the potash feldspar crystal. Composition of the plagioclase apparently ranges from An_{15} to An_{00}.

In the upper part of Unit 1 the intergrowths between plagioclase and microcline appear as one type of vein perthite (Fig. 60) characterized by excellent twinning of the plagioclase. The composition of the plagioclase ranges from An_{10} to An_{05}.

The origin of these various forms of perthite is unknown. As indicated in the previous section, the intergrowths appear to be the result of simultaneous crystallization. Although some veining by albite has probably occurred (as shown by patches of albite localized around inclusions of quartz in potash feldspar), much of the more calcic, untwinned, vein perthite may have formed by exsolution. It is not certain whether the form of the plagioclase in the perthite (e. g., vein, rod, etc.) or the composition of the plagioclase is a more significant indication of mode of formation.

Fig. 60. Perthitic intergrowth between microcline and plagioclase in sample 85 of upper facies of Unit 1 of White Tank quartz monzonite. Crossed nicols, X25.

(4.) Textures involving albite:

Three types of texture are formed by albite: rims around plagioclase laths; small, irregular grains around potash feldspar; and myrmekite.

Many of the oligoclase laths are partially bordered by a distinct rim of albite. Generally, but not exclusively, the albitic rims occur only between oligoclase and potash feldspar, and the thickest rims occur around inclusions of plagioclase in potash feldspar. Inclusions of quartz may also be surrounded by albite (section 13, Fig. 43). The albite and oligoclase invariably show the same crystallographic orientation, twin lamellae in the host grain extending without interruption into the rim. Some rims are untwinned.

Many small, untwinned grains of albite (section 122, Fig. 61) occur around the borders of some potash feldspar grains. In some places they seem to extend as a band through the host feldspar. Rarely, albite grains may not adjoin potash feldspar, at least as seen in thin section. These grains show no constant orientation with regard to surrounding minerals.

Most of the myrmekite in the White Tank quartz monzonite consists of small elongate blebs of quartz in albitic rims around plagioclase laths (section 83, Fig. 62).* The long axes of these blebs are commonly oriented normal to the rim, and the blebs seem to increase in thickness

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* A few laths of oligoclase are myrmekitic where they contact potash feldspar. Quartz blebs show no orientation but are restricted to the outer portion of the grain. The plagioclase is the same in both the myrmekitic and non-myrmekitic portions even though there is a sharp border between the two areas.

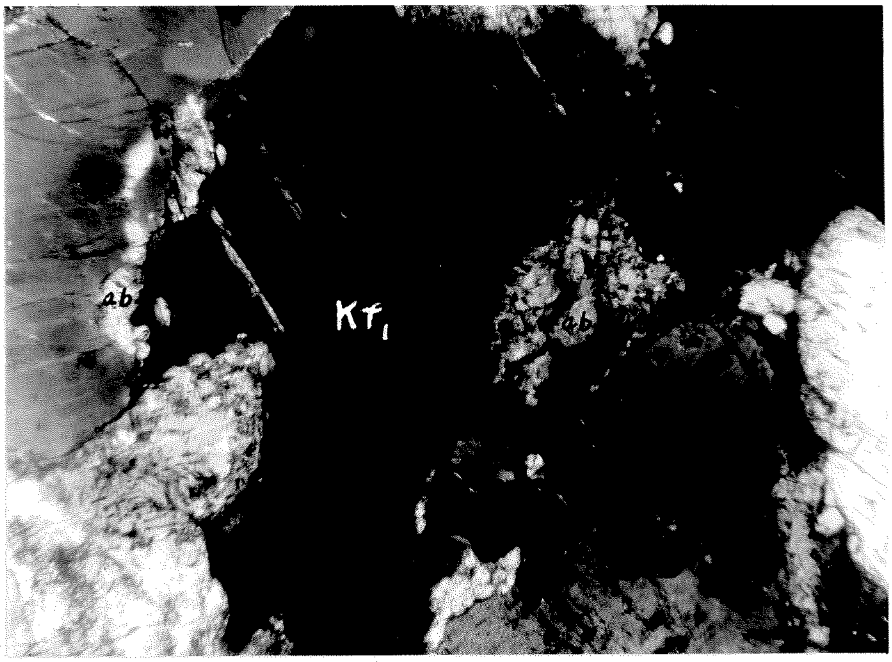

Fig. 61. Small grains of albite (ab) around potash feldspar (Kf) in sample 122 of Unit 2 of White Tank quartz monzonite. Crossed nicols, X65.

Fig. 62. Myrmekitic rim of albite on plagioclase lath next to potash feldspar. From sample 83 of Unit 2 of White Tank quartz monzonite east of Cap Rock. Crossed nicols, X65.

outward. A rough estimate suggests that about one out of every four rims is myrmekitic. Albitic rims around inclusions of plagioclase in potash feldspar are rarely myrmekitic, and around inclusions of quartz are not myrmekitic.

Myrmekite is generally considered to have formed by replacement of potash feldspar by plagioclase, although Drescher-Kaden (1948), stated that it might form by replacement of plagioclase by microcline. In both cases, the amount of myrmekitic quartz formed is considered to be proportional to the anorthite content of the plagioclase, and there does not seem to be any mechanism whereby free quartz could be generated by albitization of potash feldspar. The rims and fine grains of albite would also be considered, by most petrologists, to have formed by replacement.

Before any replacement hypothesis for the formation of the albitic rims and their associated myrmekite can be adopted, several questions must be answered: 1, if the albite replaced microcline, what possible origin is there for the quartz in the myrmekite?; also, why is myrmekite not associated with albitic rims around quartz inclusions in potash feldspar, and why is myrmekite rarely, if ever, found in perthite which shows as much evidence of having formed by replacement as is shown by the albitic rims?; 2, if the albite replaced plagioclase, why are nearly all of the rims next to potash feldspar, and why are not all rims myrmekitic?; 3, if potash feldspar replaced plagioclase, what mechanism could cause the formation of albitic rims, and why are not all of these rims myrmekitic?.

Tuttle (1952) has suggested that some albitic rims on plagioclase next to potash feldspar may have formed by exsolution of albite from the potash feldspar. There are three objections to this hypothesis: 1, how could such a mechanism form myrmekite?; 2, why are not all (instead of just most) rims and small grains of albite next to potash feldspar?; 3, why should the exsolved albite occur mainly along the border between potash feldspar and plagioclase and be almost absent from other borders of potash feldspar?.

A logical hypothesis for the origin of the albite and its associated myrmekite is that all of the textures formed by the albite are the result of primary crystallization. Take, for example, plagioclase of composition An_{30} or more sodic in equilibrium with a melt of nearly pure albite: any factor which would cause non-equilibrium crystallization in this mixture of solid and liquid would cause the formation of albite as a second plagioclase. According to Dr. R. H. Jahns (personal communication), crystallization in the sodic portions of the diopside-albite-anorthite system may completely remove anorthite from the melt and leave a fluid phase consisting solely of $NaAlSi_3O_8$ and $CaMg(SiO_3)_2$. If the fluid phase consists only of two components, eutectic crystallization might then occur and the resulting solid phases would be diopside, albite, and calcic plagioclase (the calcic plagioclase having previously formed during cotectic crystallization). If diopside acts solely as a third component without any special action of its own, then potash feldspar (in a highly fluid system so that it would crystallize separately from albite) might act in the same way as diopside and thereby promote the formation of pure albite in the presence of solid plagioclase. Thus, the final solid phases formed by crystallization of a highly water-rich system of potash feldspar, albite, and anorthite (with an Ab/An ratio of approximately 3:1 as in the total White Tank quartz monzonite) would be potash feldspar, oligoclase, and albite.

In the final stages of crystallization of the White Tank quartz monzonite, the fluid probably consisted largely of potash feldspar, albite, quartz, and a presumably high percentage of water. Crystallization of such a fluid would probably result in the addition of more potash feldspar to the already-growing microcline grains, formation of rims of albite on plagioclase as oriented overgrowths, and in areas where the crystallization was particularly rapid or where there was a fortuitous excess of quartz, simultaneous growth of quartz with one of the other minerals. Support for this theory is shown by the following evidence: 1, albite and myrmekite are far more abundant in the upper portions of Unit 1 than in the lower portions*; this fact correlates with the previously demonstrated enrichment of water and residual fluids upward in the unit; 2, quartz blebs in the myrmekitic rims grow perpendicularly to the surface of the plagioclase laths and enlarge outward as they grow; both features are typical of growth from solution; 3, although most quartz forms in the albite, some graphic textures are formed in the outer portions of potash feldspar grains.

The absence of albitic rims from many, but not all, of the borders of plagioclase grains not in contact with potash feldspar indicates

* Mackie (1909) reported a higher concentration of myrmekite (he called it a type of micropegmatite) in the more silicic rocks.

that growth of potash feldspar promotes a simultaneous growth of albite nearby. Many theories of crystal growth consider that preservation of new nuclei takes place most readily in the vicinity of a growing crystal of similar structure, and the albite and microcline lattices are similar enough that they might promote each other's growth. Small grains of albite scattered interstitially through the rock may have formed by a similar process of primary growth.

The irregular distribution of myrmekite (present in only about one fourth of the albitic rims) seems more easily accounted for by fortuitous fluctuations in the quartz content of solutions undergoing primary crystallization than it is by any mechanism of replacement. Myrmekitic portions of the plagioclase laths may also have formed by primary crystallization from a fluid.

Albitic rims around inclusions of quartz in potash feldspar and some types of vein perthite may have formed by replacement. As mentioned previously, they are not myrmekitic. The reason why potash feldspar should be replaced, indicating that it was out of equilibrium with the environment, without the formation of another potassium-bearing mineral is not obvious. Perhaps the increase in water content of the remaining fluid causes the following hypothetical reaction to shift toward the right:

$$\text{potash feldspar} + \text{plagioclase} \xrightarrow{H_2O} \text{sericite} + \text{albite} + \text{epidote}$$

b. Twinning in potash feldspar:

Though a grain of potash feldspar with well-developed grid twinning (and a large 2V) is undoubtedly microcline, one without twinning may have any of several crystal structures. Thus, although untwinned potash feldspar is generally called orthoclase, it may be untwinned or sub-microscopically twinned microcline, and in this thesis the non-committal term "potash feldspar" is used.

Untwinned potash feldspar is most common in the lower portion of Unit 1 and throughout Unit 2. Some grains contain thin bands, irregular patches, or borders, of twinned microcline, and all parts of the quartz monzonite contain some grains which are completely twinned microcline. Microcline is most abundant in the upper part of Unit 1 and in Unit 3; thus it is associated with the more sodic plagioclase and with the irregular, oriented intergrowths of the two feldspars. Potash feldspar in pegmatites invariably shows grid twinning, but in aplites it is untwinned. Perhaps the formation of twinned microcline rather than untwinned potash feldspar is promoted both by low temperature and the presence of water.

c. Clusters of minerals:

(1.) Mafic minerals:

The early-forming, basic minerals and the accessory minerals commonly form aggregates of several grains (section 6, Fig. 63). Clusters, averaging five millimeters in diameter, of a dozen or so flakes of biotite with 5 to 10 euhedrons of magnetite and apatite are scattered randomly through the rock. Rarely is there any mutual orientation among the grains even though some of the accessory minerals may be

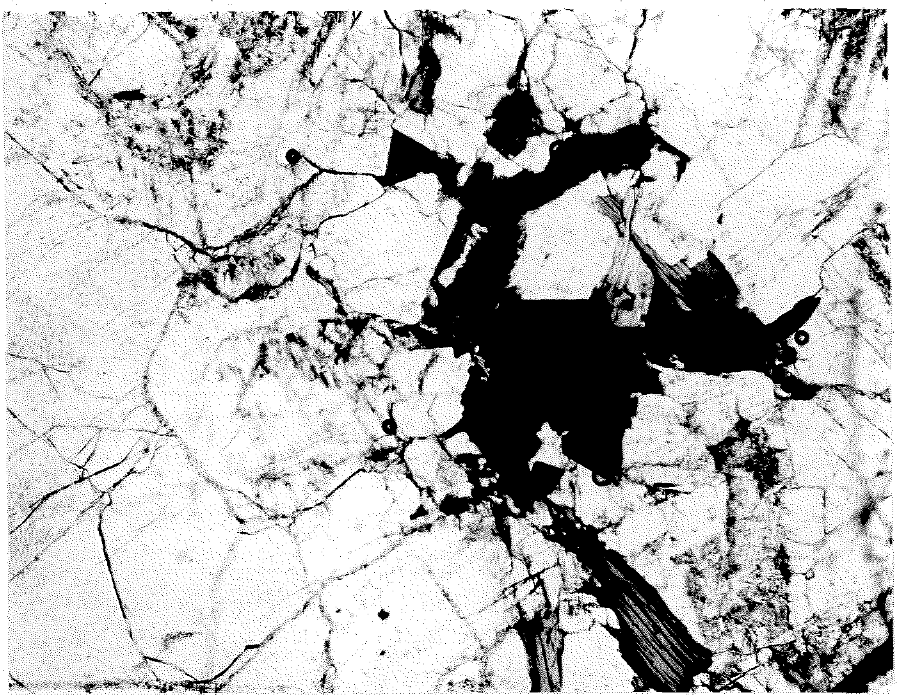

Fig. 63. Cluster of biotite and magnetite grains in sample 6 of Unit 2 of White Tank quartz monzonite. Plain light, X25.

included in the biotite. In many cases the grains do not touch each other but merely form a small patch uncommonly rich in mafic minerals.

(2.) Quartz:

Throughout all but the margins of the quartz monzonite, about three fourths of the quartz forms aggregates of 10 to 20 undulant, fretted grains (section 6, Fig. 64). There is a great deal of interpenetration among the grains but no mutual orientation. The remaining one fourth of the quartz in the central portion of the quartz monzonite intrusions is in individual, interstitial grains very irregularly warped around feldspar. In the margins, the aggregates are absent, and all quartz forms interstitial grains.

The aggregation of interpenetrating grains is, presumably, caused by preservation of many nuclei in one area. During subsequent growth each small grain touches, and interferes with, its neighbors, thus forming highly sutured and interpenetrating boundaries. Inasmuch as growing crystals may tend to promote the growth of other nuclei around themselves*, the formation of these aggregates by a process of simultaneous growth of many grains seems most reasonable. The conditions under which the nuclei will be preserved as new crystals rather than be redissolved or incorporated as a new layer in the adjoining crystal are not well understood. The aggregates cannot represent recrystallized portions of the gneiss, for they are absent in the border phases of the quartz monzonite.

The origin of undulant extinction in quartz is uncertain. There is no evidence to indicate that it is the product of stress undergone

* This phenomenon is reported by Anscheles (1936), page 154. It is not, however, substantiated.

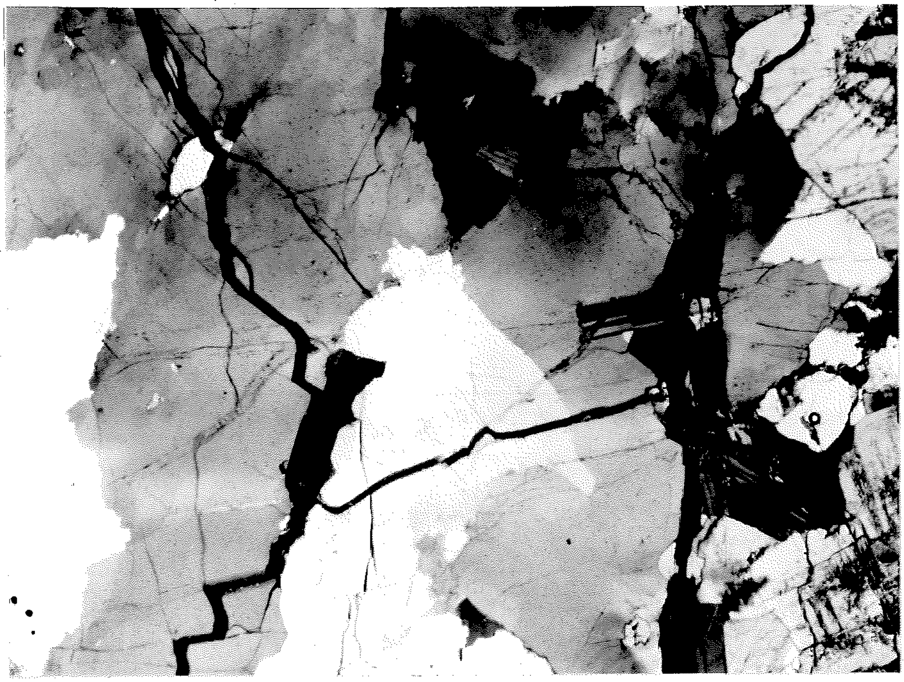

Fig. 64. Aggregate of quartz grains in sample 6 of Unit 2 of White Tank quartz monzonite. Crossed nicols, X25.

by the rock. It has been suggested that mosaic structure is produced by inversion from the high to the low temperature form of quartz.* This inversion is accompanied by fracturing; the writer can see no difference in the amount of fracturing of undulant and non-undulant quartz, but this is not surprising in such a disaggregated rock.

D. <u>Features Related to Contacts</u>:

The quartz monzonite shows six different types of contact zones, partly related to the nature of the wall rock, partly to position in the intrusion, partly to the type of quartz monzonite (different units or different facies may have slightly different contacts), and partly to unknown causes.

1. Fine grained borders:

Along the eastern border of Unit 1, where the quartz monzonite is in contact with highly quartzitic gneiss, the rock is much finer grained than it is at equivalent heights in the center of the unit. A section across the border near White Tank shows the following zones:

(1.) At the contact is a white, fine grained, equigranular zone, approximately one inch wide, with knife-edged contacts against both the gneiss and the rest of the quartz monzonite. A modal analysis of section 102 (Fig. 65), which is typical of the rock, gave the following results:

[See page 197]

* Wright and Larsen (1909) describe some changes which occur in quartz crystals upon passing through the inversion point.

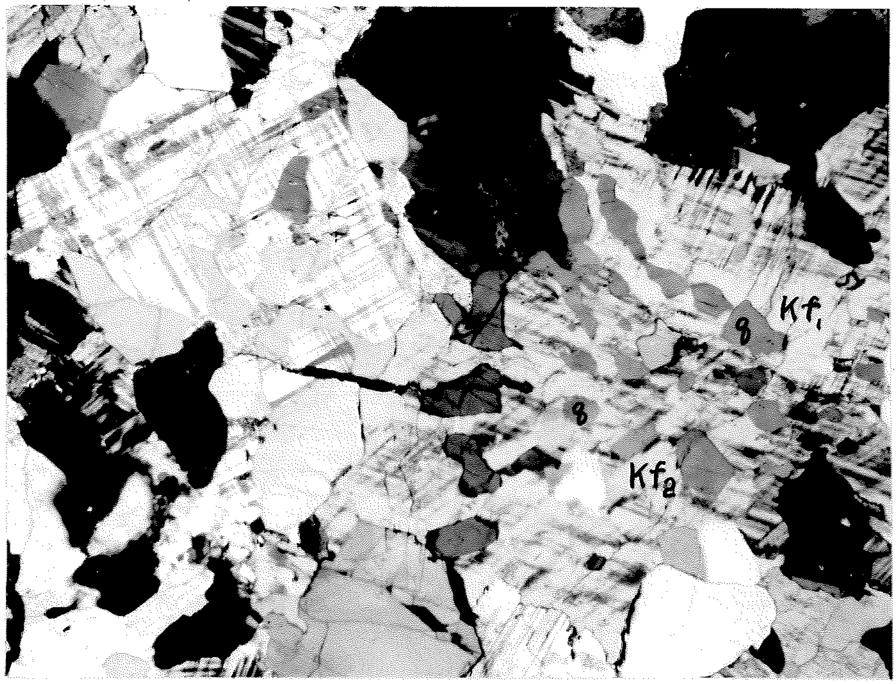

Fig. 65. Sample 102 of eastern edge of Unit 1 of White Tank quartz monzonite. Graphic quartz grains (q) have the same orientation in two adjacent grains of potash feldspar (Kf_1 and Kf_2). Crossed nicols, X25.

	102
quartz	35.6%
potash feldspar	35.7
plagioclase	27.7
biotite	0.9
accessory	0.2
total points	1034

The characteristic feature is a graphic texture in which 0.25-millimeter-sized blebs of quartz are scattered through both microcline and plagioclase. Quartz blebs may have an identical orientation over five to six millimeters* and may show the same orientation in several adjacent, unoriented grains of microcline. Non-graphic quartz, occurring as equant anhedrons, has an average diameter of 0.5 millimeter. None of the quartz exhibits undulant extinction. Almost all of the potash feldspar is microcline, which forms anhedral grains having an average diameter of 1.0 millimeter and a maximum of 4 (as measured in thin section). Plagioclase forms subhedral, twinned, unzoned laths with an average length of 1.0 millimeter and a composition of An_{20}. Plagioclase in the irregular or vein perthite has the same composition as the laths. Small irregular grains of albite are scattered around the borders of some microcline, and albitic, partly myrmekitic, rims are common. Rare biotite and accessory minerals are scattered through the rock.

(2.) The quartz monzonite next to the fine grained rim is gradational over about 500 feet from a relatively fine grained rock near

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* This is much larger than any quartz in the adjacent gneiss, indicating that this quartz is not a remnant from the partially replaced gneiss. There is no increase in the size of quartz grains in the gneiss caused by recrystallization at the contact.

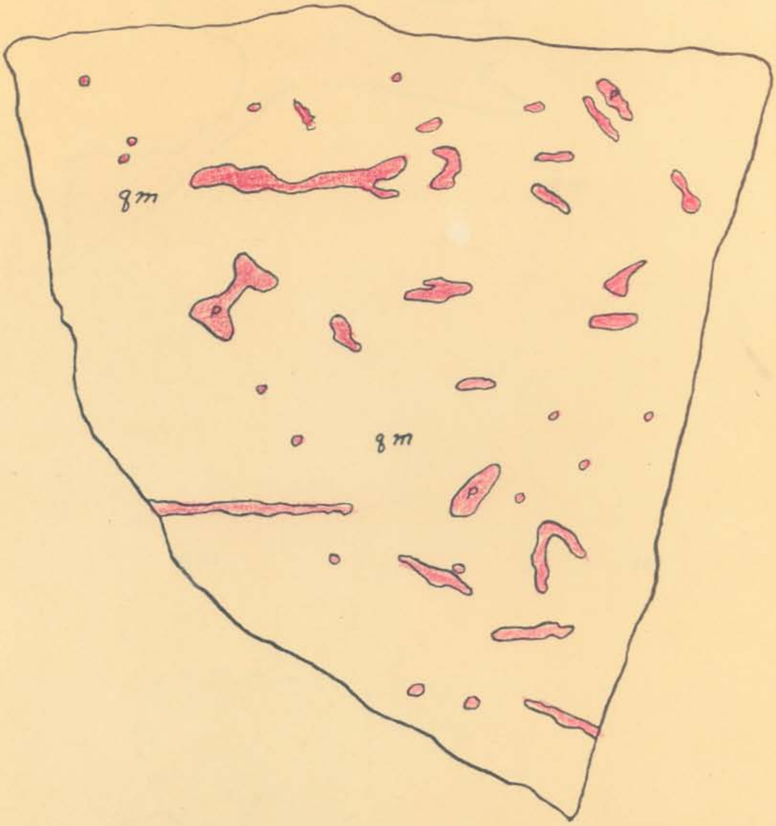
the contact into rock apparently typical of its height in the unit. About 10 feet from the contact the average size of all minerals is about 1 millimeter, with microcline ranging up to 2 millimeters. The average grain sizes 500 feet from the contact are these: quartz, 1.9 millimeters; plagioclase (An_{20}), 1.4 millimeters; and microcline, 6.5 millimeters. The percentage of quartz in aggregates as opposed to individual grains increases inward, and 500 feet from the contact most of the quartz is in aggregates.

(3.) Scattered randomly along a zone 5 to 10 feet from the contact are small, isolated patches of pegmatite (Fig. 66), most of which are roughly spherical and have a diameter of less than one foot. These pegmatites consist almost entirely of quartz and microcline. Borders with the surrounding quartz monzonite are irregular and somewhat gradational as seen in thin section, but appear abrupt and easily distinguishable in hand specimen. Quartz may be slightly more concentrated near the center, but zoning is not obvious, possibly owing to the small size of the pegmatite.

A contact east of Stirrup Tank (Fig. 67) is very similar to the one described above. The gneiss is light tan and consists mainly of quartz and microcline. Sample 98 is from a thin band almost identical to the fine grained rim east of White Tank (sample 102). Some anhedral quartz grains (up to five millimeters in diameter) next to the gneiss are irregularly intergrown with microcline and plagioclase. As shown by Table 10, the percentage of quartz decreases inward from the contact, the percentage of potash feldspar increases, and the grain size increases.

Fig. 66

Sketch of pegmatitic segregations in White Tank quartz monzonite a few feet from contact with quartzitic gneiss east of White Tank

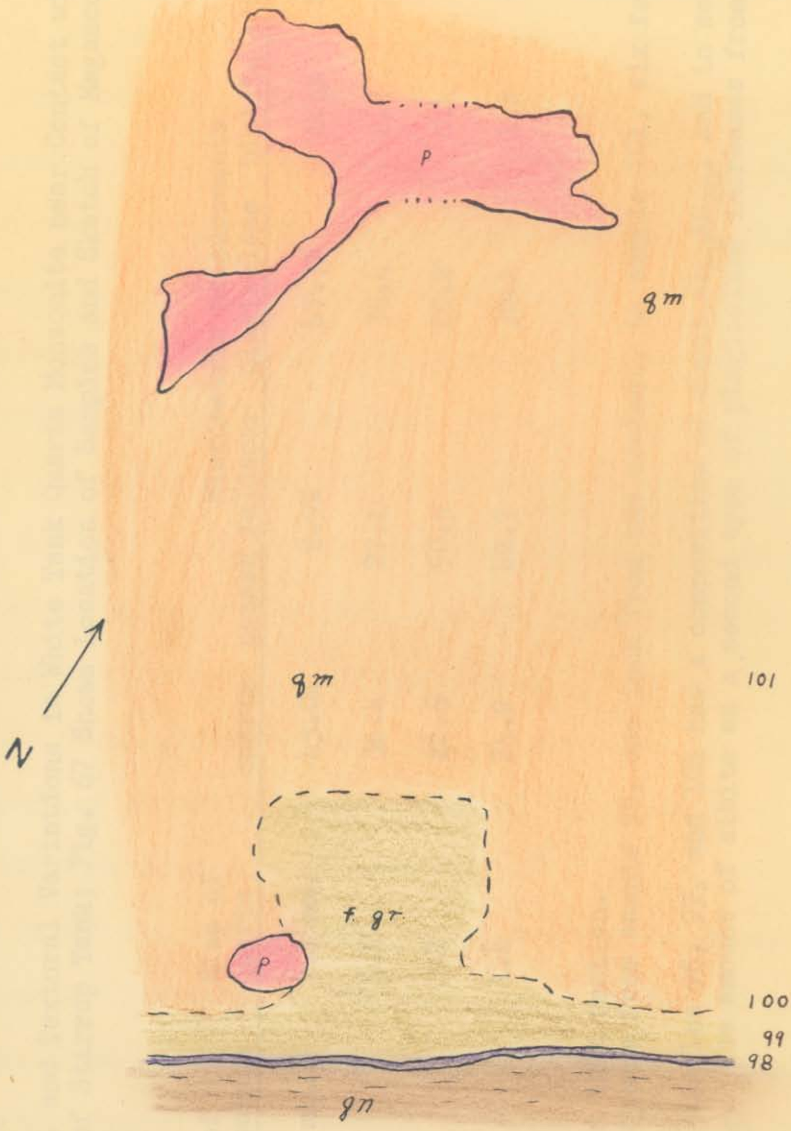


gm	White Tank quartz monzonite; tan; massive; roughly equigranular; average grain size of two millimeters.
	Pegmatitic vugs; unzoned to slightly zoned with more quartz in center; grains of pink microcline up to one centimeter in diameter.

1 foot

Fig. 67

Sketch of contact between White Tank quartz monzonite and quartzitic gneiss east of Stirrup Tank



Normal quartz monzonite.

Relatively fine grained quartz monzonite.

Very fine grained rim.

Pegmatite; large vug zoned; small vug unzoned.

Gneiss, (showing foliation).

1 ft.

Samples 98 to 101 are described more fully in Table 10.

Table 10. Compositional and Textural Variations in White Tank Quartz Monzonite near Contact with Gneiss East of Stirrup Tank; Fig. 67 Shows Location of Samples and Sketch of Megascopic Features:

Sample	Size of potash feldspar	Size of plagioclase	Size of quartz	Micrometric measurements quartz	potash feldspar	plagioclase	biotite	accessory
98	1.5 mm.	1.3 mm.	1.1 mm.	43.0%	8.9%	47.7%	0.4%	trace
99	2	1.1	1.1	34.4	27.1	36.4	2.2	---
100	3	1.7	3.1	22.6	50.5	25.2	0.4	0.3
101	3	1.4	1.4	24.9	42.7	30.1	1.8	0.4

All measurements were made in thin section.
These samples represent a sequence from sample 98, one inch from the contact, to sample 101, six feet from the contact.
The principal plagioclase in samples 98, 99, and 101 has a composition of about $Ab_{80}An_{20}$, and in sample 100 a composition of $Ab_{85}An_{15}$. The amount of albite as a second type of plagioclase increases from sample 98 to 101.

Sample 100 is from a slightly pegmatitic zone which characteristically occurs a few feet from the contact. The large pegmatites are several feet from the contact, and the larger one is zoned.

A thin zone, not recognizable in the field, along the contact of the micaceous eastern rim of Unit 2 is illustrated by section 191 (Fig. 68). The phenocrysts are normal grains of all minerals in Unit 2, and the groundmass, which comprises 20 percent of the rock, is a fine grained aggregate of 40 percent quartz, 50 percent potash feldspar, and 10 percent plagioclase (percentages by estimation). Potash feldspar may contain several zones of quartz inclusions, the size of the inclusions increasing outward to the edge of the feldspar. Albitic rims, common on plagioclase in the quartz monzonite further from the contact, are absent in rock containing a groundmass consisting partly of albite. Myrmekite occurs on borders of plagioclase laths (An_{15}) where they are in contact with phenocrysts of potash feldspar. Most of the contacts of Unit 2 do not have associated fine grained material.

In Unit 4 the border phase contains about 75 percent phenocrysts and 30 percent groundmass. The phenocrysts consist of quartz, microcline, and plagioclase (An_{30}). The groundmass is a fine grained mixture of the three major minerals plus biotite, chlorite, magnetite, apatite, and allanite. Borders of potash feldspar phenocrysts commonly contain inclusions of the groundmass. Biotite is generally on the border between phenocrysts and groundmass, and chlorite forms rounded grains apparently unrelated to biotite. Plagioclase in the groundmass is An_{20}.

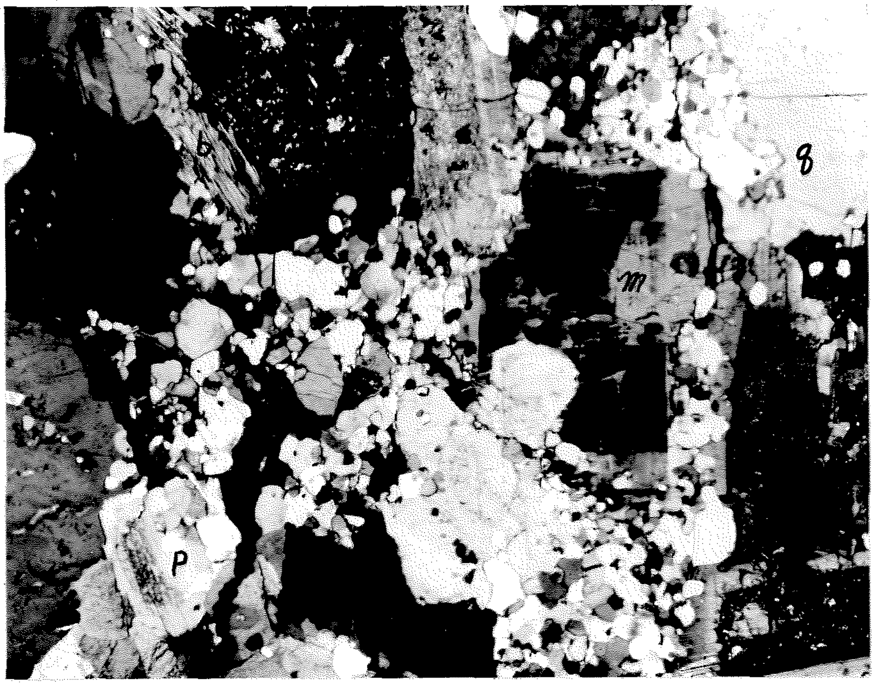


Fig. 68. Sample 191 of eastern edge of Unit 2 of White Tank quartz monzonite. Major minerals are quartz (q), plagioclase (p), microcline (m), and biotite (b) in a groundmass of quartz and feldspar. Note zoned grain of microcline. Crossed nicols, X25.

The grain size of microcline decreases toward the contact in Unit 4 (Fig. 56), indicating that it crystallized after intrusion and formed smaller crystals in the more rapidly cooled zone. Crystallization of the microcline after intrusion is also indicated by the inclusions of groundmass which it contains.

Sizes of quartz and plagioclase phenocrysts appear to increase toward the contact in Unit 4. A possible explanation lies in the method of measuring grain sizes. In the chilled rock near the border, only the phenocrysts were measured, the groundmass being too fine grained. In the central portion of the unit, however, the plagioclase and quartz in the groundmass were coarse enough to measure with the phenocrysts, and thus the average dimension of measured grains is smaller in the center than in the border zone. The average size of the more calcic plagioclase crystals (An_{30}) is the same in the center of the unit as it is near the border. This conclusion implies that very little material was added after intrusion to the crystals already formed, but that independent nucleation and growth of new grains has occurred.

With the exception of a more sodic plagioclase in Unit 3, the border zone of Unit 3 is very similar to that of Unit 4. The outer portions of the potash feldspar crystals contain some inclusions of groundmass. Inasmuch as only 10 percent of the border zone of Unit 3 is groundmass, there is essentially no difference between the size of the quartz and plagioclase phenocrysts in the border zone and the average size of grains in the center of the unit. Potash feldspar grains are also the same size near the border as in the center of the unit.

The porphyritic border of Unit 4 is undoubtedly the result of chilling of a partially crystallized melt. Quartz and plagioclase partly formed before injection, but the coarseness of the potash feldspar developed largely by growth after intrusion. If the groundmass near the border of Unit 3 is attributed to chilling of a partially crystallized melt, then the melt was 90 percent crystallized when injected (even the potash feldspar must have formed before injection, for it exhibits the same grain size near the border as in the center of the unit). Such a high percentage of solid material is possible, but the rock does not show any crushing of grains or formation of mylonitic texture as would be expected upon injection of material that is 90 percent solid. Similarly, it is difficult to explain the fine grained border of part of Unit 2 by chilling of a partially crystallized melt.

The gradual increase in grain size inward from the border of Unit 1 is most readily explained by injection and chilling of a fluid. Potash feldspar, plagioclase, and quartz all seem to have grown after injection, for they all decrease in size toward the contact. For reasons to be discussed in the next section, however, the very fine grained, inch-thick rim is believed to have formed partly by replacement of quartz by potash feldspar.

2. Quartzose zones:

At many of its contacts the border of the quartz monzonite is rich in quartz.* Sections 98 and 102 both show this phenomenon and also the

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* Another example of enrichment of igneous rock in quartz near its contact was described by Warren (1913).

characteristic resorption of quartz by potash feldspar. Section 41 (Fig. 69), 100 feet from the gneiss east of Cap Rock, contains what appear, in hand specimen, to be veins of quartz cutting the quartz monzonite. The veins are about one half inch wide and six inches long. In thin section, however, the microcline is clearly shown to be later than the quartz by the fact that single grains of microcline may cut several diversely oriented quartz grains. Although rock 100 feet from the contact is not in a strongly chilled zone (in fact, the border of Unit 2 east of Cap Rock shows no diminution of grain size from the center of the unit), these quartzose bands may be the remnants of a partially resorbed aggregate formed in the border zone previous to crystallization of potash feldspar; at least, part of the quartz in Unit 2 crystallized before potash feldspar either near the contact or throughout the intrusion.

A border of the quartz monzonite one millimeter thick in the cupola above Unit 1 consists of (estimated) 60 percent quartz, 35 percent muscovite, and 5 percent potash feldspar. The quartz forms anhedral, non-undulant, non-fretted grains with an average diameter of 0.1 millimeter. Muscovite forms masses of tiny flakes, and untwinned potash feldspar occurs as scattered, irregular grains. The minerals in this border are not oriented. The border zone has a very sharp contact with the wall rock (and apparently no effect on it), and a sharp contact with the rest of the quartz monzonite in the cupola. The quartz monzonite next to this border is typical of rock in the cupola except that it contains untwinned potash feldspar, whereas most of the potash feldspar in the cupola is twinned. A mixture of muscovite and ferric oxides seems to

Fig. 69. Sample 41 of Unit 2 of White Tank quartz monzonite east of Cap Rock. Microcline (m) cuts three differently oriented quartz grains (q_1, q_2, and q_3). Crossed nicols, X25.

take the place of biotite near the border, possibly indicating alteration from the original biotite. Whether this border represents a true quartz-rich rim or not is uncertain; it has an unusual mineralogic composition for a chilled zone.

The resorption of quartz in the border zones of the quartz monzonite correlates well with the commonly observed presence of corroded quartz phenocrysts in silicic extrusive rocks.* The corrosion of phenocrysts in lavas may either be caused by a rise in temperature of the lava near the surface (owing to exothermic reactions), or may indicate that the original crystallization of the quartz was a disequilibrium process. Either explanation might account for the resorption of quartz in the border phases of the quartz monzonite.

Thus, the textures of the very fine grained rim of Unit 1 and other quartzose areas may be largely the result of early crystallization of quartz and later replacement by potash feldspar. It is uncertain whether the replacement occurred in the solid state or by resorption of the quartz and later precipitation of potash feldspar in the vacant space. Probably the plagioclase and other minerals in these fine grained rims had crystallized at the time the quartz was precipitated, but there is no definite evidence against their formation by replacement.

3. Areas of pegmatitic development not connected with fine grained borders:

The most striking example of this phenomenon is at the border between White Tank and Palms quartz monzonites in Rattlesnake Valley. The contact

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* Lämmlein (1930) disagreed with the idea that apparently corroded quartz phenocrysts had actually undergone resorption. He attributed their unusual shapes to growth effects.

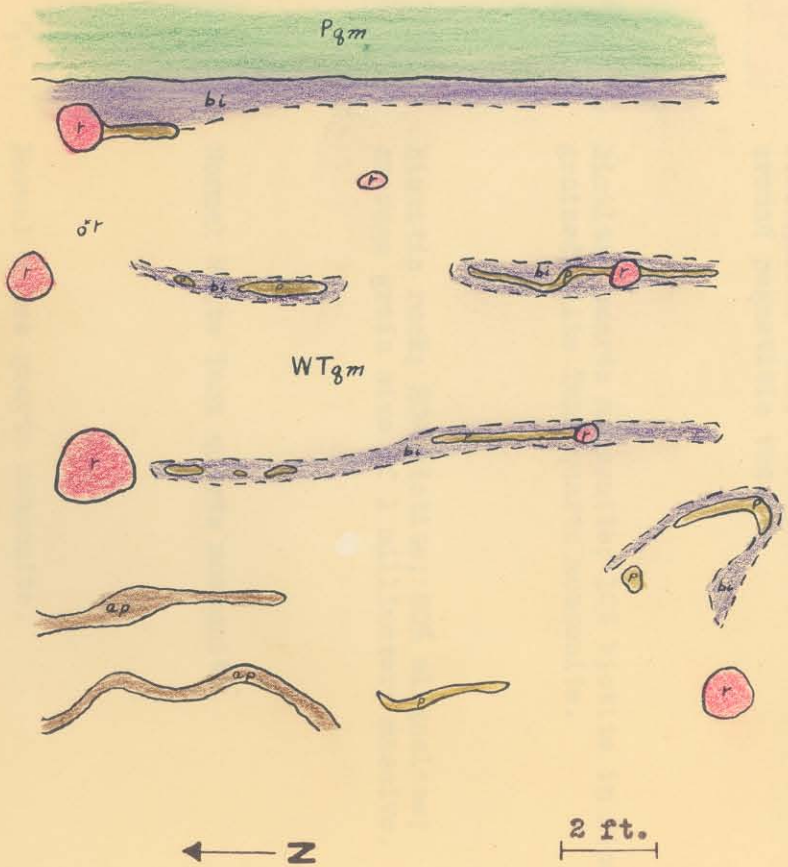
is knife-edged, and a thin zone of pegmatite occurs along much of the contact. Samples of the Palms quartz monzonite near and away from the contact show that the intrusion has had no effect on the wall rock. With the exception of the various special features shown in Figs. 70 and 71, there is no change in grain size or other textural characteristics in the White Tank quartz monzonite at the contact.

The biotitic rim contains about 10 percent biotite as unoriented flakes, 35 percent quartz scattered through the rock as individual grains with an average diameter of 0.25 millimeter, and the rest microcline and twinned, unzoned plagioclase in 0.5-millimeter grains. Scattered through this rim are graphic potash feldspar crystals (generally untwinned), up to 10 millimeters long, and aggregates of undulant, fretted, 2-millimeter quartz grains. The graphic quartz may have the same orientation in several adjacent potash feldspar grains. Abundant rod perthite contains plagioclase of the same composition as the plagioclase laths in the rest of the rock (ca. An_{25}).

As shown in Fig. 70, there is a distinct association between the biotitic streaks and the pegmatites, possibly because a local concentration of water is needed to form both lithologies. Thus, as is apparent from pegmatitic vugs along many of the contacts of Units 1 and 2, segregations of water-rich phases must be rather common near rapidly cooled borders of the intrusion, providing that water cannot escape through the wall rock; and apparently, in the presence of sufficient ferromagnesian material, these fluid phases localize the crystallization of biotite as well as pegmatite. It is also possible

Fig. 70

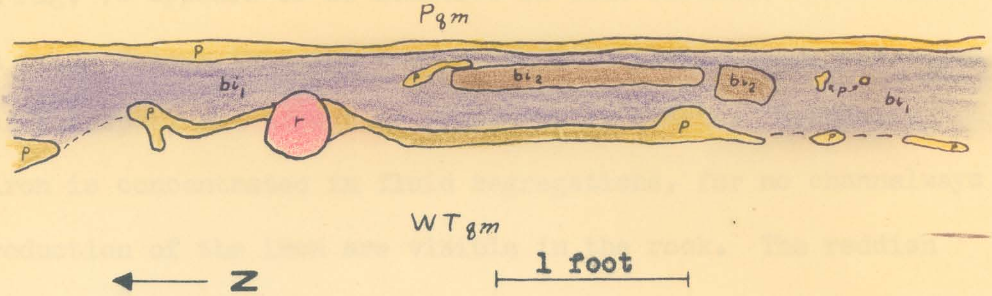
Sketch of contact between White Tank quartz monzonite and Palms quartz monzonite in Rattlesnake Valley



ap	Aplite dike.
p	Pegmatite; unzoned or slightly zoned with white feldspar near borders; average 50% pink microcline and 50% quartz; crystals up to 15 millimeters in size.
bi	Biotitic quartz monzonite; 10% biotite in fine grained White Tank quartz monzonite.
r	Ferruginous areas; ferruginous stain in and around pegmatitic vugs.
WTqm	Normal White Tank quartz monzonite.
Pqm	Normal Palms quartz monzonite.

Fig. 71

Sketch of border zone of White Tank quartz monzonite at contact with Palms quartz monzonite in Rattlesnake Valley



p	**Pegmatite; unzoned; average 70% pink microcline and 30% quartz; crystals from 5 to 15 millimeters in size.**
r	**Ferruginous area; ferruginous material in and around pegmatitic vug.**
bi_1	**Biotitic quartz monzonite; 10% biotite in fine grained White Tank quartz monzonite.**
bi_2	**Biotitic rock; 20% biotite; 80% oligoclase; average grain size of 1 millimeter; massive.**
WT_{qm}	**Normal White Tank quartz monzonite.**
P_{qm}	**Normal Palms quartz monzonite.**

that the biotitic streaks acted as planes of weakness for slightly later injection of pegmatite.

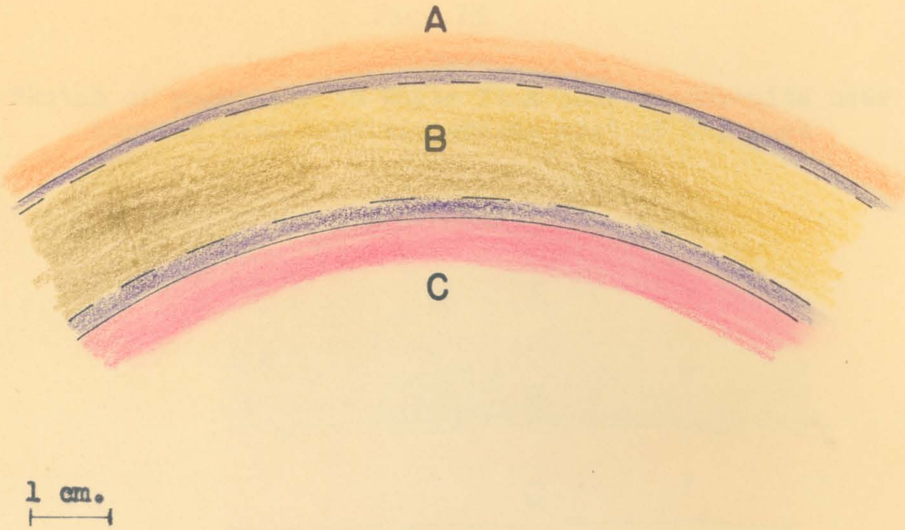
The ferruginous material in and around some of the pegmatitic vugs shown in Fig. 70 appears to be hematite in thin section. Thin bands of the iron oxide follow twin and zone borders in plagioclase, cleavages in potash feldspar, and irregular fractures in quartz. Evidently, ferric iron is concentrated in fluid segregations, for no channelways for introduction of the iron are visible in the rock. The reddish areas are topographic highs but invariably contain a round cavity in the center (possibly this cavity was left by removal of muscovite, which makes up the center of some pegmatites). The round shape of the red areas, their occurrence near or away from biotitic streaks, and the absence of ferruginous material from some pegmatites are all problems which are unanswered.

Zoning in a pegmatitic vug in Unit 2 50 feet from the contact with biotitic gneiss east of Cap Rock is illustrated in Fig. 72. The concentration of biotite in the zone around the pegmatite is similar to the relations described above.

Another pegmatite next to biotitic gneiss east of Cap Rock has a diameter of four feet. The succession of zones is illustrated in Fig. 73. The biotitic rim is characteristic of many pegmatites in the area. Zoning is more pronounced in large vugs (such as the one in Fig. 73) than in small ones.

Fig. 72

Sketch of pegmatitic vug in White Tank quartz monzonite 50 feet from biotitic gneiss east of Cap Rock



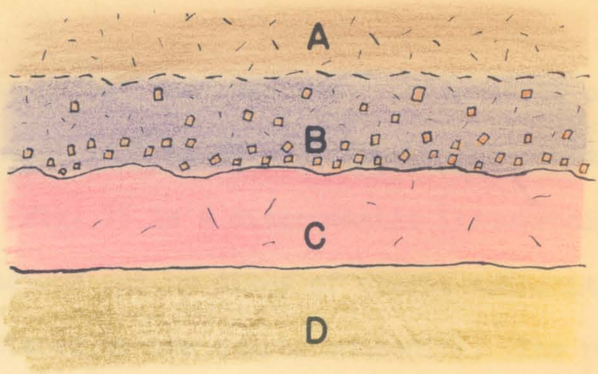
A — Normal quartz monzonite; roughly equigranular; average grain size of two millimeters; 25% quartz; 25% untwinned potash feldspar; 40% oligoclase; 5% biotite; 5% other minerals.

B — Fine grained quartz monzonite with biotitic rims; roughly equigranular; average grain size of one half millimeter; 30% quartz; 45% untwinned potash feldspar; 20% oligoclase; 5% biotite in main part of zone, but up to 50% biotite in rims.

C — Pegmatite; unzoned; average of 50% quartz and 50% pink to white microcline; crystals up to one centimeter long; total diameter of pegmatite is 10 centimeters.

Fig. 73

Sketch of pegmatite in White Tank quartz monzonite near contact with biotitic gneiss east of Cap Rock



COVERED

1 foot

A — Biotitic quartz monzonite; approximately 10% biotite in otherwise normal quartz monzonite.

B — Biotitic quartz monzonite with 20% crystals of pink microcline; some microcline crystals as large as 15 millimeters.

C — Pegmatite; 95% pink microcline in crystals up to 15 millimeters long; 5% biotite flakes with an average length of 1 millimeter.

D — Pegmatite; 50% pink microcline in crystals up to 5 centimeters long; 50% quartz in crystals up to 8 centimeters long; rare books of muscovite.

4. Intimate injection and ingestion at the contact:

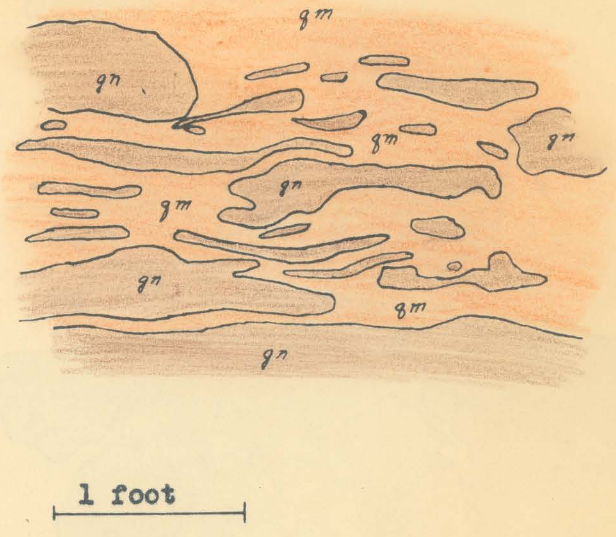
Biotitic gneiss northwest of the Anaconda Mine is intimately injected by quartz monzonite as illustrated in Fig. 74. The quartz monzonite in this injection zone is identical to the rock in the center of the unit except for its slightly smaller potash feldspar grains. The various fragments of gneiss have been moved from their original positions, as is shown by the discordance in their foliation trends.

The contact between gabbro and quartz monzonite north of Jumbo Rocks is marked by abundant inclusions and dikes. The contact zone is about 10 feet wide. Fig. 75 is a diagrammatic illustration of a group of gabbroic inclusions cut by dikes of quartz monzonite and, along certain zones, altered by the quartz monzonite. The rock in the small dikes is texturally and mineralogically identical to the typical rock in the upper facies of Unit 1, but the gabbro near the contact is slightly altered.

In general, areas of gabbro which have been altered by intrusion of quartz monzonite contain quartz, potash feldspar, and sodic plagioclase, in addition to the minerals of the gabbro. All of these minerals occur either as aggregates distinct from the enveloping gabbro or scattered randomly throughout the gabbro. Minerals in the gabbro are, in places, aligned parallel to the borders of the aggregates of introduced minerals. Quartz introduced to the gabbro commonly forms individual grains with an average diameter of 0.25 millimeter. Most of the potash feldspar is microcline as anhedral

Fig. 74

Sketch showing contact between White Tank quartz monzonite and biotitic gneiss northwest of the Anaconda Mine



Quartz monzonite.

Biotitic gneiss.

Fig. 75

Diagrammatic sketch of inclusions of gabbro in White Tank quartz monzonite at contact north of Jumbo Rocks

qm — Normal quartz monzonite.

ga — Normal gabbro.

Zone of reaction; mixed gabbro and quartz monzonite.

Crystals of feldspar; white; mainly oligoclase but some potash feldspar; up to 15 millimeters long.

grains with an average diameter of 0.25 millimeter. Rod perthite occurs in some microcline. Plagioclase forms rectangular, anhedral crystals up to 15 millimeters long. The large plagioclase grains are twinned and unzoned, and may contain abundant oriented intergrowths of quartz (not myrmekitic). Small patches of microcline in the plagioclase may be antiperthite. Most of the introduced plagioclase has a composition of median oligoclase, but a few small, irregular, partly myrmekitic grains of albite occur near microcline grains.

The White Tank quartz monzonite shows essentially no changes near the contact with the fine grained phase of the Palms quartz monzonite south of Queen Mountain. The wall rock is intimately injected by small dikes which are identical to the rest of the upper facies of Unit 1 except for a slightly smaller average grain size of potash feldspar. Some microcline crystals up to 3 millimeters long have formed in the wall rock, and some contain graphic quartz and vein perthite. Some of the plagioclase in the perthite (with indices of calcic albite) contains small, unoriented grains of quartz. Myrmekite occurs in small grains of albite scattered around the borders of the large microcline grains and in albitic rims on the plagioclase laths.

Two types of alkali feldspar have formed in the Palms quartz monzonite at the contact with the White Tank quartz monzonite northeast of Jumbo Rocks. Both feldspars consist of oriented intergrowths of potash feldspar and plagioclase which appear to have formed by exsolution from originally homogeneous phases. Plagioclase in both feldspars has a composition of An_{13} (determined by indices), and the bulk compositions of the two feldspars are $Or_{65}Ab_{31}An_{04}$ and $Or_{20}Ab_{71}An_{09}$. On the solvus diagram presented by Bowen and Tuttle (1951, page 497), the homogeneous feldspars of the compositions shown above would be in equilibrium at about 600° C (counting anorthite as albite). The anorthite content of the plagioclase would undoubtedly raise this equilibrium temperature, but how much is not known. This determination of temperature assumes, of course, that the potash feldspar and plagioclase are pure phases at the present time.

On the basis of this evidence it is believed that the upper portion of Unit 1 crystallized at a minimum temperature of 600° C. It is not known why homogeneous feldspars should have formed in the wall rock and later exsolved, whereas (with the possible exception of some perthite) this exsolution is not noted in either microcline or plagioclase in the intrusive.

5. No change in quartz monzonite near contact:

In some places the White Tank quartz monzonite at its contact is identical to the rock in the center of the intrusion. At a contact on the west side of the Lost Horse Mountains quartz monzonite grades into highly biotitic gneiss through a thickness of about an inch. Except for a slightly higher content of biotite, the quartz monzonite in this marginal zone is identical to most of the rock in Unit 2. Clusters of unoriented flakes of biotite (partly replaced by muscovite) form 10 percent of the marginal rock. The absence of accessory minerals associated with these biotitic clusters may indicate that at least part of the biotite was derived from the gneiss.

A series of sections across two contacts between Unit 2 of the White Tank quartz monzonite and Unit C of the Palms quartz monzonite in Lost Horse Valley shows that the later intrusion has had absolutely no effect on the wall rock. The quartz of the White Tank quartz monzonite is in individual grains rather than aggregates, but otherwise there is no textural or mineralogic difference from the rest of Unit 2. The contact is gradational through about an inch.

6. Hydrothermal alteration associated with contacts:

In places along the upper contact of Units 1 and 2 of the White Tank quartz monzonite, thin veinlets (less than one inch thick) cut both the intrusive and its roof rocks. In addition to these veinlets, Unit 2 exhibits bands along which the feldspars in the quartz monzonite have been altered to a pink, iron-stained clay. These bands, some of which are parallel to joints, range up to one inch thick. Plagioclase appears more intensely altered than potash feldspar. The argillization seems to have been imposed upon a previous sericitization of the plagioclase. It is not certain that these veinlets and bands of alteration are directly related to the intrusion of the White Tank quartz monzonite.

7. Summary of features related to contacts:

The White Tank quartz monzonite shows markedly different contacts against different wall rocks. Contacts against highly quartzitic, non-biotitic gneiss are very abrupt and invariably exhibit thin chill zones, broad zones of relatively fine grained rock, and pegmatitic segregations. Contacts against some of the coarser phases of the Palms quartz monzonite (Units A and B) are also very abrupt and characterized by the presence of pegmatites. Intrusive contacts between quartz monzonite and biotitic gneiss are generally slightly gradational; some have associated pegmatite but most do not. Gabbro-diorite is intimately cut and ingested by the quartz monzonite, and commonly quartz and alkali feldspars are added to the mafic rock.

Different units of the White Tank quartz monzonite exhibit slightly different contact effects against the same type of wall rock. Zones in which all minerals are relatively finer grained than in the center of the intrusion are present only in Unit 1. Pegmatitic segregations occur only near the borders of Units 1 and 2. Porphyritic borders with a fine grained groundmass are most characteristic of Unit 4, are present in Units 2 and 3, and are absent from Unit 1. Iron-stained pegmatitic vugs occur only in Unit 2.

Possibly the permeability of the wall rock is one of the factors which determine the effect of the wall rock on the quartz monzonite. Impervious (?) rocks (such as silicic gneiss or Units A and B of the Palms quartz monzonite) caused chilling of the intrusive and, in Units 1 and 2, segregation of fluid, pegmatitic phases. The first effect of such impervious (?) rocks on Unit 1, and possibly Unit 2, was the formation of a quartzose rim around the intrusive; this rim was later partially replaced by potash feldspar.

Wall and roof rocks such as biotitic gneiss and Unit C of the Palms quartz monzonite may be permeable to the intrusive fluid. Fine grained margins and pegmatitic segregations are generally not developed near such country rocks, although Unit 4 (which is surrounded primarily by biotitic gneiss) does exhibit a porphyritic, partly chilled border. Reaction of the gabbro-diorite with the quartz monzonite affects only the narrow zone of ingestion (less than 10 feet wide); presumably the reaction permits escape of fluids from the intrusion and prevents the formation of other contact features such as pegmatite.

E. Origin of Petrographic Variation:

The overall textural and compositional similarity of the four units just described, the fact that one unit may resemble a small facies in another unit, and their identical age (insofar as it can be determined) indicate that the four units of the White Tank quartz monzonite represent differentiates from the same original source.

The upper and lower facies of Unit 1 probably differentiated from a single intrusion. Gravitational settling of the dark minerals and calcic plagioclase (An_{30}), the early-crystallizing materials, left the upper portion of the unit rich in potash feldspar and sodic plagioclase. If the oriented intergrowths of microcline and sodic plagioclase represent simultaneous crystallization of the two minerals, then the water content of the crystallizing medium in the upper part of the unit must have been high (Bowen and Tuttle [1950]). A high fluidity is also indicated by the large size of the microcline phenocrysts.* The enrichment in water is probably the result of gravitational differentiation and removal of early-crystallizing minerals from the residual fluid. Enrichment of ferric iron in the later fluids is possibly demonstrated by the extensive iron-staining in the cupola above the main portion of the unit. Reports

* The effect of fluidity on the formation of large crystals is discussed by Jahns (1953).

of differentiation in other bodies of silicic plutonic rocks are uncommon. Sargent (1925) described similar upward enrichment of volatile material and acidic silicates in an intrusion of diorite-granite. Van Biljon (1939) described differentiation of a granite in which the upward changes were increase in total silica, increase in Ab/An ratio, and decrease in the sizes of all minerals. The reasons for the differences between the results of the present study and those of van Biljon are unknown.

The genetic relationship between Unit 4 and the upper facies of Unit 1 is indicated by the similarity of the two rocks with regard to bulk composition, Ab/An ratio for the whole rock, and the abundance of large gray microcline phenocrysts. Unit 4 probably originated by injection of small amounts of partly crystallized material from Unit 1 into the overlying Pinto gneiss and Palms quartz monzonite. The high proportion of albite to calcic oligoclase in Unit 4 indicates that equilibrium was not established between solids and fluid after injection. The disequilibrium is probably the result of rapid cooling owing to the small size of the intrusion, and it correlates well with the abundance of a fine grained, presumably chilled, groundmass (this fine grained material is absent from the much larger Unit 1). The large potash feldspar crystals probably grew in a water-rich environment, as in the upper part of Unit 1, although a very high water content appears incompatible with the formation of a chilled, fine grained matrix. Possibly sudden escape of water vapor caused apparent "chilling" after the crystallization of most of the potash feldspar. Presumably, injection of Unit 4 occurred before the laths of oligoclase in the upper part of Unit 1 had entirely settled out of or reacted with the remaining fluid, and the albite in the fluid crystallized in Unit 4 without further reaction with the existing plagioclase laths.

Judging from its high content of muscovite and garnet and the sodic nature of its plagioclase (all similar to the micaceous eastern rim of Unit 2), Unit 3 is a differentiate of Unit 2. The presence of muscovite in Unit 3 indicates the retention of water during crystallization, and perhaps the formation of garnet is promoted by a high fluidity which reduces the polymerization of the silicate melt. Similar retention of water in the eastern rim of Unit 2 led to the formation of muscovite (and garnet?). High water content in Unit 3 and the eastern rim of Unit 2 is probably related to the impermeability of Units A and B of the Palms quartz monzonite, which form the eastern wall of Unit 2 and the walls and roof of Unit 3; all contacts of later intrusions with these phases of Palms quartz monzonite are knife-edged, indicating the tightness of the rock. Possibly the abruptness of these contacts is a result of lack of reactivity of wall rock with a melt of nearly identical composition. Conversely, the fine grained Palms quartz monzonite (Unit C), which forms the roof for Unit 2, shows slightly gradational contacts with later intrusions, indicating that fluids may have escaped through it. Upward enrichment of water in Unit 2 is shown by the presence of the micaceous rim against the impermeable Palms quartz monzonite high in the unit but the absence of the rim against the same wall rock at the mouth of Rattlesnake Valley, low in the intrusion. The high percentage of albite in the plagioclase in this rim compared with the plagioclase in the central portion of Unit 2 shows that water in the rim maintained crystals and melt in equilibrium at a lower temperature than in the center of the intrusion.

The reasons for the differences between Units 1 and 2 are not understood. The overall compositions of each intrusion are essentially the same, but a high fluidity in the upper portion of each unit and its related smaller intrusion has led to an entirely different product in each case. Differentiation of Unit 2 has led to the formation of a highly micaceous rock, whereas differentiation of Unit 1 has led to the formation of coarse crystals of microcline. Perhaps the controlling factor for these differences is some variable other than fluidity, e. g., temperature of the wall rocks at the time of intrusion.

F. <u>Dikes Associated with the White Tank Quartz Monzonite</u>:

As described below, six different types of dikes are related to the White Tank quartz monzonite. Apparently, dikes are associated only with Units 1 and 2, and there seems to be no difference between the types of dikes related to each of these units.

1. Dikes of quartz monzonite that cut wall rock:

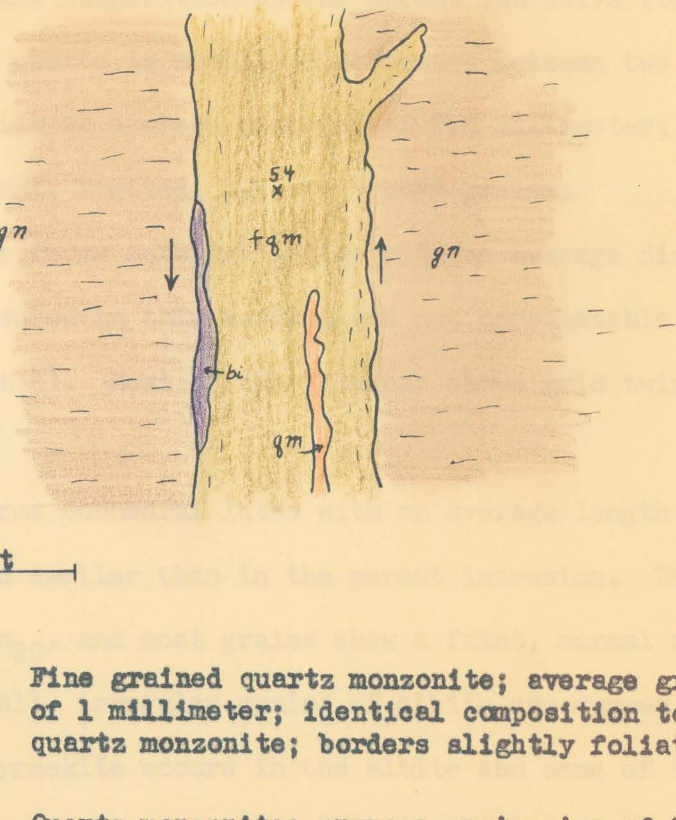
Sample 54 (Fig. 76), from the dike illustrated in Fig. 77, is typical of the bordering dikes around Unit 2. A micrometric analysis gave the following results:

[See page 228]

Fig. 76. Sample 54 of dike of White Tank quartz monzonite cutting Pinto gneiss in Lost Horse Mountains. Quartz occurs both in aggregates (q_1) and individual grains (q_2). Crossed nicols, X25.

Fig. 77

Dike of quartz monzonite in biotitic gneiss east of Cap Rock



fqm — Fine grained quartz monzonite; average grain size of 1 millimeter; identical composition to normal quartz monzonite; borders slightly foliated.

qm — Quartz monzonite; average grain size of 2 millimeters; identical composition to normal quartz monzonite.

bi — Biotitic quartz monzonite; 10% biotite but identical to fine grained quartz monzonite.

gn — Biotitic gneiss.

Location of sample 54 shown by "x".

Gneiss on opposite sides of dike offset 2 to 3 feet.

	54
quartz	34.7%
potash feldspar	24.0
plagioclase	35.2
biotite	5.9
accessory	0.3
total points	1078

This dike has the same composition as the parent intrusive (Unit 2).

In section 54, quartz is equally distributed between two forms: individual grains with an average diameter of 0.6 millimeter; and aggregates of undulant, fretted, 1.9-millimeter grains.

Potash feldspar forms anhedral grains with an average diameter of 1.0 millimeter (measured in thin section and not correlatable with other measurements in Unit 2). Most of the feldspar shows grid twinning. Perthite is rare.

Plagioclase forms subhedral laths with an average length of 0.8 millimeter, much smaller than in the parent intrusion. The composition is about An_{20}, and most grains show a faint, normal zoning. Albitic rims and small, irregular grains of albite are common near potash feldspar. Myrmekite occurs in the albite and some of the oligoclase near potash feldspar.

Biotite forms ragged flakes approximately 0.5 millimeter long. Most grains are highly altered either to muscovite or to a reddish-brown material. Some of the muscovite may be primary.

Accessory minerals are apatite and zircon.

Some of the oligoclase is thoroughly sericitized. Kaolin forms a light dust on both feldspars.

Sample 54 is identical to most of the rock in Unit 2 except that this sample contains a higher percentage of individual quartz grains (as opposed to quartzose aggregates) and slightly smaller plagioclase crystals.

Another dike of quartz monzonite on the west side of the Lost Horse Mountains, illustrated in Fig. 78, shows biotitic streaks which are undoubted inclusions of the gneiss.* A fine grained, chilled zone and a pegmatitic zone are also present in the dike.

Section 105 (Fig. 79), from another dike near White Tank, is identical to the rock in Unit 1 nearby, except for the following features:

(1.) The percentage of quartz in individual grains as opposed to quartzose aggregates is higher in the dike.

(2.) Instead of most of the plagioclase consisting of laths of median oligoclase as in the parent intrusion (Unit 1), plagioclase in the dike consists of laths of calcic oligoclase (An_{30}) and abundant small grains of albite. The percentage of albite is much higher in the dike than in most of Unit 1.

(3.) All minerals form grains slightly smaller than the size normal for the nearby quartz monzonite.

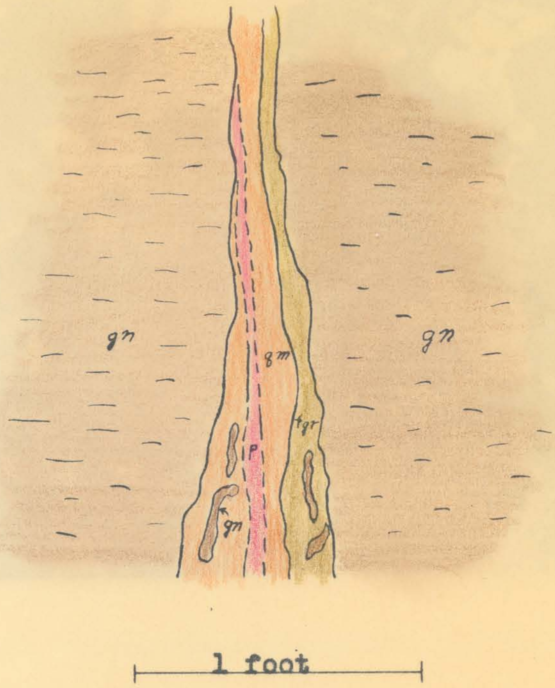
(4.) Small veinlets of brown, ferruginous material cut the dike.

An apophysis (about 50 feet wide) of Unit 1 into Palms quartz monzonite north of Queen Valley contains 50 percent laths of plagioclase having a composition of An_{30}. The laths show a faint normal zoning,

* Not all biotitic streaks in the quartz monzonite may be explained by inclusion of the wall rock. The streaks near the contact in Rattlesnake Valley could not have been derived from adjoining Palms quartz monzonite.

Fig. 78

Dike of quartz monzonite in biotitic gneiss east of Cap Rock



p — Pegmatite; unzoned; 50% pink microcline; 50% quartz; crystals 5 to 15 millimeters in size.

fgr — Fine grained quartz monzonite; average grain size of 1 millimeter; 10% biotite but otherwise normal composition for White Tank quartz monzonite.

gm — Normal White Tank quartz monzonite; average grain size of 2 to 4 millimeters.

gn — Biotitic gneiss.

Fig. 79. Sample 105 of dike of White Tank quartz monzonite cutting Pinto gneiss east of White Tank. Major minerals are quartz (q), plagioclase (p), and potash feldspar (Kf). Crossed nicols, X25.

may or may not be twinned, and contain a little antiperthite. Some plagioclase with a composition of An_{15} is in oriented intergrowth with microcline, and a little albite forms rims or interstitial grains. The rock contains about 10 percent biotite. This offshoot is evidently more basic than the average rock in the upper facies of Unit 1. Presumably the offshoot represents injection and chilling of the original material in Unit 1 before differentiation allowed the basic minerals to settle out of the upper part of the unit.

Some dikes in Queen Valley appear to have been injected into the roof rock after differentiation of Unit 1, for they have the same composition as the upper facies of the unit (which is a differentiate of the original intrusion).

The hill in Queen Valley, described previously as a cupola in the top of Unit 1, is cut by dikes of brown to red quartz monzonite about 10 feet thick. Much of the ferruginous material is enclosed as patches and veinlets in microcline. Generally, the reddish dikes show marked differences in composition among themselves. Most have an average grain size of 0.5 millimeter. Minerals are evenly distributed; quartz forms individual, interstitial grains. Microcline forms the largest grains (1 millimeter in diameter as measured in thin section), and may show graphic intergrowths with quartz. Plagioclase is twinned, faintly zoned, and highly sodic (sodic oligoclase or calcic albite). Plagioclase is thoroughly sericitized, but some white mica appears primary. In addition to ferruginous alteration and sericitization, kaolinization is intense on both feldspars. One dike (non-ferruginous) contains strongly epidotized and sericitized plagioclase.

2. Pegmatite dikes:

Pegmatite dikes are scattered abundantly through Units 1 and 2 of the White Tank quartz monzonite. They are most common near the top of the units, but a few occur near the base of Unit 1 (near Squaw Tank). Most pegmatites are less than six inches thick and are unzoned, but some of the small ones and all of the large ones show a zoning from microcline (with or without albite) or graphic granite near the walls to quartz in the center of the pegmatite. The zoning in one pegmatite is illustrated in Fig. 80 and is typical of zoning in other pegmatites in the area.

A few of the aplite dikes contain pegmatitic portions either near the center or near one edge. Boundaries between the two rocks are abrupt. The pegmatite masses are generally too small to show zoning.

Some dikes contain both aplite and pegmatite distributed irregularly throughout the dike. Borders between the two rocks are abrupt.

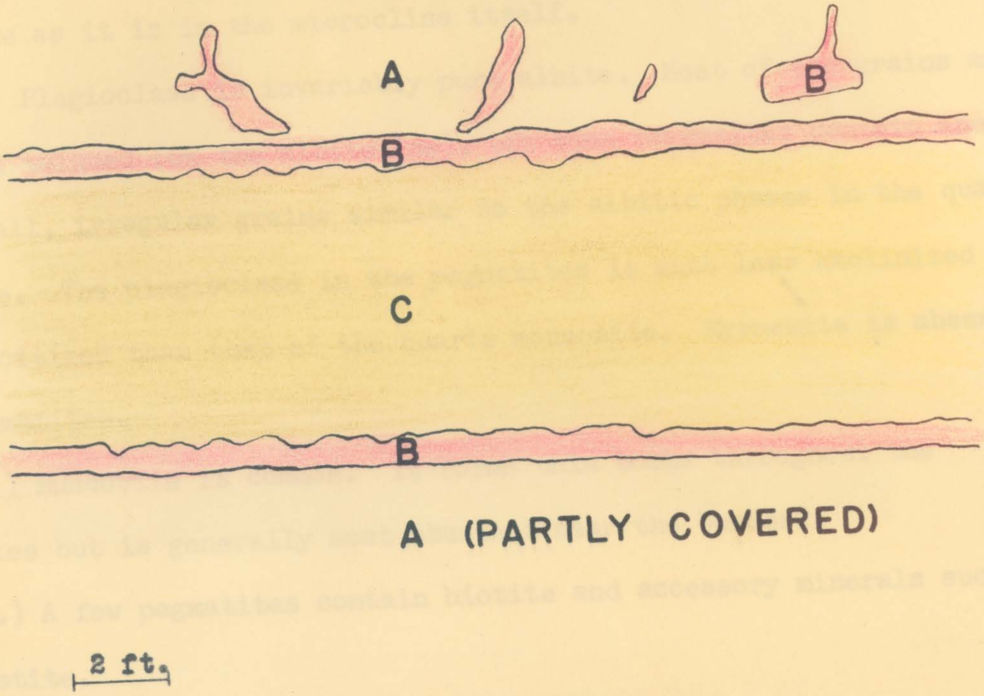
A few general characteristics of the pegmatites associated with the White Tank quartz monzonite are listed below.

(1.) Microcline is the most abundant mineral. Untwinned potash feldspar does not occur. The microcline may be either pink or white, the white variety being restricted to dikes near the top of the units and the pink occurring throughout. Any one pegmatite contains microcline of only one color. Vein perthite ranges from abundant in some dikes to absent in others.

(2.) Graphic textures are common in some dikes. Quartz grains may show several different orientations in the same grain of microcline and

Fig. 80

Cross-section of pegmatite in White Tank quartz monzonite northwest of Squaw Tank



A — Normal White Tank quartz monzonite.

B — Graphic granite; pink microcline crystals up to 15 centimeters long; 5% biotite in flakes up to 3 centimeters long.

C — Massive quartz.

may be of different sizes in different orientations. Unlike some of the graphic textures in the very fine grained rim around part of Unit 1, the quartz orientation in pegmatites is rarely the same in neighboring, differently oriented, grains of microcline. The orientation of quartz grains, however, may be the same in inclusions of plagioclase in the microcline as it is in the microcline itself.

(3.) Plagioclase is invariably pure albite. Most of the grains are large and twinned (on the albite law), but some pegmatites contain abundant, small, irregular grains similar to the albitic phases in the quartz monzonite. The plagioclase in the pegmatites is much less kaolinized and sericitized than that of the quartz monzonite. Myrmekite is absent from pegmatites.

(4.) Muscovite is common. It forms thin books throughout the pegmatites but is generally most abundant near the borders.

(5.) A few pegmatites contain biotite and accessory minerals such as magnetite.

3. Aplite dikes:

Aplite dikes are scattered even more abundantly than pegmatites throughout the upper part of the White Tank quartz monzonite. Most are less than six inches thick, but some are large and complex.

Modal analyses of two aplite dikes are given below. Sample 14 is from a dike east of Hidden Valley, and sample 33 (Fig. 81) is from a dike east of Cap Rock.

[See page 237]

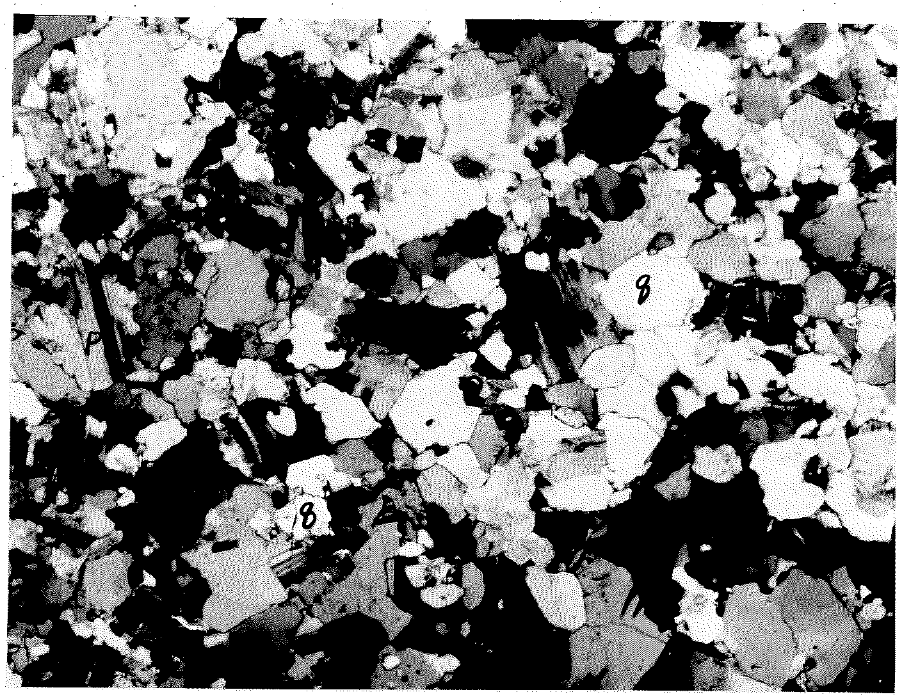


Fig. 81. Sample 33 of aplite dike cutting Unit 2 of White Tank quartz monzonite. Major minerals are quartz (q), plagioclase (p), and potash feldspar (Kf). Crossed nicols, X25.

	14	33
quartz	35.2%	28.2%
potash feldspar	21.6	26.3
plagioclase	42.3	38.1
biotite	0.5	---
muscovite	---	7.0
accessory	0.4	---
garnet	---	0.5
total points	1093	1111

All minerals are evenly distributed, the quartzose aggregates and clusters of mafic minerals in the quartz monzonite being absent from the aplite dikes. All minerals in the aplites have an average diameter of approximately 0.5 millimeter; the difference in sizes of different minerals which develops in the coarser quartz monzonite is not present in the finer grained aplites.

Quartz is generally anhedral, undulant, and slightly fretted in contact with other quartz grains. Contacts between quartz and feldspar or other minerals are not fretted.

Most of the potash feldspar is untwinned. Vein perthite may be present or absent. All grains are anhedral.

Plagioclase generally forms twinned, unzoned (or faintly, normally, zoned) anhedral grains. Compositions range from An_{15} to An_{05}, the more calcic plagioclase occurring in those dikes which contain biotite and accessory minerals such as magnetite. Some albite forms small, irregular, interstitial grains; the albite does not necessarily occur on the border of potash feldspar grains. Myrmekite is present in a few sections; it occurs either in the albite or in the larger plagioclase grains.

Biotite forms small tablets which are commonly altered to a reddish material and tiny opaque white needles. The flakes of biotite may show some alignment in the rock.

Muscovite is either a primary mineral, forming flakes about 0.25 millimeter long, or a product of the replacement of biotite or plagioclase.

Garnet and accessory minerals form small euhedral grains.

In addition to the widespread sericitization, plagioclase is commonly kaolinized. Biotite is intensely altered as mentioned above.

Inasmuch as the aplites associated with the White Tank quartz monzonite are generally more basic than the pegmatites, the aplites presumably represent an earlier differentiate. This sequence of formation is also indicated by dikes of pegmatite cutting aplite near some contacts, especially along the eastern edge of Lost Horse Valley. The reverse relation (aplite cutting pegmatite) is never found. The aplites vary in composition among themselves, however, sample 14 above being more basic than sample 33.

4. Epidote-bearing dikes:

A few dark green dikes cut the upper part of Unit 1. Section 71, a typical example of one of these dikes north of Split Rock, exhibits the following estimated mode:

	71
quartz	20%
plagioclase	15
epidote-clinozoisite	60
biotite	5
apatite	trace
magnetite	trace

Most of the minerals are about 0.1 millimeter in diameter, but the epidote ranges to as large as 1 millimeter. All minerals are anhedral and scattered evenly through the rock. Biotite is pleochroic from yellow to olive green. The composition of the untwinned to poorly twinned plagioclase is hard to determine, but indices indicate that it is approximately pure albite. Kaolinization is slight on the plagioclase.

The lower part of Unit 1 contains thin veinlets of epidote-clinozoisite. Most of the veinlets are near contacts with the wall rock.

5. Quartz-latite-porphyry dikes:

Rare porphyry dikes are associated with the White Tank quartz monzonite. Phenocrysts generally make up approximately one third of the rock and consist of quartz, microcline, calcic plagioclase, and biotite. Euhedral crystals of microcline range up to one inch long. The groundmass consists of quartz, biotite, potash feldspar (both twinned and untwinned), calcic oligoclase, and a few accessory minerals. There is some parallelism of the feldspars and biotite in the groundmass. Some potash feldspar phenocrysts contain rims of plagioclase, the contact between the two feldspars being very irregular.

6. Hornblende-bearing dikes:

Rare dikes containing approximately 50 percent hornblende and 50 percent andesine cut Unit 1 of the White Tank quartz monzonite. The average grain size is one millimeter. The dikes are apparently massive.

G. Inclusions in the White Tank Quartz Monzonite:

Scattered randomly through the quartz monzonite and showing no apparent relation to the contacts are small inclusions of the wall rocks. Most of them are less than six inches in diameter, and, in those cases where the parent rock is identifiable, seem to be remnants of the Pinto gneiss.

Some clusters of biotite appear to be residuals of the gneiss. They are commonly very rich in quartz and low in magnetite and other accessory minerals. Other clusters of biotite, which contain about 5 percent magnetite and 60 percent calcic oligoclase, have a mineralogy totally dissimilar to any gneiss in the area and may be merely large segregations of mafic minerals. (Smaller segregations have been described on page 191.)

Untwinned potash feldspar has been added by the quartz monzonite to some of the undoubted gneissic inclusions. This feldspar forms large crystals which poikilitically enclose grains of the gneiss. The untwinned feldspar forms overgrowths on some potash feldspar grains originally of the gneiss.

Plagioclase in the inclusions is generally identical to the plagioclase in the surrounding plutonic rock. Slightly zoned grains of calcic oligoclase; twinned, unzoned grains of sodic oligoclase; and small grains of albite are all common in the inclusions. Myrmekite occurs either in the albite or in the larger plagioclase laths. Remnants of the original plagioclase of the gneiss have never been found in the inclusions, indicating the ease with which equilibrium was attained between the inclusion and the quartz monzonite.

Some fine grained areas in the quartz monzonite may represent more thoroughly digested inclusions of unknown source. One example may be a small area about six inches in diameter near Split Rock. This area contains microcline grains with an average maximum dimension of 5.3 millimeters, whereas the surrounding quartz monzonite has grains with an average maximum dimension of 8 millimeters. The border between the two types of rock is abrupt.

Sample 36, a fine grained area in Unit 2 about six inches in diameter, may represent the digestion of light colored, feldspathic gneiss. Micrometric measurements of sample 36 and the nearby gneiss (sample 34) gave the following results:

	36	34
quartz	30.8%	41.3%
potash feldspar	38.6	28.8
plagioclase	27.4	28.4
biotite	2.6	1.1
accessory	0.5	0.4
total points	1016	1044

Both samples are from rocks east of Cap Rock.

Although it appears that potash feldspar has been added to sample 36 at the expense of quartz, the variation between different layers of the gneiss is probably sufficient to account for the difference between the two samples. In sample 36 quartz occurs as individual grains with an average diameter of 0.6 millimeter and in aggregates of 2.0-millimeter grains. Plagioclase forms laths approximately 0.8 millimeter long. Thus, both the fine grained quartz and the plagioclase are about one half as large as in the surrounding quartz monzonite.

As mentioned above, it is believed that the small grain size of the minerals in these areas is the result of growth in the solid or semi-solid inclusion. This concept may seem to conflict with the method proposed for the formation of the monzonitic porphyry, in which it was assumed that growth in the presence of solid material was responsible for the formation of the large crystals of potash feldspar. There are, however, two important differences between the methods of formation of the porphyry and the fine grained areas in the White Tank quartz monzonite:

1. The phenocrysts in the monzonitic porphyry probably formed over the same period of time as the crystals in the neighboring Palms quartz monzonite. In distinction, the inclusions may have been added to the White Tank quartz monzonite at any time during its cooling history, and the time allowed for ingestion may have been very small. More completely digested inclusions, incorporated at an earlier time, may now be indistinguishable from the surrounding quartz monzonite or may be responsible for the slightly coarser areas (of the same size as most inclusions) which are scattered through Units 1 and 2.

2. The monzonitic porphyry and its associated rocks appear to be more of a plutonic complex than the White Tank quartz monzonite. Thus, the solid material in which the porphyry was formed was probably heated to nearly the same temperature as the intrusive, and the temporary chilling effect which inclusions had on the White Tank quartz monzonite was not important.

IV. Origin:

It is proposed that the White Tank quartz monzonite was formed by the intrusion and solidification of molten or partially crystallized silicates, volatiles, and accessory oxides. The four units now exposed in the area are thought to be the result of the crystallization of different portions of this melt under slightly different conditions. Detailed analyses of the origins of individual features have been given throughout the descriptive material, and this section contains merely a summary of the arguments in favor of a magmatic origin.

A mass of rock which has formed by any process and has come to equilibrium under a given set of conditions should be homogeneous. The possible causes for inhomogeneity are these: 1, kinetic difficulties in establishing uniformity between originally different rock types; 2, difference in phase between different mediums of growth; and 3, chronologic sequence of events which affect different portions of the mass at different times. The inhomogeneities in the White Tank quartz monzonite are the following:

1. A vertical variation in composition and texture of the rock and trace element content of potash feldspar in one unit.

2. A difference in composition and texture of the rock and trace element content of potash feldspar among different units.

3. Local patches of different material (such as pegmatites, fine grained rims, etc.) near many contacts with the wall rocks.

4. Scattered and randomly oriented small inclusions of the wall rocks, many of which appear almost unaffected by the quartz monzonite.

No original variation in rocks which have now been converted to quartz monzonite could explain all of these inhomogeneities. Wall rocks around different units are identical in many places, although the units may be quite different in composition and texture. Gneissic wall rocks marked by nearly vertical foliation and compositional banding should not, if replaced, show the horizontal layers of different rock types which occur in one unit. It is also difficult to account for local patches of pegmatite near the borders by means of original variations in the parent rock.

It seems difficult to explain the inhomogeneities by assigning each one a different time in which to form. The compositional variations within one unit (such as the two facies of Unit 1, the pegmatitic vugs near the contacts, etc.) do not seem logically explained by assigning different periods of formation to each rock type. It is recognized, of course, that any hypothesis of formation by crystallization of a melt implies that different minerals formed at different times, but the argument here is directed against the idea of entirely separate periods of formation of the different parts of the quartz monzonite. The compositional differences among different units probably imply that the composition of the intrusions changed with time (unless there were separate, coexistent sources of slightly different composition for each unit).

It is believed, then, that the variations in the quartz monzonite are largely the result of difference in phase between different portions of the rock. This distinction of phases is more logically the difference between solid and liquid than the difference between portions of a solid rock which is undergoing replacement. For example, the crystallization of calcic oligoclase and mafic minerals and their settling toward the base of the melt intruded to form Unit 1 could cause the nearly horizontal layering of composition and texture which characterizes the unit. Differentiation of a portion of the melt which formed Unit 2 and injection of the resultant, more silicic, remaining fluid would cause Unit 3 to have a different composition from Unit 2. Segregation of a highly fluid, residual liquid from the partly crystallized rock near the contact of Unit 1 would form the pegmatitic vugs characteristic of the border zone. Thus, it is possible to explain the origin of the various features shown by the quartz monzonite by known or reasonably expectable mechanisms of crystallization of a silicate melt of appropriate composition. It does not seem possible to account for the detailed variations in texture and composition by any theory which explains the formation of the quartz monzonite by replacement of preexisting rock.

The concept of fractional crystallization and formation of two different rocks implies, of course, a certain amount of disequilibrium during the formation of the quartz monzonite. Evidence such as the zoning of plagioclase grains, the coexistence of different plagioclase grains of different compositions, and the coexistence of potash feldspar grains with different contents of trace elements indicates that disequilibrium was common during the formation of the White Tank quartz monzonite. As mentioned above, it is believed that this disequilibrium is more expected in the crystallization of a melt than in the replacement of solid rock.

Some petrologists have suggested that much of the albite and potash feldspar in igneous rocks has been introduced by metasomatism after consolidation of a more basic melt. In the case of the White Tank quartz monzonite, potash metasomatism is unlikely for several reasons:

1. Potash feldspar is distributed very unevenly through the quartz monzonite, both with regard to percentage and to grain size.

2. Trace element content of potash feldspar shows a marked variation through the rock.

3. Certain details, such as quartz inclusions increasing in size outward in a microcline crystal, suggest that potash feldspar grew concurrently with some other minerals in the rock.

Soda metasomatism seems unlikely for the following reasons:

1. Albite as a distinct phase is distributed very unevenly through the rock. For example, albitic rims are more abundant in the upper facies of Unit 1 than in the lower facies.

2. There appears to be no logical method whereby replacement of potash feldspar or plagioclase by pure albite would lead to the formation of myrmekite, which is commonly associated with albite.

3. The distribution of albite is explainable by theoretical disequilibrium processes during the crystallization of a silicate melt, and these processes would cause the distribution of albite found in the quartz monzonite.

These reasons against widespread potash and soda metasomatism do not rule out the possibility of magmatic late-stage replacement reactions involving soda and potash.* Those textures (such as myrmekite) which petrologists most commonly attribute to replacement, however, may also be explained by primary crystallization.

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* An early, and very good, summary of features formed by late-stage activity in igneous rocks is given by Colony (1923).

COMPARISON OF WHITE TANK AND PALMS QUARTZ MONZONITES

The two different quartz monzonite formations described in this thesis have almost identical compositions. The two rocks may be distinguished only by the difference in their textures. The White Tank quartz monzonite is generally coarser grained than the Palms quartz monzonite. Also, grains in the White Tank quartz monzonite are, with the exception of the quartz aggregates, distinct units not intergrown with other minerals. All minerals, and especially the feldspars, in the Palms quartz monzonite, however, are highly intergrown; borders between grains of potash feldspar and plagioclase are very complex and (as seen in thin section) are marked by "islands" of each mineral in the other.

The reason for the formation of sharp grain borders in one quartz monzonite and complexly intergrown borders in another is not definitely known. One possible explanation lies in the fluid content of the two melts from which the rocks crystallized. The White Tank quartz monzonite apparently formed from a melt relatively rich in water, as is indicated by the abundance of associated pegmatites and the coarse grained nature of the later-forming, differentiated rocks. Crystallization of the Palms quartz monzonite may have occurred in an environment relatively free of water, as is suggested by the lack of associated pegmatites and a grain size generally smaller than that of the White Tank quartz monzonite. Possibly, then, a low water content in the medium in which crystallization was completed resulted in the complexly intergrown borders, whereas a more fluid medium permitted the growth of distinct crystals with sharp borders.

This conclusion does not mean that the two melts as intruded contained different amounts of water. Possibly the presence of a zone of monzonitic porphyry peripheral to part of the Palms quartz monzonite implies that much of the water in the original intrusion was lost to the wall rocks, where it promoted the formation of the porphyry. The absence of pegmatites associated with the Palms quartz monzonite may, also, merely signify loss of volatiles at an early stage in the crystallization of the melt. The hypothesis expressed above merely proposes a difference in water content of the two melts during the later stages of their crystallization.

If both of the intruded melts contained originally about the same amount of water, the loss of water from one intrusive and not from the other is difficult to explain. The wall rocks are roughly identical for each intrusive. Perhaps the temperature of the wall rock or the depth of intrusion was the deciding factor in determining loss or retention of volatile material, but the true explanation is unknown.

DIKES

I. Introduction:

Scattered throughout the mountains around Forty Nine Palms are numerous small dikes. They are rarely more than one foot thick and generally can be traced for only a few feet in outcrop. Miller (1938) called attention to their general distribution by mapping a few large dikes and stating that there were many others too small to map (the scale of his map was approximately three miles to the inch). The present writer feels, however, that none of the dikes is large enough to map, even on the scale used in the present work (one mile to the inch).

These dikes cut the Palms quartz monzonite and monzonitic porphyry, but their age relation to the White Tank quartz monzonite has not been determined. It has also been impossible to determine whether or not these dikes are related to one of the major plutonic intrusions.

II. Structure:

Most of the dikes are too fine grained to exhibit any megascopic structure. The dikes appear massive in thin section.

III. Composition and Texture:

Two types of dike rock occur: white to light gray, silicic dikes; and, in lesser amounts, greenish-gray, basic dikes.

The silicic dikes are typified by sections 428 (Fig. 82) and 429. They contain about 20 percent phenocrysts, 0.5 to 1 millimeter in diameter, consisting of quartz, potash feldspar, and plagioclase.

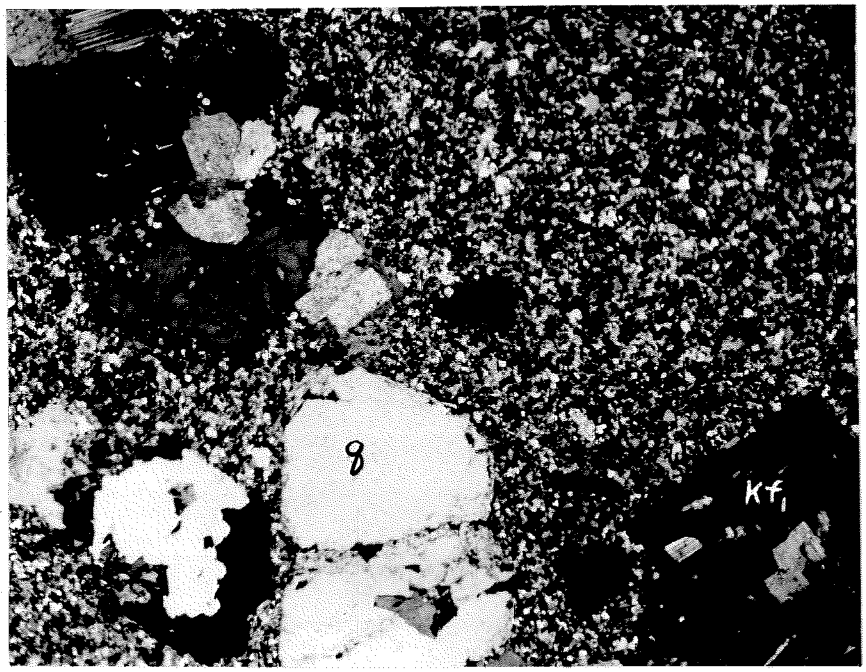

Fig. 82. Sample 428 of silicic dike cutting Palms quartz monzonite north of Forty Nine Palms. Phenocrysts are quartz (q), plagioclase (p), and potash feldspar (Kf). Groundmass is a mixture of quartz and feldspar. Crossed nicols, X25.

The potash feldspar phenocrysts are anhedral, either twinned or untwinned, and may exhibit zones of slightly different crystallographic orientation. The potash feldspar may contain inclusions of quartz in the outer parts of the grains or along zonal borders. Some of the potash feldspar phenocrysts contain patch perthite. Plagioclase forms subhedral to euhedral, faintly zoned and/or twinned, grains with an average composition of An_{30}. Quartz occurs in subhedral, equant grains.

The groundmass consists of quartz, potash feldspar, and plagioclase (in that order of abundance). A few biotite flakes, muscovite flakes up to 0.75 millimeter long, and some opaque white powder make up the rest of the groundmass. The average grain size in the groundmass is 0.1 millimeter or less and is different in different dikes or different layers of the same dike. In section 428, some of the potash feldspar in the groundmass may poikilitically include the quartz and plagioclase. In section 429, an 0.5-millimeter-wide stringer of massive quartz separates layers of different grain size (0.05 millimeter and 0.3 millimeter) in the groundmass of the dike. Possibly these two layers represent separate intrusions. Section 429 contains a few patches of graphic granite in the groundmass.

The best example of the more basic dike rock is sample 430. It contains an estimated 30 percent hornblende pleochroic from yellowish green to greenish blue; 5 percent biotite pleochroic from yellow to reddish brown; 45 percent irregularly twinned, strongly zoned plagioclase with a compositional range from An_{50} in the center to An_{30} on the edge; 20 percent quartz; and a little magnetite, apatite, and allanite. All grains are anhedral and average 0.1 millimeter in size (except for some plagioclase laths which are seriate from the groundmass size up to 1 millimeter). Some of the quartz occurs in aggregates of 0.5-millimeter grains. Sericitic alteration is abundant in the center of many plagioclase grains.

IV. Origin:

These dikes have almost certainly formed by intrusion and crystallization of a melt. The distinction between phenocrysts and groundmass is partly caused by chilling of a partially crystallized melt, although the inclusions of groundmass in the outer portions of potash feldspar phenocrysts indicate that at least some of the groundmass started crystallizing before the feldspar phenocrysts stopped growing. The presence of quartz phenocrysts is significant in view of the previously postulated early crystallization of quartz in the White Tank quartz monzonite.

BASALT

Malapai Hill (Fig. 83) is composed largely of black, aphanitic, olivine-bearing basalt. Similar rock is present at one place in the Lost Horse Mountains outside of the map area. No flows are associated with Malapai, and apparently it is a shallow intrusive rock. Columnar structure is commonly vertical but forms wide loops and is nearly horizontal in places. The basalt cuts the White Tank quartz monzonite and is probably quite young, but its true age is unknown.

Fig. 83. Malapai Hill.

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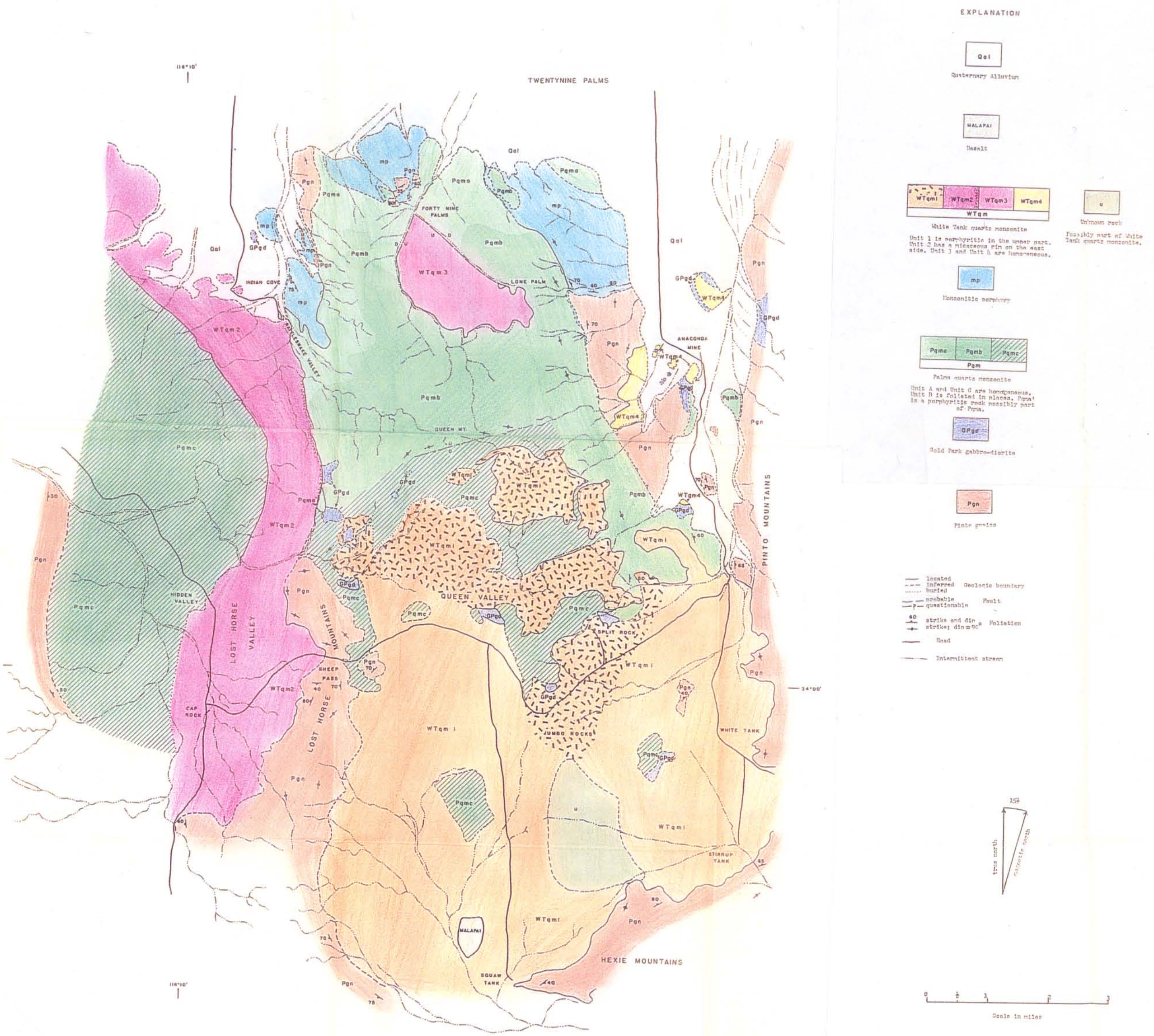

GEOLOGIC MAP OF A PORTION OF JOSHUA TREE NATIONAL MONUMENT

Geology by John J. W. Rogers, 1953-1954. (In part adapted from W. J. Miller, 1938.)

Planimetric base by John J. W. Rogers from aerial photographs obtained from U. S. Air Force.