PETROGRAPHY AND PETROGENETIC HISTORY OF A QUARTZ MONZONITE INTRUSIVE, SWISSHELM MOUNTAINS, COCHISE COUNTY, ARIZONA

by

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ABSTRACT

PETROGRAPHY AND PETROGENETIC HISTORY OF A QUARTZ MONZONITE INTRUSIVE, SWISSHELM MOUNTAINS, COCHISE COUNTY, ARIZONA

by

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The Swisshelm Quartz Monzonite covers about two square miles on the western slope of the Swisshelm Mountains, Cochise County, Arizona. Field observation and petrographic study indicate that the quartz monzonite was derived by differentiation and late-stage alkali metasomatism of probably a quartz dioritic magma rich in alkali and volatile constituents. The high concentration of the volatiles is believed to be of great importance in the development of the different facies and rock types. Four different facies of the Swisshelm Quartz Monzonite have been distinguished as (1) the normal facies, (2) the altered facies, (3) the fine-grained facies, and (4) the contact facies. Also, several aplite dikes, local beryl-bearing pegmatite patches, and numerous quartz veins are present and attributed to

late magmatic differentiation. Inclusions of an early and late magmatic facies are sparsely disseminated throughout the quartz monzonite.

The Swisshelm Quartz Monzonite magma has intruded and metamorphosed the Upper Paleozoic sediments of the Naco Group as well as the Lower Cretaceous sediments of the Bisbee Group. The metamorphism is of a contact metasomatic type to which the mineralogical and textural changes in the country rocks have been attributed.

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INTRODUCTION

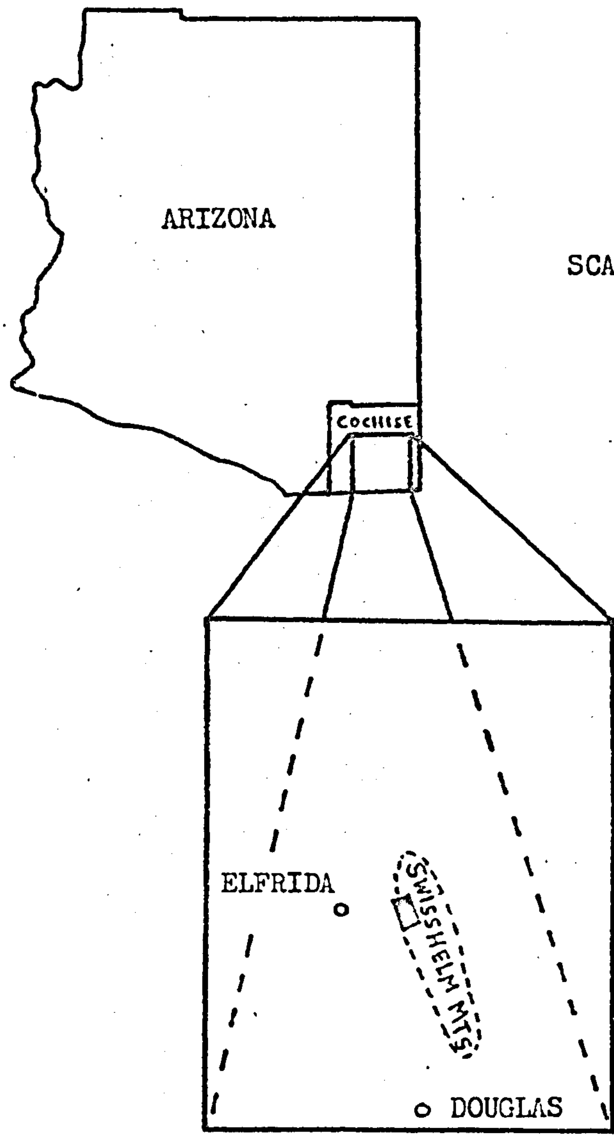
Location and Accessibility

This thesis covers a portion of the Swisshelm Mountains which are located in Cochise County in the extreme southeast corner of Arizona, twenty miles from the town of Douglas and the Mexican border, and thirty miles from the Arizona-New Mexico border. They extend from 109°30' to 109°35' N latitude and from 31°30' to 31°40' W longitude. The Swisshelm Mountains are easily accessible from all sides via ungraded gravel roads.

The area investigated is a portion of the northwestern part of the Swisshelm Mountains and lies on the western side of the range. It comprises approximately the southern three-fourths of Sec. 14, Sec. 23, the northern quarter of Sec. 26, and the eastern fourth of Sec. 15 and 22. The area is reached by a seven mile drive over a partially improved road east from Elfrida (Fig. 1).

Purpose of Investigation

This investigation interprets the petrographic features and proposes a petrogenetic history for a quartz monzonite stock. The igneous rocks are intrusive into a series of Paleozoic and Mesozoic sediments which have been contact metamorphosed. The characteristics of these rocks will also be discussed.



SCALE : 1 INCH = 146 MILES

SCALE : 1 INCH = 24 MILES

FIGURE 1

INDEX MAP SHOWING THE AREA OF STUDY

Method of Investigation

Mapping of rock features was carried out in the field and plotted on an enlarged U. S. G. S. topographic map of the Swisshelm Mountains Quadrangle. Macroscopic characteristics were noted in outcrops and in hand specimens. Specimens were collected in the field at the stations shown on the specimen location map (Plate 1). About 300 thin sections were prepared and studied in the Laboratory under the polarizing microscope. Selected thin sections from the various facies of the quartz monzonite stock and the aplite dikes were stained to aid in the estimation of the percentage of K-feldspar present. Modal analyses for the igneous rock types were made by the point count method, using a mechanical stage with a minimum grid interval of 0.2 mm. Chemical compositions of the various facies of the quartz monzonite were calculated from their modal analyses by use of the tables given in Wahlstrom (1955). Photographs and photomicrographs were taken to illustrate important features.

Previous Work

Loring (1947) wrote a thesis on the geology and ore deposits of the Mountain Queen area of the northern Swisshelm Mountains to the northeast of the thesis area.

Galbraith and Loring (1951) studied the Swisshelm district (in Arizona Zinc and Lead Deposits, part 2).

Rogers (1954) studied the stratigraphy and structure of the southern Swisshelm Mountains, an area to the south of the area under investigation.

A partial section of the Abrigo Limestone on the northwestern spur of the Swisshelm Mountains has been described by Gilluly (1956).

Epis and Gilbert (1957) recognized El Paso Limestone, of Ordovician age, and correlated it with that of the Peloncello Mountains in southwestern New Mexico.

Epis, Gilbert, and Langeheim (1957) described the upper Devonian Swisshelm formation.

A reconnaissance geologic map of southeastern Cochise County, Arizona, including the Swisshelm Mountains, was compiled by Cooper (1959).

A short discussion of the Swisshelm Mountains by Dickinson and Pye is included in <u>Southern Arizona Guidebook II</u> (1959), published by the Arizona Geological Society.

Balla (1962), in a thesis, "The geology and geochemistry of beryllium in southern Arizona," discusses the occurrence of beryllium in the quartz monzonite of the Swisshelm Mountains.

Acknowledgments

The writer wishes to express his sincere appreciation to Dr. Robert L. DuBois, Department of Geology, University of Arizona, for his constant guidance and direction in every phase of this study. The writer also acknowledges the help of other members of the faculty of the Geology Department.

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R. Mauger, for staining thin sections

L. C. Arnold, for X-ray measurement

S. Hanson, for universal stage technique

V. Hoffman, for photomicrographs

GEOLOGIC SETTING

Rocks exposed in the vicinity of the mapped area range in age from Pre-cambrian to Quaternary. Pre-cambrian rocks consist of a granitic mass which underlies Middle Cambrian sediments and the Bolsa Quartzite. Paleozoic formations above the Bolsa consist of the Upper Cambrian Abrigo formation, Ordovician El Paso limestones, Upper Devonian Swisshelm formation, Lower Mississippian Escabrosa Limestone, and Pennsylvanian-Lower Permian Naco Limestone. A thick accumulation of Lower Cretaceous sediments of the Bisbee Group unconformably overlies the Paleozoic rocks. Tertiary rhyolite is exposed on the northeastern and southeastern margins of the Swisshelm Mountains (Loring, 1947 and Rogers, 1954).

In the thesis area a quartz monzonite stock of Laramide age (?) outcrops. It is bounded on the northeast and south by contact metamorphosed rocks and is transected by numerous dikes. The metamorphic rocks are derived from the Paleozoic sediment of the Naco Group and the Lower Cretaceous sediments of the Bisbee Group. They range from recrystallized limestone and dolomite to lime-silicate hornfels and metaquartzites.

PETROGRAPHY

Igneous Rocks

The main igneous rock in the mapped area is a quartz monzonite mass which probably represents an upward extension of an intrusive stock. Associated with this mass are aplite dikes, pegmatite, quartz veinlets, porphyritic rhyolite dikes, andesite porphyry dike, and lamprophyric dikes.

Swisshelm Quartz Monzonite

A large mass of quartz monzonite, here termed the Swisshelm Quartz Monzonite, is well exposed on the northern part of the mapped area where it forms two large ridges or spurs called here the northern and the southern spurs. The quartz monzonite extends southward and occurs in smaller outcrops in dry washes. The mass is thought to extend for a considerable distance beneath the alluvium to the west of the area studied (Plate 1).

The quartz monzonite is porphyritic and is remarkable for the large size of the orthoclase phenocrysts, which may reach a length of about 6 cm. and a width of 3-4 cm. They are especially conspicuous on weathered surfaces. Dark, fine-grained, irregularly shaped inclusions are sparsely disseminated throughout the main facies. Light blue to colorless beryl occurs as patches and single crystals on fractures associated with muscovite and colorless to light-purple fluorite.

Striking features of weathering are the formation of large rounded boulders and eroded joints (Fig. 24).

The quartz monzonite stock is intrusive into the Paleozoic-Mesozoic sedimentary rocks with which it is in contact. Contact metamorphism of adjacent sedimentary rocks amply supports this conclusion. The contact is irregular and shows considerable evidence of reaction. Apophysis and blocks of country rock in the intrusion near the contact are observed. The age of the quartz monzonite is Post-Lower Bisbee Group and most likely Laramide Age (?)

Four facies of the Swisshelm quartz monzonite have been recognized: 1. The northern spur normal facies, 2. The southern spur altered facies, 3. The southern spur fine-grained facies, and 4. The contact facies. These four facies differ in grain size and in the relative proportion of the minerals present. These four facies could not be distinguished in field mapping. The average mineral and chemical compositions of the various facies are summarized in Tables 1 and 2, respectively.

The northern spur normal facies includes rocks of the northern spur, the eastern part of the southern spur, and small outcrops to the south of the southern spur. Megascopically the rock is light gray to light-pinkish gray.

The northern spur normal facies is light gray to light-pinkish gray on fresh surface and light-brownish gray on weathered surface. It is porphyritic and consists of large phenocrysts of orthoclase scattered in a medium-grained and mostly equigranular ground mass. The minerals recognizable are quartz, pinkish orthoclase, white plagioclase, and biotite slightly altered to chlorite. Muscovite is recognizable in places where it occurs in clusters with iron stains along the quartz veinlets. Microscopically the texture ranges from seriate to almost equigranular. The essential minerals are quartz, orthoclase, plagioclase, and biotite. Accessory minerals are magnetite, sphene, zircon, apatite, calcite, fluorite, and allanite (?). This last-named mineral has been tentatively identified in thin sections as allanite. X-ray techniques did not give conclusive results, because the data fit both allanite and apatite. On the universal stage the mineral appears to be uniaxial, which is in agreement with apatite rather than allanite. Alteration minerals are chlorite, muscovite, hematite, sericite, and clay minerals.

Quartz is an abundant mineral and makes up 20 to 27 per cent of the rock. It occurs as rounded to subrounded grains filling the interstices between other constituents. The grain size ranges from 0.08 mm. to 5.00 mm. in diameter. The larger quartz grains are usually fractured and show undulatory extinction; those of smaller size frequently are included in the outer rims of the feldspar crystals (Fig. 2a and Fig. 2b).

Inclusions of apatite, sphene, zircon, and magnetite grains are the most common in quartz; those of mica and feldspar are less abundant. Also present are inclusions of hair-like needles of a mineral which is considered to be rutile. They are irregularly scattered throughout some of the quartz grains and vary in length.

Orthoclase occurs as large phenocrysts and as a major constituent in the ground mass forming 37 per cent to 45 per cent of the ground mass. It forms subhedral to anhedral crystals as much as 5 mm. in diameter. Carlsbad twinning is common and the orthoclase is mostly perthitic (Figs. 2a and 2b). The intergrown albite in some perthites shows polysynthetic twinning. Clay alteration is common in the orthoclase.

Three types of perthite are recognizable, a vein type and a patchy type (Figs. 2a and 2b). A film type is present but not as abundant as the other two. Vein perthite occurs as irregular and lens-shaped albite blebs intergrown with the host orthoclase crystal. It is considered to have been formed by a filling of contraction cracks. In the patchy perthite, the orthoclase has been partly replaced by albite in irregular patches that are generally irregularly distributed throughout the orthoclase host. In modal analysis no attempt has been made to estimate separately the plagioclase content of the perthite and the perthite is counted as orthoclase.

In thin section the large phenocrysts are patchy perthite, with orthoclase forming 77 per cent of the single phenocrysts as determined by point counting. The phenocrysts enclose poikilitically the following minerals: quartz, 8 per cent; oligoclase, 6 per cent; biotite, 3 per cent; muscovite, trace; magnetite, 3 per cent; apatite 1.5 per cent, sphene and zircon, 2 per cent. The grain size of the inclusions ranges from 0.20 mm. to 3 mm. in diameter. They occur as local segregations of subhedral to anhedral crystals and also as sporadic individual crystals throughout the phenocrysts (Fig. 3). The quartz is in part in optical continuity suggesting some graphic texture type. Alteration of oligoclase to sericite and sphene to

Figure 2a - Photomicrographs of the normal facies showing anhedral interstitial quartz, vein to patchy perthitic orthoclase with carlsbad twin, and subhedral, slightly sericitized and albite-twinned plagioclase.

Figure 2b - Same as above.

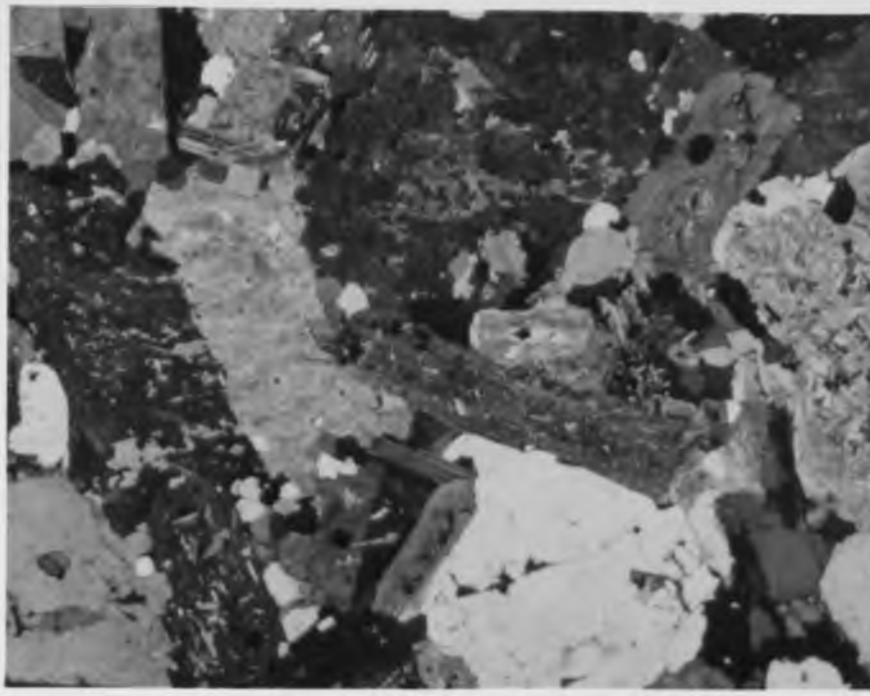

Figure 2a

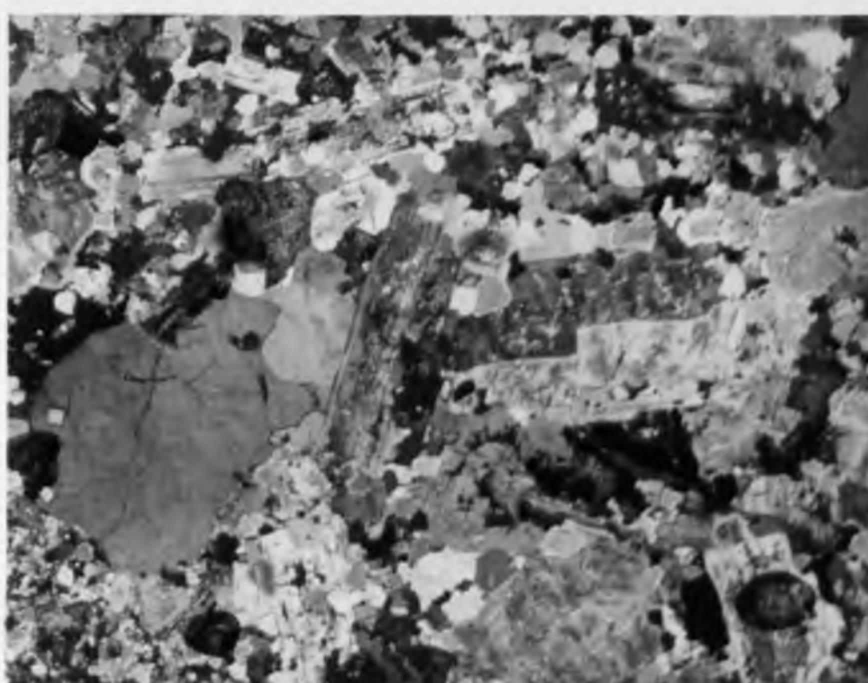

Figure 2b

Figure 3 - Photomicrograph of a phenocryst from the normal facies showing patchy perthite with local segregation of quartz, biotite, and magnetite inclusions (crossed nicols, 24x).

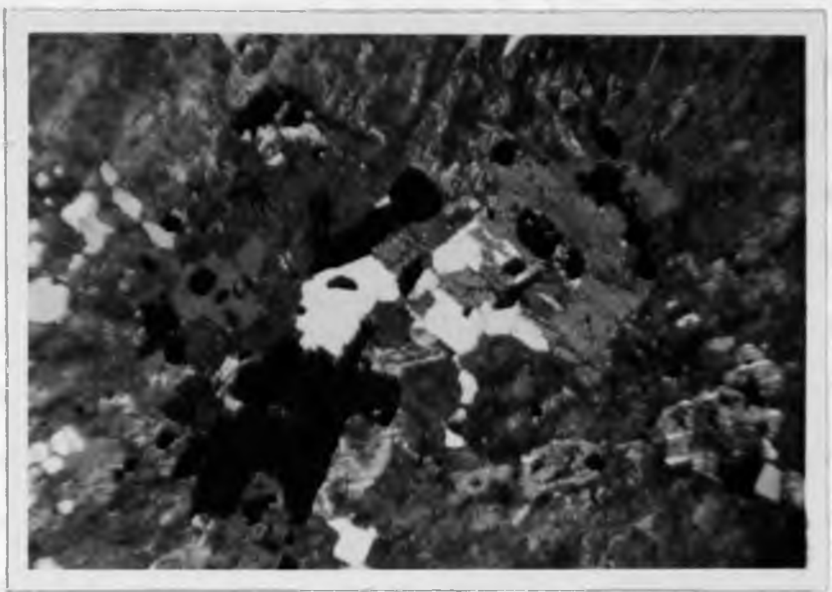

Figure 3

leucoxene is observed. Muscovite partly replacing biotite, and oligoclase was seen in some thin sections.

Plagioclase (An_{22-30}) is definitely subordinate to perthitic orthoclase in every specimen examined. It comprises 23.5 per cent to 30 per cent of the rock and varies in composition from albite to oligoclase. The plagioclase (oligoclase) usually occurs in subhedral to anhedral plates which measure up to 4 mm. or 5 mm. in length. It also occurs as inclusions in quartz. The albite occurs as perthitic intergrowths with orthoclase. The plagioclase is not strongly zoned; albite twinning is characteristic. Some of the plagioclase crystals are nearly fresh and free from alteration, others are slightly to highly altered to sericite or coarse muscovite and clay minerals (Figs. 2a and 2b). Replacement along the twin lamellae by muscovite, calcite, and fluorite was observed in some thin sections. Rounded, small, quartz grains partly surround the outer rims of some of the plagioclase crystals. Quartz occurs in these rocks as an essential, ground mass-forming mineral which tends to occur as separate subhedral crystals rather than interstitial to other crystals.

Biotite is a common subhedral mineral in the specimens examined, making up 4 per cent to 5 per cent of the rock. The biotite crystals are locally clustered, but generally uniformly distributed throughout the rock. The biotite is partly to completely altered to chlorite and is frequently interlaminated with muscovite, and locally the muscovite partly surrounds the biotite as a mantle. Usual accessory minerals such as magnetite, apatite, sphene, zircon, and sometimes fluorite are associated with biotite. The chlorite and muscovite, formed as alteration products of biotite, were counted as biotite in modal analysis.

Muscovite is subordinate to biotite in the normal rock type. In some specimens it is the only mica present and constitutes 6 per cent to 8 per cent of the mass. It occurs in irregular patches or locally in fanlike aggregates in the same size range as biotite. Locally muscovite is intergrown with orthoclase and also occurs as alterations of plagioclase, and as inclusions in quartz. Associated minerals are apatite and fluorite.

Chlorite is the major alteration mineral of biotite. It is a pennine type with parallel extinction and occasionally an abnormal blue interference color. The color in plain light is usually pale green, and the interference color is lower first order.

Magnetite is the most abundant accessory mineral making up 2 per cent to 3 per cent of the rock. It occurs as irregular grains and octahedrons scattered throughout the rock. The grain size varies from 0.05 mm. to 1.00 mm. in diameter and the magnetite is usually associated with biotite, zircon, and sphene. It is slightly altered to hematite which forms a partial rim around the grains.

Apatite is a common accessory mineral forming irregular grains and euhedral prismatic crystals up to 0.35 mm. in length. Apatite also forms aggregates and appears as inclusions in other minerals.

Sphene occurs as relatively large euhedral to subhedral crystals up to 1 mm. in diameter. It is usually associated with biotite, magnetite, and zircon.

Zircon forms euhedral to subhedral crystals as much as 0.5 mm. in diameter. It occurs as inclusions in a host mineral and usually is associated with biotite, magnetite, and sphene.

Fluorite and calcite are usually present as irregular grains and thin films filling the spaces between the other minerals. These minerals replace partly some of the plagioclase crystals and the fluorite locally occurs as inclusions in biotite. Allanite (?) is present in some specimens as irregular grains up to 0.8 mm. in diameter. It is associated with biotite, magnetite, sphene, and zircon.

Sericite is an alteration product of some of the plagioclase crystals and occurs mainly in the cores of the crystals. It forms fine-grained shreds less than 0.05 mm. in size which give the plagioclase core a semi-opaque appearance.

Clay minerals are derived from the alteration of the feldspars. They occur as finely disseminated dust which gives a faint cloudy effect to the host crystal. The alteration is greater in orthoclase and less in the plagioclase.

The southern spur altered facies is almost confined to the western part of the spur. Megascopically, the rock is highly weathered and crumbly with a dusty brown color on the weathered surface and light gray on the fresh surface. This altered facies is generally similar in mineral composition, texture, and grain size to the northern spur normal facies. Thin sections and point counting show considerable variations in the degree of alteration and in the proportions of some of the minerals present. Locally, subgraphic texture was observed. The main mineral assemblage is composed of quartz 21 per cent to 28 per cent, perthitic orthoclase 28 per cent to 38 per cent, oligoclase (An_{20-30}) 28 per cent to 30 per cent, and biotite 1 per cent to 1.5 per cent. The perthitic orthoclase is highly altered to clay minerals and most of the oligoclase crystals are altered to sericite, coarse muscovite, and clay minerals. In some thin sections oligoclase occurs as euhedral crystals beside the more common subhedral and anhedral forms. Muscovite is predominant and forms 6.5 per cent to 8 per cent of the rock as a replacement of the biotite and feldspar (Fig. 4). Chlorite after biotite was not observed in these rocks, whereas it is common in rocks of the northern spur. Minor minerals are magnetite, apatite, sphene, zircon, fluorite, and calcite. They are more or less similar to those of the northern spur normal facies, but the fluorite is more abundant and the alteration of magnetite to hematite and sphene to leucoxene is more conspicuous in this altered facies.

The southern spur fine-grained facies is mainly associated with the southern spur altered facies forming separate blocks or masses partly capping some of its exposures (Fig. 5). Other outcrops of this facies are exposed between the two spurs to the west of the contact with Cretaceous rocks and in some of the dry washes to the south of the southern spur. Megascopically the rocks of this facies are light brownish gray to light olive gray on both weathered and fresh surfaces. They generally have a porphyritic texture with small phenocrysts of altered feldspar crystals, irregular quartz grains, and mica flakes scattered throughout a fine-grained ground mass.

The phenocrysta make up 10 per cent to 15 per cent of the rock and consist of 5 per cent to 7 per cent of oligoclase forming subhedral

Figure 4 - Photomicrograph of the altered facies showing muscovite partly replacing perthitic orthoclase (crossed nicols, 24x).

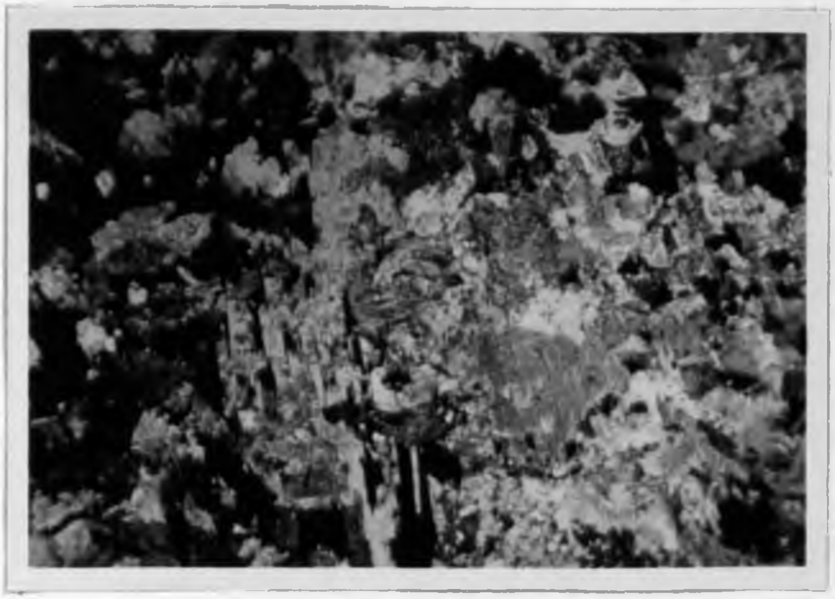

Figure 4

Figure 5 - Photograph of a field outcrop showing the fine-grained facies capping the altered facies on the northern slope of the southern spur. A sharp contact exists between the two types.

Figure 5

to anhedral crystals as much as 5 mm. in diameter, 3 per cent to 4 per cent of perthitic orthoclase occurring as subhedral and anhedral crystals up to 4 mm. in length, 1 percent to 2 per cent of rounded to subrounded, fractured quartz grains that reach 3 mm. to 4 mm. in diameter, and 1 per cent to 2 per cent biotite and muscovite flakes. The remaining portion of the rock consists of a ground mass with an average grain size about 0.5 mm. in diameter. The ground mass is characterized by graphic texture and composed of quartz 16 per cent to 22 per cent, orthoclase 41 per cent to 47 per cent, microcline 1 per cent to 2 per cent, oligoclase (An_{24-28}) 11 percent to 14 per cent, biotite 1 per cent to 2.5 per cent, muscovite 4 per cent to 6 per cent, and magnetite 2.5 per cent to 3 per cent. Apatite, sphene, zircon, and fluorite are minor constituents, although fluorite is notably more abundant. Quartz occurs in the ground mass as patches, blebs, and lobes subordinate to the larger areas of the orthoclase. It is also found filling the interstices of the fabric. Orthoclase is partly perthitic with slight alteration to clay minerals. It is intergrown with quartz, forming a graphic texture in the ground mass (Fig. 6). Microcline is nearly free from alteration. Locally the oligoclase phenocrysts are so extensively altered to sericite, coarse muscovite, and clay minerals that the albite twinning is partly obscured. Oligoclase in the ground mass is nearly fresh. Biotite forming dirty patches and bundles is usually associated with muscovite, magnetite, and other accessory minerals. In one specimen taken from station 6, the biotite is partly altered to chlorite. Magnetite generally is altered to hematite.

Figure 6 - Photomicrograph of the fine-grained facies showing a fine-grained matrix with local graphic intergrowth (crossed nicols, 24x).

Figure 6

Fluorite is present replacing the oligoclase. The southern fine-grained facies is gradational to the altered facies in texture and composition. The modal analysis and chemical composition of typical specimens of this facies are included in Table 1.

The contact facies is confined to the contact with the upper Paleozoic metamorphic rocks. Three subfacies are recognizable as diorite, monzonite, and syenite. Generally the rocks of this facies are finer-grained and lighter in color than the other facies of the Swisshelm Quartz Monzonite.

The diorite subfacies is not well exposed in the field. It is present just as small rock fragments scattered on the dump material of the beryl prospect pit. Near the prospect pit an aplite dike occurs which is covered by the dump material (Pl. 1). No contact was observed either with the quartz monzonite normal facies or with the upper Paleozoic metamorphic rocks.

Megascopically, the rock is fine-grained to medium-grained in texture and highly altered, forming a soft clay-like white to bluish-white material. Recognizable minerals are white altered feldspars, white and black mica, colorless to light purple fluorite, nearly colorless to light blue beryl, and clay minerals. The beryl occurs mainly as irregular patches on fractures and is formed of subhedral to anhedral crystals associated with muscovite and fluorite.

Microscopically, the rock is hypidiomorphic granular to xenomorphic granular in texture with an average grain size of about 1.5 mm. in diameter. The proportions of the minerals present are quartz, 1 per cent; oligoclase (An_{30}), 52 per cent; muscovite, 25 per cent; fluorite, 10 per cent; calcite, 9 per cent; sphene, zircon, and apatite, 2 per cent. Quartz is a rare mineral. However, a few small interstitial grains were seen. Oligoclase is the major constituent mineral and occurs as unzoned, subhedral to anhedral crystals that are, in part, twinned. It is mainly altered to clay minerals, muscovite, and calcite and slightly to sericite. Muscovite, calcite, and fluorite are abundant and form subhedral to anhedral crystals, replacing the oligoclase and filling the interstitial spaces. Original biotite is generally completely replaced by muscovite. Sphene, zircon, and apatite are common accessory minerals which occur as euhedral, subhedral, and anhedral crystals disseminated throughout the rock. Locally, sphene is altered to leucoxene (Fig. 7).

In thin section the beryl patch consists of beryl, 80 per cent; fluorite, 15 per cent; muscovite, 3 per cent; zircon, sphene, and garnet, 2 per cent. The beryl occurs as subhedral to anhedral crystals up to 1 cm. in length. Fluorite and muscovite form irregular patches interstitial to the beryl crystals. Zircon, sphene, and garnet form irregular grains disseminated throughout the patch.

The monzonite subfacies is only exposed immediately to the west of the fluorite prospect pits shown on the map and occurring in a dry wash to the north of the syenite exposure. The contact with the quartz monzonite normal facies and the syenite subfacies was not observed in the field; whereas, the contact with the upper Paleozoic metamorphic limestone is sharp and abrupt.

Megascopically, the rock is medium-grained in texture and pinkish-brown, gray to light yellowish-gray in color. The minerals

Figure 7 - Photomicrograph of the diorite contact subfacies showing abundant and highly altered plagioclase associated with isotropic fluorite (crossed nicols, 12x).

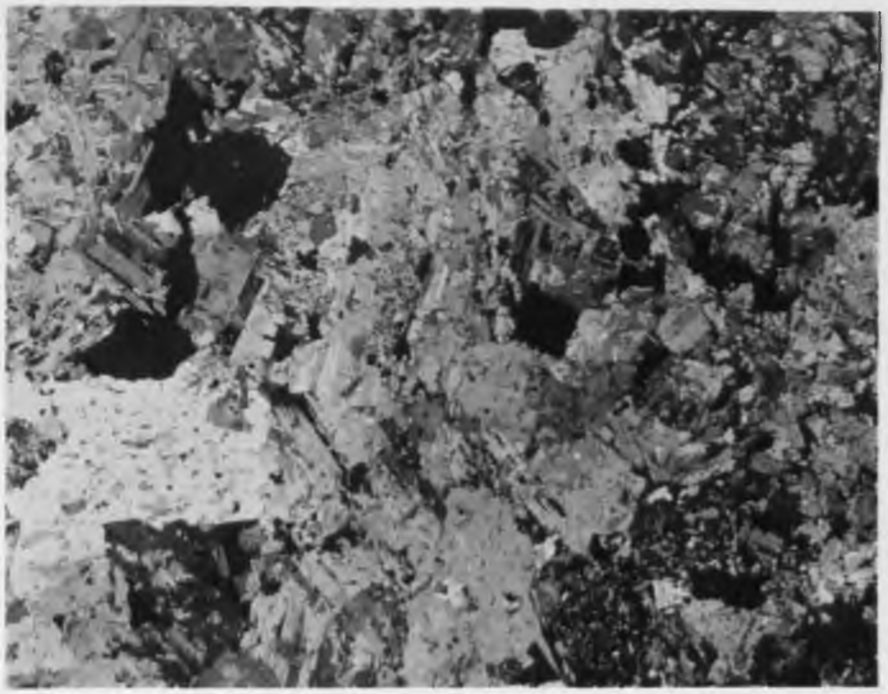

Figure 7

identified in hand specimens are as follows: Pinkish K-feldspar, white plagioclase, yellowish-brown sphene, muscovite, and violet fluorite.

Microscopically, the rock has a hypautomorphic-equigranular texture with an average grain size of about 2 mm. in diameter. The rock consists of quartz, 1 per cent; orthoclase, 42 per cent; plagioclase, 35 per cent; muscovite, 10 per cent; fluorite, 5 per cent; calcite, 4 per cent; sphene, 2 per cent; zircon and apatite, 1.5 per cent.

Quartz is rare in this subfacies; however, a few tiny irregular grains are present interstitially and as inclusions in the orthoclase. Orthoclase, as in the quartz monzonite normal facies, is partly patchy and veinlike perthite interstitial to the plagioclase crystals. Plagioclase forms subhedral to anhedral oligoclase (An_{28}) crystals and small patches or strings of albite perthitically intergrown with the orthoclase. The plagioclase is partly altered to sericite, coarse muscovite, and clay minerals. Muscovite, fluorite, and calcite occur in irregular patches filling the interstices or partly replacing the feldspars. Sphene forms anhedral grains highly altered to leucoxene. Zircon and apatite are abundant accessory minerals occurring as sporadic crystals and are usually associated with sphene and muscovite as inclusions in the feldspars.

The syenite subfacies is exposed northwest of the main fluorite prospect pits in the southern part of the mapped area (Pl. 1). It forms a narrow border zone with gradational contact with the normal facies of the quartz monzonite stock to the west and has a sharp contact with the upper Paleozoic metamorphic rocks to the east. The border zone is traceable for only a short distance along the contact.

Megascopically, the rock is medium-grained in texture and light greenish-gray on fresh surface and light brownish-gray on weathered surface. Recognizable minerals are gray feldspar, pale greenish muscovite and small magnetite grains with red iron stains scattered throughout the rock.

Microscopically, the rock is hypautomorphic-equigranular with an average grain size of about 2 mm. in diameter. The following minerals are identified: Quartz, orthoclase, plagioclase, muscovite, fluorite, magnetite, sphene, zircon, and apatite. Quartz is present in amounts up to 2.5 per cent and occurs as interstitial grains (Fig. 8). Orthoclase is perthitic and makes up 79 per cent of the rock. Plagioclase is confined to albite, which is intergrown with orthoclase as perthite. Muscovite is the only mica present and forms irregular patches and fanlike aggregates which make up to 8 per cent of the rock. Six per cent fluorite is present and occurs as irregular patches filling spaces between the other constituents. Magnetite, up to 1 per cent, forms irregular grains highly altered to hematite. Sphene, zircon, and apatite constitute about 2 per cent of the rock, but sphene is the most abundant and locally is altered to leucoxene. Slight alteration of orthoclase to clay minerals is present.

Figure 8 - Photomicrograph of the syenite contact sub-facies showing abundant orthoclase with film to vein-like perthite (crossed nicols, 13x).

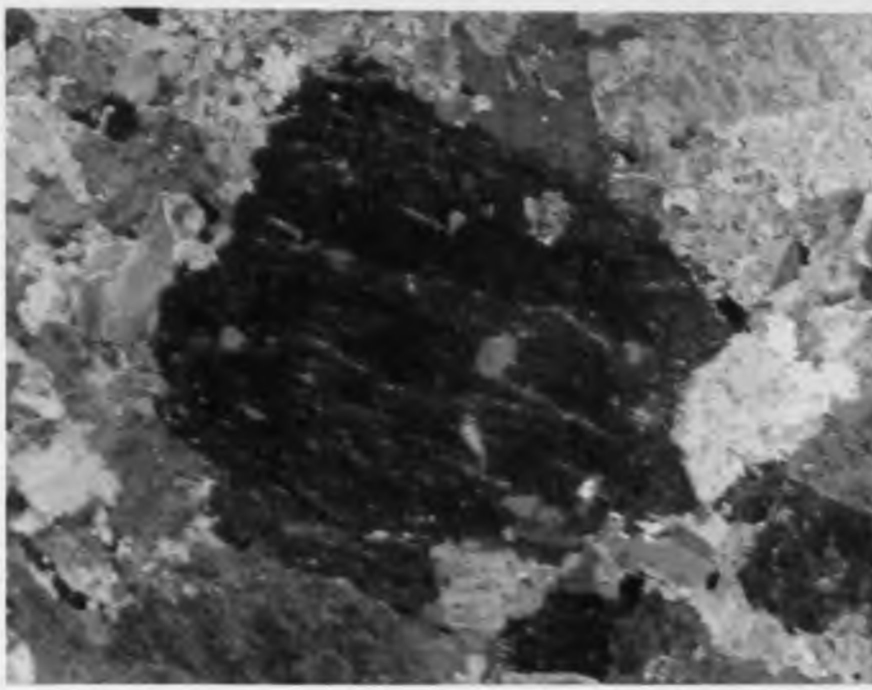

Figure 8

Table 1. Modal Analysis of Swisshelm Quartz Monzonite

Facies	Sub-facies	Sample No. *1	Quartz	Orthoclase	Plagioclase	Biotite-Chlorite	Muscovite	Magnetite	Others *2
		1	20.0	44.5	24.5	5.0	Trace	3.0	3.0
		7-E	22.0	45.0	23.5	4.0	"	2.5	2.5
Normal		8-A	25.0	37.0	30.0	4.0	"	2.0	1.5
facies		9-A	27.0	37.0	28.0	4.0	"	2.5	2.0
		32	24.0	44.0	22.0	4.5	1.0	3.0	1.5
		33	24.5	40.0	27.0	4.0	Trace	3.0	1.5
		6-A	22.5	40.5	25.0	3.5	4.0	2.0	2.0
		18-C	24.5	40.0	26.0	4.0	2.0	2.5	1.0
		21-A	26.5	32.0	34.0	3.0	1.0	2.0	1.5
Altered		11-B	22.0	37.0	28.0	1.5	7.5	2.5	2.5
facies		12-A	21.0	38.0	30.0	1.0	6.5	1.5	2.0
		20	28.0	32.0	29.0	1.0	8.0	3.0	3.0
		29-A	28.0	39.0	23.0	1.0	5.0	2.5	1.5

Table 1. Continued

Facies	Sub-facies	Sample No.[1]	Quartz	Orthoclase	Plagioclase	Biotite-Chlorite	Muscovite	Magnetite	Others[2]
Fine-grained facies		11-A	23.0	45.0	23.0	1.0	4.0	3.0	1.0
		10-C	18.0	53.0	17.0	2.5	6.0	2.5	2.0
		6-B	17.0	54.0	17.0	2.5	6.0	2.5	1.0
		29-C	24.0	50.0	18.0	1.0	2.5	2.5	2.0
		32-B	21.5	51.0	17.0	1.5	3.0	3.5	2.5
Contact facies	Diorite	25-M	1.0	-	52.0	-	25.0	-	22
	Monzonite	30-G	1.0	42.0	35.0	-	10.0	-	12
	Syenite	31-F	2.0	80.0	1.0	-	9.0	-	7

[1] The samples are not in numerical order, but they are arranged according to a transition in composition from one facies to another.

[2] Generally includes sphene, zircon, apatite, allanite (?), fluorite, and calcite.

Table 2. Chemical Analysis calculated from Modal Analysis

Facies	Sub-facies	Sample No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Others
		1	63.32	14.50	3.88	1.84	1.38	1.43	1.96	7.57	0.08	4.04
		7-E	65.55	14.12	3.26	1.54	1.25	1.11	2.06	7.65	0.07	3.39
Normal facies		8-A	68.06	14.31	2.64	1.26	1.11	1.42	2.65	6.44	0.06	2.05
		9-A	67.58	13.70	3.24	1.53	1.10	1.42	2.38	6.29	0.06	2.70
		32	66.05	14.10	3.88	1.83	1.24	1.21	1.83	7.60	0.12	2.14
		33	66.74	13.94	3.88	1.82	1.11	1.27	2.37	6.79	0.06	2.02
		6-A	65.92	15.40	2.64	1.24	0.97	1.39	2.10	7.37	0.24	2.73
		18-C	67.14	14.75	3.27	1.54	1.11	1.43	2.17	7.07	0.16	1.36
		21-A	68.04	14.82	2.61	1.22	0.83	2.01	2.76	5.57	0.10	2.04
Altered facies		11-B	64.31	16.24	3.14	1.43	0.41	1.57	2.27	6.91	0.37	3.35
		12-A	65.93	16.68	1.93	0.89	0.28	1.67	2.52	7.04	0.33	2.73
		20	69.42	15.89	0.04	0.02	0.27	1.73	2.62	5.65	0.41	3.95
		29-A	68.85	14.71	2.43	1.11	0.28	1.31	1.97	7.02	0.27	2.05

Table 2. Continued

Facies	Sub-facies	Sample No.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Others
Fine-grained facies		11-A	66.45	15.15	3.82	1.73	0.28	1.27	1.92	7.82	0.20	1.36
		10-C	63.84	16.05	3.19	1.48	0.69	0.93	1.40	9.41	0.32	2.69
		6-B	64.37	16.46	2.23	1.50	0.69	0.94	1.43	9.70	0.32	1.36
		29-C	67.06	14.21	3.19	1.46	0.28	0.92	1.55	8.46	0.14	2.73
		32-B	64.39	13.90	4.46	2.06	0.82	0.80	1.49	8.59	0.12	3.37
Contact facies	Diorite	25-M	41.0	21.24	-	-	-	9.53	3.90	2.95	1.13	20.25
	Monzonite	30-G	52.60	19.90	-	-	-	4.36	2.85	8.00	0.47	11.82
	Syenite	31-F	56.60	18.07	1.28	0.58	-	0.06	0.08	14.13	0.43	8.71

Aplite Dikes

Numerous aplite dikes were found cutting the Swisshelm Quartz Monzonitic mass and extending into the country rocks. The dikes range in thickness from less than one foot up to twenty-five feet and generally follow a northeast to northwest trend with variable dip; many tend to be vertical (Pl. 1).

Numerous pegmatite segregations and quartz veins and veinlets are associated with these aplite dikes. Some areas of graphic intergrowth were observed, especially on the northern spur at station No. 9, and small patches of porphyritic texture are found on the outer part of an aplite dike on the southern spur at station No. 10 (Pl. 1).

Megascopically, the rock is gray to white to pale yellow with fine to medium-grained texture. Recognizable minerals are quartz, feldspar, muscovite, minor biotite, and, locally, fluorite.

Three facies of the aplite dike rock have been distinguished: 1. The aplite normal facies, 2. the aplite porphyritic facies, and 3. the aplite graphic facies.

Microscopically, the aplite normal facies has fine to medium-grained, hypidiomorphic to xenomorphic granular texture. The minerals of the aplite are locally sutured and intimately interlocked, showing a mosaic texture. The grain size ranges from 0.05 mm. to 2 mm. in diameter, but in places grain size up to 4 mm. in diameter was noted. Essential minerals are quartz, orthoclase, microcline, and plagioclase. Accessory minerals are muscovite, biotite, magnetite, zircon, apatite, sphene, allanite, and fluorite. Secondary minerals are chlorite, leucoxene, hematite, sericite, and clay minerals.

Interstitial quartz forms 33 per cent to 41 per cent of the rock. Orthoclase is partly perthitic and makes up 32 per cent to 40 per cent of the rock. Microcline is present in small amounts and was counted as orthoclase in the modal analysis. The potash feldspars are interstitial to all other minerals. Plagioclase occurs as albite intergrowths in perthitic orthoclase and as oligoclase (An_{20-28})crystals. It constitutes 21 per cent to 25 per cent of the rock. Muscovite comprises 0.5 per cent to 5 per cent of the rock and partly replaces the feldspar and biotite. Biotite is slightly altered to chlorite and makes up 0.5 per cent to 1 per cent of the rock. It is locally associated with magnetite, zircon, and apatite. Magnetite, partly hematized, forms 1 per cent to 1.5 per cent of the rock. Zircon, apatite, sphene, and allanite are minor accessories and leucoxene after sphene was locally observed. Fluorite is an abundant accessory mineral in the aplite dike rock of the western part of the southern spur. Sericite and clay minerals as alteration products after feldspar are present in small amounts.

The aplite porphyritic facies has a porphyritic texture and contains 28 per cent quartz, orthoclase, oligoclase, and mica phenocrysts set in a fine-grained ground mass forming about 72 per cent of the rock. The phenocrysts occur as subhedral to anhedral crystals as much as 4 mm. in diameter. The quartz phenocrysts make up 7 per cent of the rock and usually are fractured, locally showing andulos extinction. Inclusions of biotite, muscovite, and apatite have been observed in some of the quartz phenocrysts (Fig. 9). Orthoclase, forming

Figure 9 - Photomicrograph of the aplite porphyritic facies showing quartz phenocryst enclosing a biotite crystal scattered in fine-grained ground mass (crossed nicols, 24x).

Figure 9

phenocrysts, is perthitic and forms 8 per cent of the rock. It is partly replaced by muscovite and is slightly altered to clay minerals. Oligoclase (An_{28}) phenocrysts comprise 10 per cent of the rock. They are partly to entirely altered to sericite, coarse muscovite, and clay minerals. Phenocrysts of muscovite and biotite constitute 3 per cent of the rock and are usually associated with magnetite, sphene, apatite, and zircon.

The ground mass is fine-grained and has a mosaic texture with an average grain size of about 0.06 mm. in diameter. It is composed of 30 per cent quartz, 33 per cent orthoclase, 3 per cent oligoclase, 2 per cent mica, and 3 per cent magnetite, sphene, apatite, and zircon. Hematite after magnetite and leucoxene after sphene are present.

The aplite graphic facies has a graphic texture developed throughout most of the rock giving a pattern resembling a coarse-grained granophric-like texture and locally has a myrmekitic texture. Constituent minerals are 40 per cent quartz, 50 per cent potash feldspar, 7 per cent oligoclase, 1 per cent muscovite and biotite, and 2 per cent magnetite, allanite, sphene, zircon, and apatite. Quartz occurs as a graphic intergrowth with potash feldspar (Fig. 10), and as myrmekitic intergrowths with oligoclase. Quartz-feldspar intergrowths are generally characterized by striped or irregularly radiating appearance resulting from the intimate intergrowth of rodlike or angular masses of quartz and feldspar. Potash feldspar is partly perthitic and consists of orthoclase and microcline with the orthoclase being most abundant. It occurs in a graphic intergrowth with quartz (Fig. 10). The oligoclase (An_{26}) is intergrown with quartz forming

Figure 10 - Photomicrographic of the aplite graphic facies showing graphic intergrowth (crossed nicols, 24x).

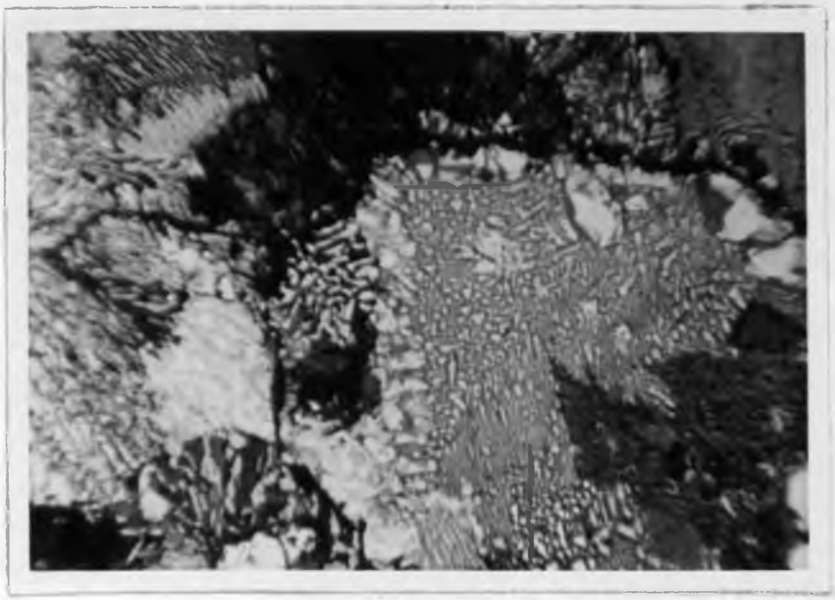

Figure 10

interstitial patches of myrmekite. All feldspars show slight alteration to clay minerals. Minor crystals of muscovite and biotite, locally associated with magnetite, allanite, sphene, zircon, and apatite are scattered throughout the rock. Magnetite is slightly hematized and sphene is partly altered to leucoxene.

Table 3. Modal Analysis of Aplite Dikes

Sample No.	Quartz	Orthoclase Microcline	Plagioclase	Biotite Chlorite	Muscovite	Others
2	31	49	14.5	1	3	1.5
9-B	32	44	20	0.5	1.5	2
10-B	38	45	16	-	4.5	1.5
10-D	36	37	23	-	1.5	2.5
24-E	36	46	13.5	1	1	2.5
26	37	45	12.5	1	3	1.5
34-A	37	50	10	0.5	1	1.5
34-B	35	51	11	0.75	0.5	2

Pegmatites

Most pegmatites, exposed throughout the area, are closely associated with aplite dikes. They occur as irregular segregations locally forming cores or rims of the aplite dikes. Some pegmatites occur as streaky or pocketty segregations within or at the eastern margin of the stock. Beryl-fluorite bearing irregular pegmatitic patches associated with a large quartz vein occur on the southern spur. Pegmatites usually show gradational contacts with the host rock and range in width from a few inches up to three feet.

Megascopically, the pegmatites are light-colored and coarse-grained with commonly a graphic texture. They are composed of quartz, potash feldspar, plagioclase, micas, magnetite, and locally beryl and fluorite. Quartz is the most abundant mineral, occurring in vugs and measures up to 8 cm. long and 4 cm. across. Potash feldspar is a major pegmatite forming constituent occurring as anhedral to euhedral crystals as much as 6 cm. in length and 3 cm. across. In certain marginal pockets, singly terminated quartz crystals and perthitic orthoclase crystal, showing carlsbad, baveno, and manebach twinning, have been found. Plagioclase is much less abundant than the potash feldspar. Micas are mainly represented by muscovite and biotite, with the latter being less common. Usually the micas are present as flakes and aggregates of flakes. Magnetite is a minor constituent, forming isolated small patches, and is partly rimmed by red iron stains. Beryl is light blue-colored and locally an abundant mineral forming euhedral to subhedral crystals up to 2.5 cm. long and 1 cm. across. It is locally associated with small, purple fluorite grains and booklike muscovite flakes. Beryl associated with quartz streaks also has been noted within the northern spur quartz monzonite.

Microscopically, beryl-free pegmatite segregations are coarse and have generally a graphic texture, locally associated with a myrmekite-like texture. Essential minerals are quartz, potash feldspar, and plagioclase; and accessory minerals are muscovite, biotite, magnetite, allanite, zircon, sphene, and apatite. Secondary minerals are hematite, leucoxene, sericite, clay minerals. Quartz occurs chiefly as graphic intergrowths with potash feldspar and less abundantly as myrmekitic intergrowths with plagioclase. The potash feldspar consists mainly of orthoclase and minor microcline. The orthoclase is partly perthitic (both patchy and vein-like types) and slightly clouded by incipient alteration to clay minerals. Plagioclase includes perthitic albite and oligoclase (An_{24}) slightly altered to sericite and clay minerals. Muscovite and biotite are present in small amounts with the muscovite partly replacing the orthoclase and biotite. Magnetite is locally a common accessory mineral and is altered to hematite. Allanite, zircon, sphene, and apatite are minor accessories with the sphene, in part, altered to leucoxene.

In thin sections the pocketty orthoclase crystals are identified as patchy perthite containing tiny inclusions of fluorite, calcite, muscovite, and quartz grains scattered throughout the crystals. The orthoclase is partly altered to clay minerals.

Quartz Veinlets

Numerous quartz veinlets, usually less than one inch wide, cut the Swisshelm Quartz Monzonite. A 5 to 8 foot wide quartz vein is exposed on the southern spur western saddle, replacing an aplite dike for a distance of about 60 feet.

Quartz veinlets are locally grading into pegmatite dikes where the quartz is associated with beryl, muscovite, and sometimes with magnetite. Beryl-bearing pegmatite segregations are locally associated with the quartz veins.

The quartz forming the vein and veinlets is milky white to light gray in color and locally is stained brown or red by iron oxides. Most of the quartz is massive and highly fractured. Singly terminated quartz crystals occur in small vugs and drusy cavities.

Inclusions

Irregularly shaped inclusions are scattered throughout the main facies of the Swisshelm Quartz Monzonite (Fig. 11). They occur both as single units and in swarms. They range in size from less than one inch up to three feet in diameter; the larger ones occur near the contact. Megascopically, the inclusions are dark gray to dark greenish-gray, but light gray to light greenish-gray colors have been observed. They have a fine- to medium-grained texture. Recognizable minerals are quartz, feldspar, mica, and magnetite. Microscopically, the inclusions show a marked variation in texture, grain size, and mineral composition. Five inclusion types have been recognized: 1) biotite-potash feldspar-rich inclusions, 2) chlorite-plagioclase-rich inclusions, 3) biotite-

Figure 11 - Photograph of the quartz monzonite inclusion showing an irregular, dark, fine-grained inclusion in the quartz monzonite of the northern spur.

Figure 11

plagioclase-rich inclusions, 4) muscovite-plagioclase-rich inclusions, and 5) muscovite-potash feldspar-rich inclusions. The first three types are the most common. Modal analyses of these types of inclusions are included in Table 4.

The biotite-potash feldspar-rich inclusions are fine-grained and granoblastic in texture, having an average grain size of about 0.3 mm. in diameter (Fig. 12). The main constituent minerals are quartz, orthoclase, microcline, plagioclase, and biotite. Accessory minerals are magnetite, apatite, zircon, sphene, allanite (?), and rarely muscovite. Quartz is an abundant constituent and occurs as anhedral crystals filling the interstitial spaces (Fig. 12). Orthoclase is the most abundant mineral of the inclusions. It is composed of anhedral crystals partly altered to clay minerals (Fig. 12). Microcline occurs as interstitial subhedral to anhedral crystals showing polysynthetic twinning and wavy extinction. Plagioclase (An_{14}) occurs as subhedral to anhedral crystals commonly fresh and twinned by the albite law. Incipient alteration of the plagioclase core to sericite and clay minerals has been locally detected. Biotite occurs as reddish brown, subhedral to anhedral crystals disseminated throughout the rock. It is commonly associated with magnetite and frequently with other accessory minerals. Magnetite, apatite, zircon, sphene, allanite (?), and muscovite are minor constituents; magnetite is the most common accessory. Leucoxene after sphene has been noted.

The chlorite-plagioclase-rich inclusions are porphyroblastic in texture and include plagioclase, biotite, and quartz porphyroblasts set in a fine- to medium-grained matrix. Plagioclase porphyroblasts occur

Figure 12a - Photomicrograph of the biotite-potash feldspar-rich inclusions showing interstitial quartz and orthoclase with a granoblastic texture (crossed nicols, 24x).

Figure 12b - The same as above but 15x.

Figure 12a

Figure 12b

as subhedral to anhedral crystals as much as 3.5 mm. in length. They are highly altered to sericite, muscovite, and clay minerals so that the characteristic albite twinning is almost obscured (Fig. 13). Calcite and fluorite replacing plagioclase porphyroblasts are common. Biotite porphyroblasts occur as anhedral crystals up to 4 mm. in length. Complete chloritization of this biotite is a characteristic feature. Quartz porphyroblasts are present as rounded to subround grains up to 3 mm. across. They are usually fractured containing plagioclase and apatite inclusions.

The matrix is fine- to medium-grained and has a hypidioblastic to xenoblastic fabric with an average grain size of about 0.5 mm. across (Fig. 13). It consists of quartz, orthoclase, plagioclase, biotite, muscovite, and fluorite, magnetitie, apatite, zircon, sphene, pyrite, and allanite (?). Generally, the matrix minerals occur as subhedral to anhedral crystals. Quartz and orthoclase are interstitial with orthoclase being slightly clouded by clay alteration and locally is replaced by muscovite. Matrix plagioclase (An_{30}) is similar to the porphyroblasts forming plagioclase. Biotite is almost completely chloritized and commonly is associated with magnetite, zircon, apatite, and allanite (?). Muscovite partly replacing plagioclase, orthoclase, and rarely biotite, is the commonly present type.

Fluorite, magnetite, and apatite are common accessories with the magnetite being partly altered to hematite. Sphene, pyrite, and allanite are less common and partial alteration of sphene to leucoxene is noted.

Figure 13a - Photomicrograph of the chlorite-plagioclase-rich inclusions showing a highly sericitized plagioclase porphyroblast associated with allanite (?) in a fine-grained matrix having a hypidoblastic to xenoblastic fabric (crossed nicols, 24x).

Figure 13b - The same as above but 18x.

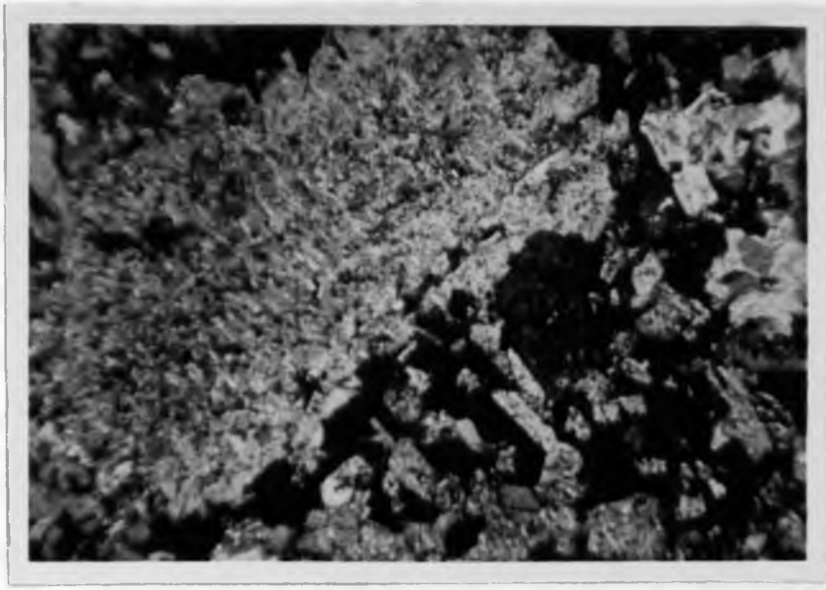

Figure 13a

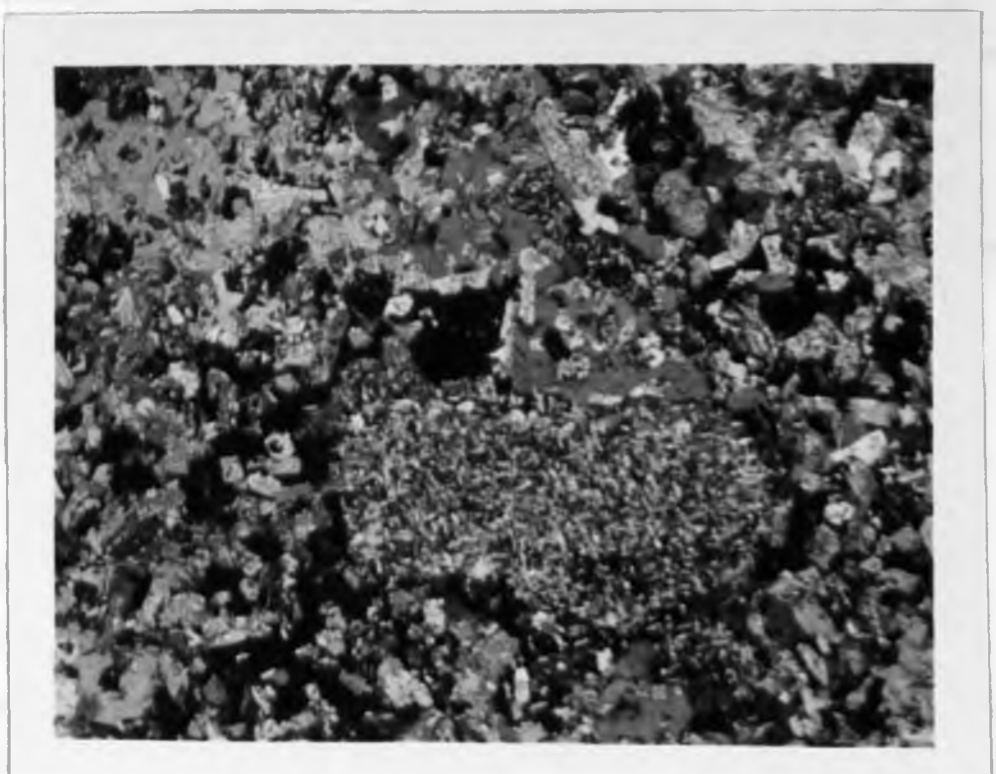

Figure 13b

The biotite-plagioclase-rich inclusions show a type of pseudo-diabasic texture developed throughout most of the rock with quartz occurring as large discrete grains filling the interstices between the lath-shaped plagioclase crystals (Figs. 14a and 14b). Locally, the rock has a graphic texture associated with the main texture (Fig. 14c). The average grain size is about 0.8 mm. across. The rock is composed of quartz, orthoclase, plagioclase, biotite, muscovite, fluorite, magnetite, apatite, zircon, and sphene. Quartz occurs as anhedral crystals that are commonly interstitial to the plagioclase crystals. This gives a pattern resembling a diabasic-like texture. Locally, quartz is intergrown with orthoclase resulting in a graphic texture. Orthoclase is partly perthitic and forms interstitial, anhedral crystals, locally intergrown with quartz. Subhedral to anhedral, subtabular, albite twinned plagioclase crystals show partial alteration to epidote, calcite, sericite, and clay minerals. The plagioclase composition is about (an_{28}). Partly chloritized biotite associated with magnetite, apatite, zircon, and sphene is common. Muscovite replacing plagioclase and orthoclase is present in a small amount. Fluorite, magnetite, apatite, zircon, and sphene are common accessories with magnetite and sphene being altered to hematite and leucoxene, respectively.

The muscovite-plagioclase-rich inclusions have a fine- to medium-grained crystalloblastic texture with a grain size ranging up to 4-6 mm. across. Constituent minerals are quartz, orthoclase, plagioclase, biotite, muscovite, fluorite, magnetite, apatite, sphene, and zircon. In general, constituent minerals form subhedral to anhedral crystals. Quartz and orthoclase are interstitial and theorthoclase

Figure 14a - Photomicrograph of the biotite-plagioclase-rich inclusions showing interstitial quartz with lath-shaped plagioclase having a pseudo-diabasic texture (crossed nicols, 24x).

Figure 14b - The same as above but 18x.

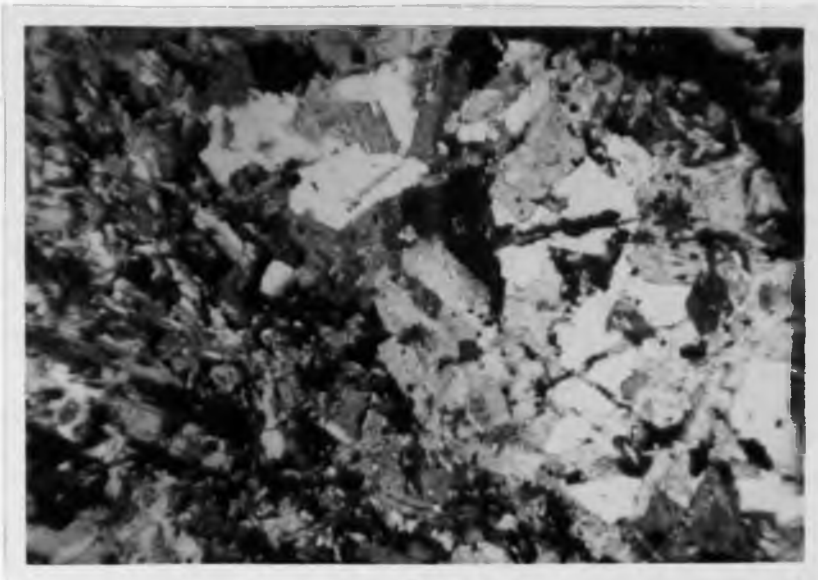

Figure 14a

Figure 14b

Figure 14c - Photomicrograph of the biotite-plagioclase-rich inclusions showing local graphic intergrowth (crossed nicols, 24x).

Figure 14c

is partly altered to clay minerals and replaced, in part, by muscovite. Plagioclase (An_{30}) is highly altered to sericite and clay minerals and largely replaced by calcite, muscovite, and fluorite. Biotite is a minor constituent and seems to be replaced by magnetite. Muscovite is the dominant present mica that replaces partly plagioclase and orthoclase. Fluorite and magnetite are abundant accessories and the magnetite is slightly altered to hematite. Apatite, zircon, and sphene are less abundant with the sphene being replaced, in part, by leucoxene.

The muscovite-potash feldspar-rich inclusions have a porphyroblastic texture and contain minor plagioclase porphyroblasts scattered throughout a fine-grained matrix (Fig. 15). The plagioclase porphyroblasts occur as albite-twinned, subhedral crystals as much as 5 mm. in length. A partial alteration to sericite and clay minerals and replacement by calcite, muscovite, and fluorite are notable features. The plagioclase composition is (An_{14-30}). The matrix is fine-grained and granoblastic to xenoblastic in texture, with an average grain size of about 0.15 mm. in diameter. Minerals present include quartz, orthoclase, microcline, plagioclase, muscovite, fluorite, zircon, magnetite, and apatite. Quartz is a major matrix mineral occurring as subhedral to anhedral interstitial crystals and, locally, as inclusions in the plagioclase porphyroblasts (Fig. 15). Orthoclase is the dominant potash feldspar and is slightly altered to clay minerals and partly replaced by muscovite. Microcline is found in trace amounts. Matrix plagioclase is nearly fresh and consists of subhedral to anhedral crystals twinned on the albite law. Muscovite is the only mica present and usually replaces the plagioclase porphyroblasts and

Figure 15 - Photomicrograph of the muscovite-potash feldspar-rich inclusion showing subhedral, albite twinned plagioclase porphyroblast with quartz inclusions scattered in a fine-grained matrix (crossed nicols, 24x).

Figure 15

orthoclase. Locally, a muscovite-zircon intergrowth has been noted. Fluorite and zircon are the most common accessories. Magnetite and apatite are minor, with the magnetite showing slight alteration to hematite.

Table 4. Modal Analysis of Inclusions

Type	Sample No.	Quartz	Orthoclase Microline	Plagioclase	Biotite Chlorite	Muscovite	Others
Biotite-potash feldspar-rich type	3	24	54	6	10	Trace	6
Chlorite-plagioclase-rich type	16	23	9	40	13	7	8
Biotite-plagioclase-rich type	22-B	25	17	42	8	2	6
Muscovite-plagioclase-rich type	22-C	21	10	41	3	17	8
Muscovite-potash feldspar-rich type	15-B	30	40	15	-	8	7

Porphyritic Rhyolite Dikes

Two short, subparallel, rhyolite dikes are exposed northwest of the old copper shafts on the southeast corner of the mapped area. The dikes are 12-20 feet wide and about 100-120 feet long. Their general trend is N25°E with a nearly vertical dip. One of the two dikes intrudes the main body and extends into the Upper Paleozoic metamorphic rocks, whereas the other dike is mainly in the country rock, 2-4 feet away from the contact (Pl. 1).

Megascopically, the rock is pale pink to buff on the weathered surface, but pinkish brown where fresh. On the weathered surface, the rock is pitted, because of leaching of the feldspar. The characteristic pinkish color is due to the weathering of the K-feldspar present in the rock. The rocks are porphyritic in texture and contain phenocrysts of quartz and feldspar with an average size of about 1 mm. in diameter. The phenocrysts are scattered throughout a fine-grained unidentifiable ground mass.

Microscopically, two facies of the rhyolite dike rock have been recognized: 1) The rhyolite dike rock central facies, and 2) the rhyolite dike rock border facies. The central facies is spherulitic and contains 15 per cent phenocrysts of quartz and sanidine which serve as the nuclei for some of the spherulites. The quartz phenocrysts make up 9 per cent of the rock and occur as euhedral to subhedral, locally embayed and corroded, crystals up to 1.2 mm. in diameter (Fig. 16). The sanidine phenocrysts constitute 6 per cent of the rock and form euhedral to subhedral crystals as much as 1.7 mm. in length. The sanidine phenocrysts, in part twinned according to the Carlsbad law, are

Figure 16 - Photomicrograph of the rhyolite central facies showing an embayed and corroded quartz phenocryst forming a core in a spherulitic ground mass (crossed nicols, 24x).

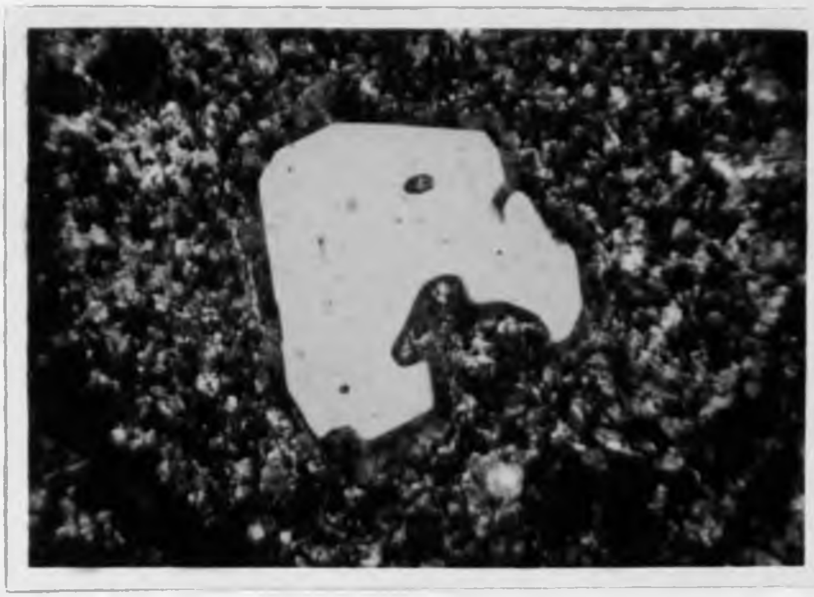

Figure 16

clouded by clay minerals and sometimes contain inclusions of biotite flakes locally associated with magnetite and zircon.

The ground mass is fine-grained to microcrystalline in texture, forming 85 per cent of the rock. It is composed of orthoclase, quartz, biotite, magnetite, and zircon. Orthoclase, the major ground mass forming mineral, is partially altered to clay minerals and gives the matrix a dusty brown color. Quartz is an interstitial constituent. Biotite is disseminated as abundant grains throughout the ground mass. It occurs as reddish brown specks and rods and is often replaced by iron ore. Partly hematized magnetite grains not associated with biotite are sparingly present. A few minute crystals and grains of zircon are scattered throughout thematrix. The ground mass contains many spherulites, ranging from 0.08-2 mm. in diameter, of radically arranged fibers of incipient crystals of orthoclase and quartz.

The rhyolite dike rock border facies has a porphyritic texture and contains 12.5 per cent quartz and sanidine phenocrysts. The quartz phenocrysts, making up 6.5 per cent of the rock, occur as euhedral to subhedral crystals up to 1.5 mm. in diameter. Locally, the quartz phenocrysts are partly embayed and corroded. The sanidine phenocrysts comprise 6 per cent of the rock and occur as euhedral to subhedral crystals as much as 1.6 mm. in length. Frequently, they are twinned according to the Carlsbad law. Generally, the sanidine phenocrysts enclosed poikilitically inclusions of biotite (in part altered to chlorite), quartz, fluorite, and sometimes magnetite and zircon grains associated with biotite flakes (Fig. 17). In places, the sanidine phenocrysts are clouded by clay minerals.

Figure 17 - Photomicrograph of the rhyolite border facies showing a euhedral sanidine phenocryst with biotite and quartz inclusion in a fine-grained ground mass (crossed nicols, 24x).

Figure 17

The ground mass is fine-grained, microcrystalline forming about 87.5 per cent of the rock. It consists of orthoclase, quartz, sericite, biotite, magnetite, and zircon. Orthoclase is essential matrix mineral and is partly altered to clay minerals. Quartz is interstitial. Sericite is abundant, forming wisps disseminated throughout the matrix. Biotite, magnetite, and zircon are minor constituents.

Andesite Porphyry

A small dike of andesite porphyry is exposed on both slopes of a dry wash to the northeast of the contact between the quartz monzonite of the southern spur and the Cretaceous metamorphic rocks. The dike trends N10°E and dips 65°SE. It is 3-4 feet in width and is exposed for about 50 feet (Pl. 1).

Megascopically, the rock is dark gray to greenish gray on fresh fracture and brownish dark gray on weathered surface. It is porphyritic in texture and formed of plagioclase and hornblende phenocrysts set in a fine-grained mass.

Microscopically, the rock has a porphyritic texture and contains about 33 per cent plagioclase and hornblende phenocrysts. The plagioclase (An_{30-35}) phenocrysts make up 28 per cent to 30 per cent of the rock occurring as twinned subhedral crystals up to 5.5 mm. in length (Fig. 18). They are nearly fresh and clear, but in places alteration has clouded the crystals with minute crystals of biotite, actinolite, and chlorite. The hornblende phenocrysts comprise 3 per cent to 5 per cent of the rock forming euhedral, subhedral, and anhedral crystals as much as 2 mm. in diameter. They are partly

Figure 18 - Photomicrograph of the andesite porphyry showing twinned plagioclase phenocryst in a fine-grained matrix (crossed nicols, 24x).

Figure 18

altered to biotite, actinolite, and chlorite.

The ground mass constitutes about 67 per cent of the rock. It is holocrystalline and has a felty texture with an average grain size of about 0.08 mm. in diameter. The ground mass is composed of plagioclase, hornblende, biotite, actinolite, chlorite, quartz, magnetite, sphene, zircon, and fluorite. Plagioclase microlaths are interwoven in irregular, unoriented fashion and, generally, are fresh and free from alteration. Most of the hornblende has been altered to biotite, actinolite, and chlorite, but locally sporadic hornblende crystals are still fresh. Quartz is found in small amounts in the ground mass. Magnetite, sphene, zircon, and fluorite are common accessory minerals disseminated throughout the matrix.

Lamprophyre (spessartite) Dikes

A lamprophyric dike, 8-12 feet wide and about 100 feet long, here termed the northern lamprophyric dike, trends N19°E and dips 85°SE. The northern lamprophyric dike cuts the Cretaceous metamorphic rocks on the southern slope of the southern spur, extending from the contact into the country rocks (Pl. 1).

Another small lamprophyric dike, called the southern almprophyric dike, is 1-3 feet wide and 9-12 feet long. It is exposed on the floor and on the northern slope of a small dry wash to the south of the beryl prospect pit. The southern lamprophyric dike cuts the intrusive body and extends along the contact with the Upper Paleozoic metamorphic rocks, trending N35°W and dipping 20°NE (Pl. 1).

The rocks of these two dikes are generally similar in mineral composition and texture. Megascopically, the rocks are dark greenish gray on fresh surface and light gray to light olive gray on weathered surface. All are porphyritic in texture and consist of hornblende phenocrysts set in a fine-grained matrix. The phenocrysts in the northern dike rock are generally prismatic, attaining a length of about 7 mm.; whereas, those of the southern dike rock are more needle-like and are as much as 5 mm. long.

Microscopically, the northern dike rock is porphyritic in texture and composed of euhedral to subhedral hornblende phenocrysts forming 20 per cent to 22 per cent of the rock. The phenocrysts show considerable alteration to biotite, chlorite, actinolite, calcite, and rarely epidote. Locally, numerous grains of magnetite and sphene are included in the phenocrysts.

The matrix is holocrystalline and has a felty texture with an average grain size about 0.08 mm. in diameter. It constitutes 78-80 per cent of the rock and is composed of plagioclase, hornblende, biotite, chlorite, actinolite, epidote, quartz, orthoclase, magnetite, sphene, zircon, apatite, fluorite, and pyrite. The plagioclase is the major ground mass forming mineral occurring as microlaths, slightly clouded by alteration products. The hornblende occurring in the matrix shows similar alteration products as the hornblende phenocrysts. Biotite, chlorite, actinolite, calcite, and minor epidote occur in the ground mass as decomposition products and partly obscure the plagioclase microlaths. Quartz and orthoclase are present in small amounts in the ground mass. Magnetite in subhedral to anhedral crystals is abundant and shows a slight alteration to hematite. Sphene, zircon, apatite, fluorite, and pyrite are common accessory minerals disseminated throughout the ground mass. Leucoxene after sphene and limonite after pyrite are present.

The southern dike rock has a porphyritic to seriate texture and contains 23 per cent to 25 per cent hornblende phenocrysts occurring as subhedral to anhedral crystals. The hornblende phenocrysts, as in the northern dike rock, are commonly altered to biotite, chlorite, actinolite, calcite, and epidote. The ground mass is similar in texture and composition to the northern dike rock and forms 75 per cent to 77 per cent of the mass. Generally, in the southern dike, epidote as an alteration product is more common; whereas magnetite, although highly altered to hematite, is less abundant. Pyrite is much more abundant in these rocks and is highly altered to limonite.

Metamorphic Rocks

The Swisshelm Quartz Monzonite has intruded and metamorphosed the Upper Paleozoic sediments of the Naco Group and the Lower Cretaceous sediments of the Bisbee Group. No attempt has been made to trace the metamorphic rocks into unmetamorphosed sediments, and samples were collected mainly near the contact of the intrusive. Occasionally samples were taken some 100 feet out from the contact in the country rock.

Metamorphosed Rocks of Upper Paleozoic Age

The Upper Paleozoic metamorphic rocks are well exposed in the southeastern part of the mapped area (Pl. 1). They form conspicuous outcrops of marblized dolomitic limestones, interbedded with hornfelsic units and locally associated with chert nodules, fluorite masses, and granofels bands and masses.

Megascopically, the marblized dolomitic limestones are commonly white to bluish gray in color; locally, black and brownish fragments were noted. They are fine- to coarse-grained and thick to massive bedded marble. Striking features of the contact metamorphism are the occurrence of large calcite crystals near the contact and the gradational grain size from the contact toward the country rocks. Porphyroblastic garnet-bearing marble has been found near the beryl prospect pit.

Microscopically, the marble is fine- to coarse-grained and commonly has a granoblastic mosaic texture, and locally the fabric is porphyroblastic and the mineralogic composition is variable. The coarse-grained marble is confined to the immediate contact and is composed entirely of anhedral calcite crystals showing a prominent mosaic texture and a conspicuous rhombohedral cleavage and polysynthetic twinning. A more common type is the fine- to medium-grained marble which consists chiefly of calcite commonly associated with forsterite, brucite, chondrodite, pyroxene, magnetite, and pyrite, but locally quartz, fluorite, sericite, phlogopite, muscovite, and biotite are also present as accessory minerals. Forsterite is the most common associated mineral occurring as anhedral, roughly equidimensional separate grains or as aggregates of such grains. It is partly altered to antigorite. Traces of brucite have been detected in some thin sections. Chondrodite resembles forsterite but differs from it in a gold to brown color. Pyroxene is of the diopside-hedenbergite series, occurring as a minor accessory mineral. Magnetite and pyrite are present in small amounts and slightly altered to hematite and limonite, respectively. Quartz is found in vein-like aggregates, but in places it forms subhedral to euhedral porphyroblasts. Fluorite occurs as irregular patches disseminated throughout the rock. Sericite locally is a common accessory mineral. Phlogopite, muscovite, and biotite are minor accessories occurring as anhedral crystals scattered throughout the marble.

Porphyroblastic marble contains andradite porphyroblasts scattered in a matrix of fine-grained calcite (Fig. 19). The porphyroblasts are subhedral to euhedral crystals up to 5.5 mm. across. The characteristic zoning is partly obscured by tiny clacite inclusions. The matrix of this rock type has a granoblastic mosaic texture.

Chert nodules are common throughout some of the marble beds and are composed mainly of a very fine-grained quartz associated with aggregates of calcite grains that are disseminated throughout the chert nodules.

Fluorite is abundantly exposed at the fluorite prospect pit (Pl. 1). The fluorite is variable in color from pale green, purple, rose, colorless to black, and consists of subhedral to euhedral crystals as much as 2 cm. in diameter.

The hornfels is light to yellowish brown on weathered surface and light greenish gray on fresh fracture. This rock is fine-grained and forms bands or thin beds interbedded with the marble. Microscopically, the hornfels, commonly, has a fine-grained and granoblastic

Figure 19 - Photomicrograph of the porphyroblastic marble showing euhedral andradite porphyroblast in a matrix of fine-grained calcite (crossed nicols, 10x).

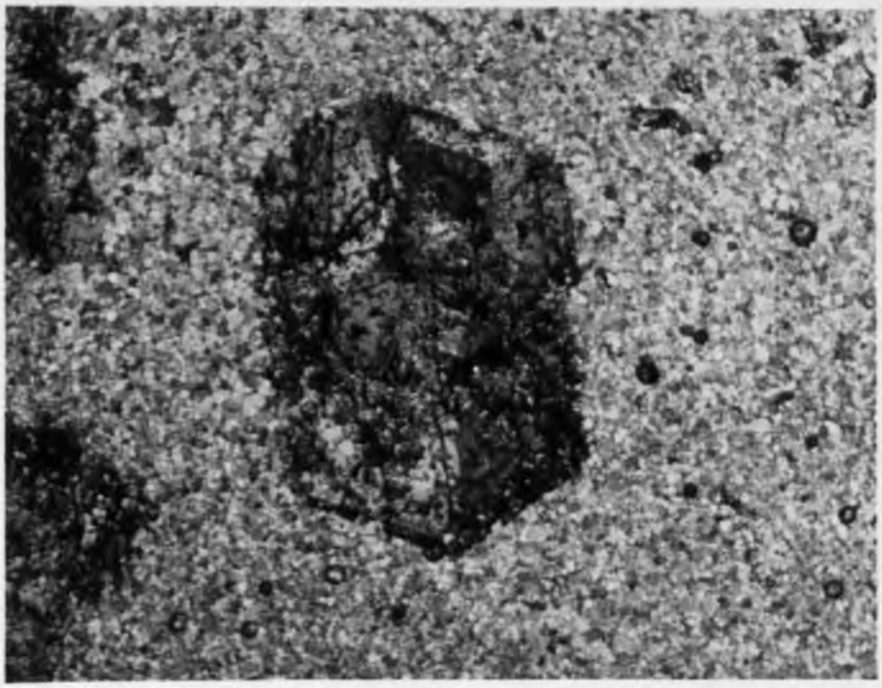

Figure 19

texture. Locally, a small scale compositional banding is noted, and concentric arrangement of mineral species is locally conspicuous. The mineralogical composition is commonly variable and includes quartz, calcite, garnet, diopside, hedenbergite, epidote, clinozoisite, orthoclase, biotite, chlorite, sericite, muscovite, idocrase, wollastonite, tremolite, plagioclase, fluorite, magnetite, zircon, and sphene. Quartz, calcite, garnet, diopside, and hedenbergite are the most common minerals, locally occurring in concentrations. Epidote and clinozoisite are common with the clinozoisite showing anomalous blue or yellowish brown interference colors. In places, orthoclase, biotite, sericite, and muscovite are abundant with the biotite being partly altered to chlorite and magnetite. Idocrase, wollastonite, tremolite, plagioclase, fluorite, zircon, and sphene, generally, are minor accessory minerals.

The granofels rock types are generally medium- to coarse-grained metamorphic rocks. They are well exposed along the contact, especially near the fluorite and beryl prospect pits (Pl. 1). Three types of the granofels have been distinguished: 1) The garnet granofels, 2) the idocrase granofels, and 3) the wollastonite granofels.

The garnet granofels is abundant and commonly forms bands up to 1-2 feet thick, alternating with other Upper Paleozoic metamorphic rocks. Locally, aggregates of euhedral-anhedral garnet crystals have been found, especially near the beryl prospect pit. To the south of this prospect, a porphyroblastic type has been observed. Megascopically, the garnet granofels is light olive brown to dark yellowish brown in color and medium- to coarse-grained in texture. It is composed mainly of garnet associated with minor calcite, fluorite, and quartz. Microscopically, the garnet is idioblastic granular to xenoblastic granular in texture. Constituent minerals are garnet, idocrase, calcite, fluorite, quartz, epidote, clinozoisite, diopside, plagioclase, tremolite, actinolite, chlorite, malachite, biotite, muscovite, sericite, phlogopite, alunite, magnetite, pyrite, hematite, limonite, and unknown hydrous iron silicates. Garnet is considered to be of the grossularite-andradite series because of its optical characteristics and mode of occurrence. It is the major constituent occurring as anhedral to euhedral crystals which frequently show characteristic complex zoning and variable birefringence (Fig. 20). Calcite, fluorite, quartz, idocrase, epidote, clinozoisite, magnetite, tremolite, and chlorite are common accessory minerals. Diopside, biotite, pyrite, actinolite, muscovite, phlogopite, sericite, and alunite are minor accessories. Hematite, limonite, hydrous iron silicates, and malachite are locally present as secondary minerals. Rocks of the porphyroblastic type are megascopically dark greenish to grayish olive green in color and porphyroblastic in texture. They are composed of pyrite porphyroblasts disseminated throughout a medium-grained matrix.

Microscopically, the rock is porphyroblastic containing euhedral to subhedral pyrite porphyroblasts being partly altered to limonite. The matrix, commonly, has a granoblastic texture and consists of garnet, fluorite, tremolite, actinolite, chlorite, quartz, and epidote. Garnet is the main constituent and similar to that of the common garnet facies. Fluorite, tremolite, actinolite, and chlorite are abundant associated minerals with the tremolite being distinguished from

Figure 20 - Photomicrograph of the garnet granofels showing euhedral garnet with complex zoning (crossed nicols, 11x).

Figure 20

wollastonite by its oblique extinction, and by the interference figure being parallel to the length of the crystals. Quartz and epidote are less abundant than the other constituent minerals.

The idocrase granofels is common at the contact zone near the fluorite prospect pit, forming brownish to greenish crystalline masses. Megascopically, the rock is brownish green to greenish gray in color and medium- to coarse-grained in texture. Recognizable minerals are idocrase, calcite, garnet, and quartz. Microscopically, the rock is idioblastic granular to xenoblastic and poikiloblastic in texture. Major minerals are idocrase, calcite, garnet, quartz, and epidote. Accessory minerals are diopside, hedenbergite, wollastonite, and magnetite. Idocrase is the most abundant mineral occurring as euhedral to anhedral crystals showing rectangular, massive, and fibrous forms. The rectangular form is the most common form and is composed of bands or zonal lamellae that differ in interference colors (Fig. 21). The massive and fibrous forms locally show an anomalous blue interference color. Calcite, garnet, quartz, and epidote are less abundant minerals which occur as subhedral to anhedral crystals, filling the interstices of the fabric. Locally, epidote occurs as radiating acicular crystals (Fig. 21c). The main minerals are partly clouded by tiny inclusions of some of the minor minerals (Fig. 21). Diopside and hedenbergite are common accessories, forming subhedral and anhedral crystals poikilitically scattered throughout the other minerals. Wollastonite and magnetite are minor accessories, with the magnetite being partly altered to hematite.

Figure 21a - Photomicrograph of the idocrase granofels showing subhedral, zoned idocrase with interstitial calcite and epidote (crossed nicols, 24x).

Figure 21b - Photomicrograph of the idocrase granofels showing euhedral, rectangular, zoned idocrase associated with calcite (crossed nicols, 24x).

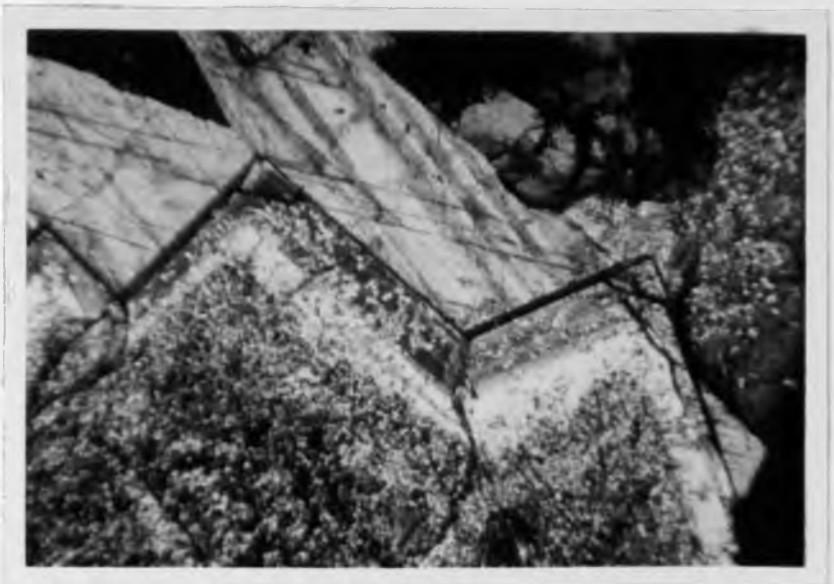

Figure 21a

Figure 21b

Figure 21c - Photomicrograph of the idocrase granofels showing basal section of idocrase crystal associated with radial acicular epidote crystals. Tiny crystals of the accessory minerals are scattered throughout the idocrase crystal (crossed nicols, 24x).

Figure 21c

The wollastonite granofels is well exposed near the contact southwest of the fluorite prospect pit, forming lenses or small masses intercalating with the other metamorphic rock types. Megascopically, the rock is yellowish gray to brownish gray and medium- to coarse-grained in texture. Recognizable minerals are wollastonite and garnet. Microscopically, the rock has a granoblastic to porphyroblastic texture. Constituent minerals are wollastonite, garnet, idocrase, quartz, epidote, and diopside. Wollastonite is the major mineral occurring as fibrous and columnar aggregates. It has been distinguished from tremolite by its parallel extinction and by the interference figure being almost normal to the length of the crystal and the main cleavage trace. Idocrase is a common associated mineral and, locally, garnet occurs as porphyroblasts scattered throughout the rock. Epidote and quartz are less common than the other constituents.

Metamorphosed Rocks of Cretaceous Age

These rocks outcrop in the northeastern part of the thesis area (Pl. 1). They are mainly hornfels, locally associated with granofels bands and masses. In places, metaquartzite beds are interbedded with the main hornfels facies.

Megascopically, the hornfels of Cretaceous age is light to yellowish gray and grayish green to greenish gray in color and fine- to very fine-grained in texture. Locally, yellowish green concentration patches and bands of lime-silicates aggregates form a medium- to coarse-grained texture. Microscopically, the hornfels is more or less similar in texture, mineral composition, and mineral characteristics to some types of the hornfels of Upper Paleozoic age. It has a fine- to very fine-grained granoblastic texture and variable mineral composition. Quartz, diopside, garnet, epidote are the most abundant minerals. In places localized patches and bands have been observed of epidote-clinozoisite or diopside-hedenbergite intergrown or alternated most commonly with garnet, quartz, and occasionally with calcite. Biotite, tremolite, and magnetite are locally abundant minerals. Minor constituents are albite, oligoclase, chlorite, sphene, zircon, pyrite, fluorite, muscovite, sericite, leucoxene, hematite, and limonite.

The granofels of Cretaceous age commonly has a fine- to medium-grained texture, but is locally porphyroblastic. The granofels usually crops out as masses and bands along the contact with the intrusive immediately to the east of the two main spurs. On the basis of composition four types of granofels have been distinguished: 1) The hornblende-biotite granofels, 2) the diopside granofels, 3) the hornblende porphyroblastic granofels, and 4) the idocrase-wollastonite granofels.

The hornblende-biotite granofels occurs as isolated lenses in direct contact with the quartz monzonite on the southern slope of the northern spur and immediately east of the southern spur. Megascopically, the rock has a greenish gray to light greenish gray color and fine- to medium-grained texture. Biotite and, locally, quartz are the only two recognizable minerals in hand specimen. Microscopically, the rock shows a porphyroblastic to poikiloblastic fabric and contains cordierite, orthoclase, plagioclase, and quartz porphyroblasts. These porphyroblasts include inclusions of some of the matrix minerals. The cordierite porphyroblasts, tentatively, have been identified and distinguished from quartz and feldspar by their axial figure with moderate to large axial angle and common inclusions (Fig. 22). The orthoclase porphyroblasts are slightly clouded by incipient clay mineral alterations. The plagioclase porphyroblasts are partly altered to clay and are locally associated with epidote-clinozoisite and minor sericite. The matrix has a granoblastic to seriate non-directional texture and consists of hornblende, biotite, orthoclase, plagioclase, and quartz as major constituents. Magnetite, sphene, zircon, and apatite are common accessories. Chlorite, epidote, clinozoisite, clay minerals, and sericite are secondary minerals.

The diopside granofels is exposed immediately east of the southern spur and about two feet away from the direct contact. Locally, it forms bands separated from the intrusive body by the biotite granofels. Megascopically, the rock is grayish-yellow green in color and porphyroblastic in texture. The only recognizable mineral is quartz, occurring as porphyroblasts scattered throughout a fine- to medium-grained matrix. Microscopically, the rock has a combination of porphyroblastic and poikiloblastic fabric and consists of quartz, plagioclase, and orthoclase porphyroblasts. These porphyroblasts poikilitically enclosed inclusions mainly of diopside and, less commonly, plagioclase, quartz, and epidote crystals. The plagioclase and orthoclase porphyroblasts are slightly altered to clay minerals with the plagioclase being replaced, in part, by epidote and clinozoisite and quartz. The matrix has a more or less granoblastic texture and is composed of diopside, quartz, plagioclase, orthoclase,

Figure 22 - Photomicrograph of the hornblende-biotite granofels showing a large cordierite porphyroblast poikilitically enclosing inclusions of the matrix-forming minerals (crossed nicols, 24x).

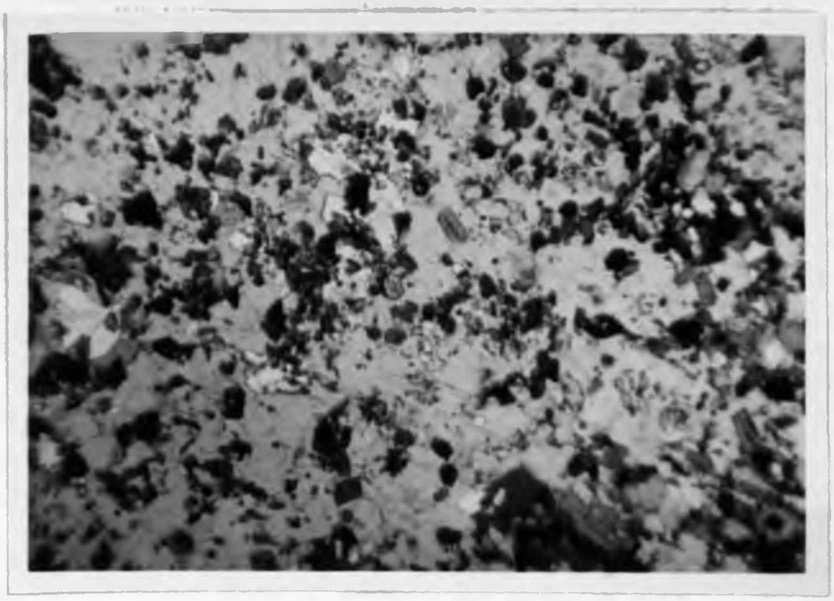

Figure 22

and epidote-clinozoisite. Minor constituents are hornblende, biotite, chlorite, magnetite, hematite, and sphene.

The hornblende porphyroblastic granofels is locally exposed some 8-12 feet out from the contact to the east of the southern spur and forms thin beds or bands interbedded with the common hornfelsic rock. Megascopically, the rock has a porphyroblastic texture and contains greenish dark hornblende porphyroblasts up to 3 cm. in length. These porphyroblasts are randomly scattered throughout a fine- to medium-grained, light greenish gray ground mass. Microscopically, the rock is porphyroblastic in texture and consists of hornblende porphyroblasts, forming about one-third of rock and occurring as euhedral to anhedral crystals. Needle-like hornblende porphyroblasts are common, and poikilitically enclose some of the matrix-forming minerals, especially biotite, magnetite, quartz, and plagioclase. The ground mass has a granoblastic texture and is composed of quartz, orthoclase, plagioclase, biotite, magnetite, sphene, zircon, and apatite. Quartz, orthoclase, and plagioclase are the major matrix minerals. Biotite and magnetite are common constituents and locally occur in concentrated patches. Sphene, zircon, and apatite are minor accessory minerals (Fig. 23).

The idocrase-wollastonite granofels of the Cretaceous age is common near the contact on the southern slope of the southern spur, occurring as masses and bands intercalated with the hornfelsic rocks. Megascopically, the rock is yellowish gray to light olive gray in color and coarse-grained in texture. Recognizable minerals are calcite, idocrase, epidote, and garnet. Microscopically, the rock is

Figure 23 - Photomicrograph of the hornblende porphyroblastic granofels showing a hornblende porphyroblast in a granoblastic matrix (crossed nicols, 24x).

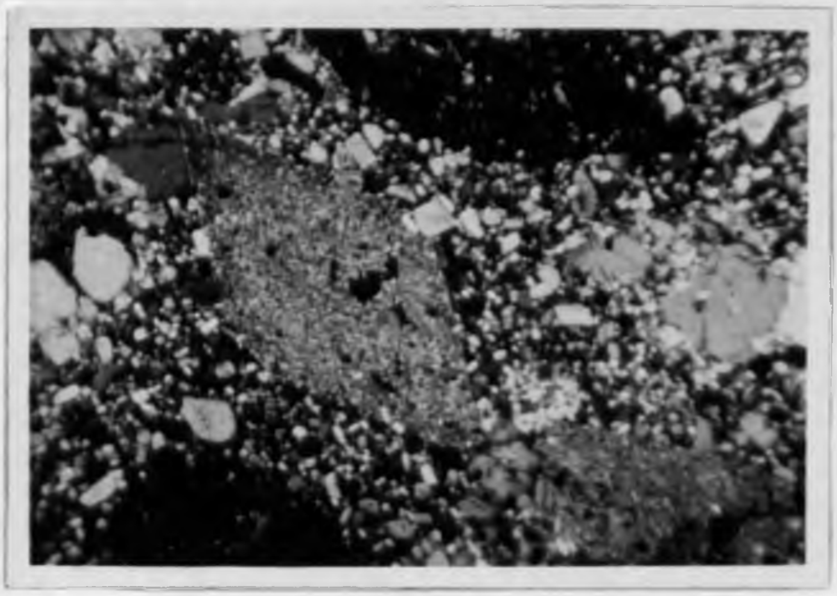

Figure 23

similar in texture, mineral associations, and mineral characteristics to the idocrase and wollastonite granofelses of Upper Paleozoic age. The idocrase-wollastonite granofels of Cretaceous age has commonly a mineralogical composition that varies over a short distance and even within the scale of a thin section. On the basis of the mineral proportions, two mineral assemblages have, therefore, been distinguished. The first assemblage consists of idocrase, calcite, epidote-clinozoisite, and quartz as the most common constituents, and diopside-hedenbergite and garnet as minor constituents. The second assemblage includes wollastonite, calcite, garnet, idocrase, diopside-hedenbergite, and quartz as the abundant minerals, with epidote-clinozoisite and fluorite as minor minerals.

Metaquartzite is well exposed northeast of the southern spur forming thick beds intercalated with the hornfels units throughout the Cretaceous rocks. Megascopically, the rock is light brown to yellowish brown and fine- to medium-grained in texture. Quartz is the only mineral that has been recognized. Microscopically, the metaquartzite is fine- to medium-grained and has a granoblastic mosaic texture. Constituent minerals are quartz, orthoclase, plagioclase, epidote, clinozoisite, chlorite, zircon, and sphene. Quartz is the most abundant constituent. Orthoclase and plagioclase are less abundant than quartz and partly altered to clay minerals and sericite, respectively. Epidote and clinozoisite are common accessory minerals. Chlorite, zircon, and sphene are minor accessories, with the sphene being partly altered to leucoxene.

STRUCTURE

The present study has accumulated generalized data concerning the geologic structure of the mapped area. The results are presented in two sections: structure of the metamorphic rocks and structure of the intrusive mass.

Structure of the Metamorphic Rocks

The metamorphic rocks are exposed along the eastern border of the stock. They strike northwest and dip gently to the northeast. An isolated outcrop, which may be a roof pendant, is exposed on the eastern part of the northern spur (Pl. 1). The concordance of lithology and attitude of the rocks of this segment suggest that it has not been rotated and was probably connected to the adjoining mass of Cretaceous rocks.

Numerous faults of small displacement were observed along the contact with the Upper Paleozoic rocks. These, in part, are parallel bedding and, in part, are cross-cutting. A series of three faults was found where the fluorite prospect pits are developed. They strike N30-35°W and dip 30-74°NE. Two faults were noted east and southeast of the small spring, striking N25-30°W and dipping 20-25°NE. As these faults are partly concealed by alluvium and talus, and as the rocks on both walls of the fault planes are lithologically similar, it is impossible to estimate the displacement. The rock on both walls has been crushed and gouge developed during the movement.

Structure of the Intrusive Mass

Structural features of the Swisshelm Quartz Monzonite are represented by the distribution and orientation of the orthoclase phenocrysts and dark inclusions and by a joint and fracture pattern developed throughout the mass. Generally, the orthoclase phenocrysts and dark inclusions are randomly distributed, but, locally, some of the phenocrysts seem to have a more or less preferred orientation with northeast trend. In places, swarms of dark inclusions show subparallelism to the strike of the adjacent sedimentary country rocks. A detailed statistical study of the phenocrysts and inclusions might disclose a linear structure that is not obvious in brief field investigations of outcrops.

Joints and fractures are developed to various degrees in all outcrops of the Swisshelm Quartz Monzonite. Parallelism of the prominent joints is a striking feature of the intrusive mass (Fig. 24). On the geologic map (Pl. 1), the joint symbol was used only where prominent joints are developed over a large area. In general, their strike ranges from northeast to north-northwest, with a variable dip. Irregular fractures are common, but seem to lack a general trend.

Figure 24 - Photograph of the Swisshelm Quartz Monzonite showing wide fissures and eroded joints on the southern slope of the northern spur.

Figure 24

VARIATION DIAGRAMS

The Swisshelm Quartz Monzonite stock is an intrusion consisting of medium-grained facies partly enclosing a core-like fine-grained facies of similar composition. The medium-grained facies, locally, passes into a fine- to medium-grained contact facies.

Field observations and microscopic studies indicate that the Swisshelm Quartz Monzonite represents a single intrusion of magma showing considerable variation among the different facies of its mass. These variations may be attributed to differentiation and a metasomatic alteration subsequent to intrusion and effected in place. The variations in different facies of the stock can be graphically exhibited in variation diagrams. Bowen (1956), in discussing variation diagrams, says,

> The principal purpose of a diagram is, of course, to offer a quick and graphic means of apprehending the chemical relations between the rocks... An outstanding exception is the diagram now most commonly used, in which the weight percentage of each oxide is plotted on rectangular coordinates against the percentage of one of the oxides, usually silica. A particular advantage is the facility with which one may determine the nature of the material that must be added to or subtracted from any rock mass to obtain another.

Generalized variation diagrams have been constructed to determine the trend of the major elements and the chemical character of the northern spur normal facies, the southern spur altered facies, and the southern spur fine-grained facies of the Swisshelm mass.

A generalized Harker diagram (Fig. 25) shows that the fine-grained facies is characterized by high K_2O, low CaO, and MgO content in contrast with the other two facies which contain more CaO and MgO and less K_2O.

The ternary variation diagram (Fig. 26) generally shows a close grouping of the results from the three different facies and emphasizes the high potash-lime character. The fine-grained facies shows a much closer grouping than the normal and altered facies and appears to have its own partly independent trend. The results from the other two facies have a greater scattering of points than those of the fine-grained facies. The patterns of the individual groups suggest an original, overall trend. The diagram for any of the individual facies or for the mass as a whole shows that the chief variation is toward the orthoclase apex. This variation is particularly noteworthy and supports the concept that the normal and altered facies are the first crystal differentiates which were effectively separated from the rest of the magma. This remaining magma or residual fluid later formed the fine-grained facies.

In general, Harker (1909) in his book points out that "... the earlier rocks are rich in the earlier minerals, and the later rocks in the later minerals." Wahlstrom (1950) in his book states "... that with an increase in alkali and silica there is a simultaneous decrease in lime, magnesia, and iron." He adds that "... with decreasing age the liquid becomes progressively enriched in silica and alkali feldspars and impoverished in calcic feldspar and ferromagnesian minerals." These basic ideas are supported by the results obtained from the variation diagrams.

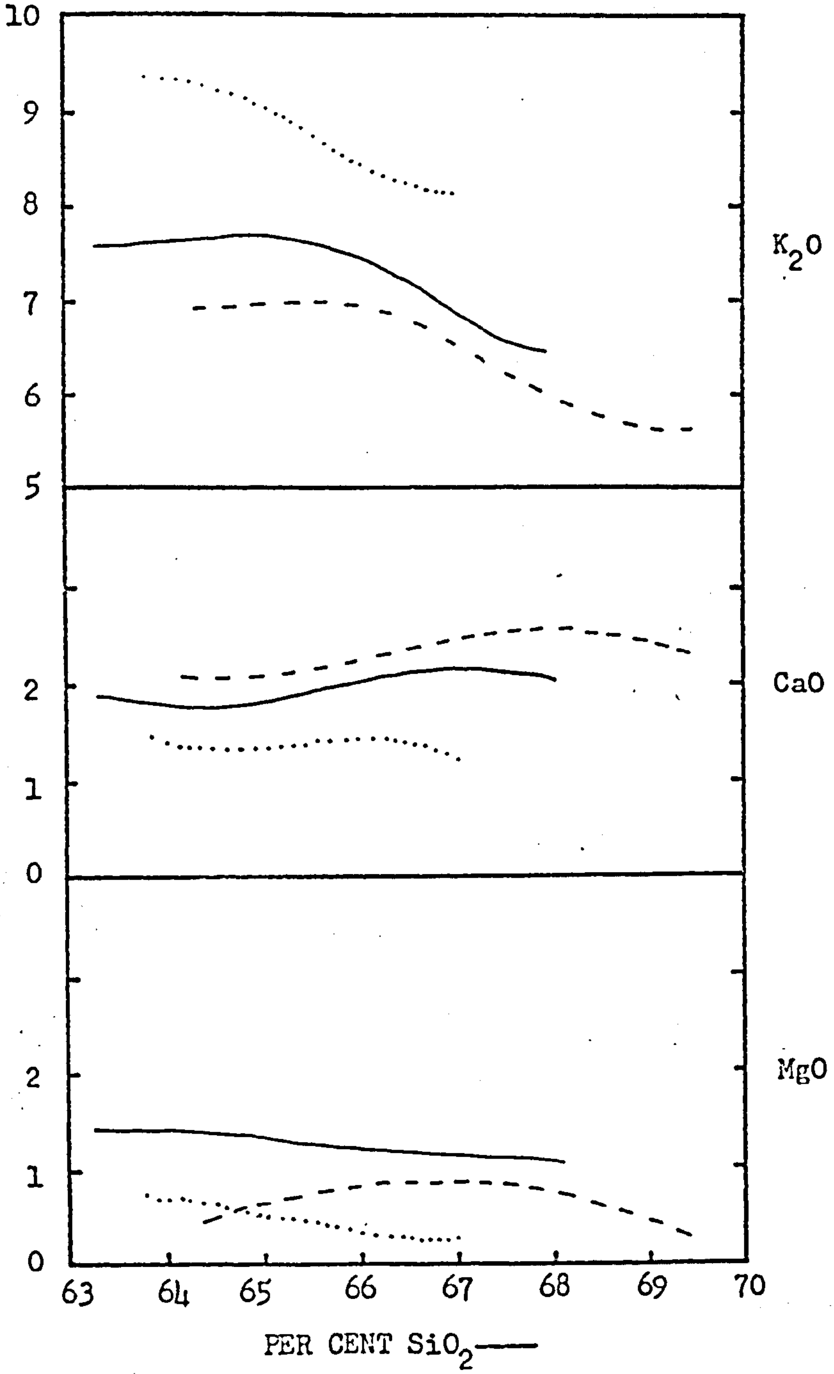

Figure 25. Generalized Harker variation diagram showing three facies of the Swisshelm Quartz Monzonite

____ Normal facies, _ _ _ Altered facies,

..... Fine-grained facies

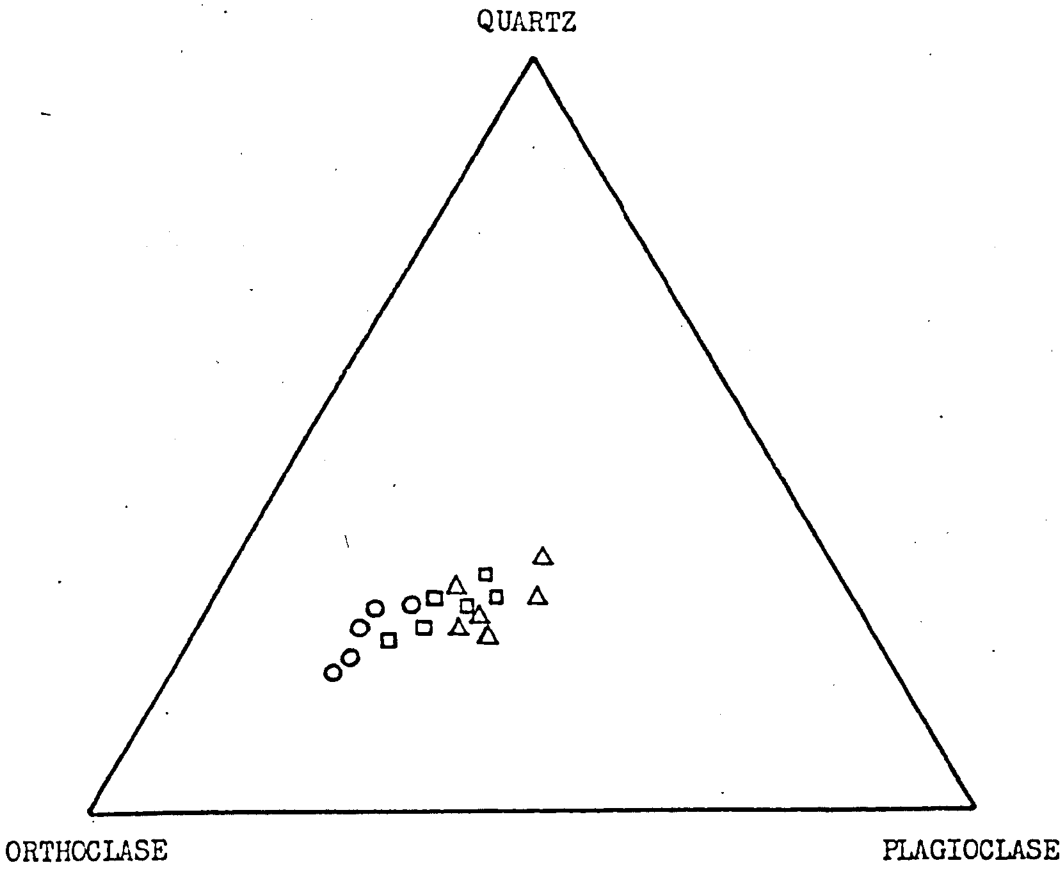

Figure 26. Triangle variation diagram showing three facies of the Swisshelm Quartz Monzonite

□ Normal facies △ Altered facies ○ Fine-grained facies

The conclusions reached may be summarized as follows:

1. All the different facies are very closely related and probably formed by differentiation of a single magma.

2. The fine-grained facies resulted from the final solidification of potash-rich residual fluid. This conclusion is also suggested by the textural characteristics.

PETROGENESIS

Swisshelm Quartz Monzonite

The origin of the Swisshelm Quartz Monzonite may be ascribed to (1) differentiation, probably of a quartz dioritic magma, and (2) metasomatic alteration of the primary intrusion.

During the early magmatic stages, apatite, zircon, magnetite, sphene, biotite, plagioclase, potash feldspar, and quartz were the primary minerals which crystallized from the magma.

Inclusions of the early-formed minerals and the local graphic texture of the large phenocrysts suggest that the phenocrysts were crystallized from the parent magma. The quartz in the orthoclase phenocrysts may be considered to have crystallized simultaneously with the host orthoclase. In connection with the porphyritic texture, Grout (1932) states "... there is also probably a relation between the increasing viscosity of a magma and the formation of a porphyritic texture. Large crystals in a fluid magma and the ground mass of fine crystals probably forms only after the cooling and possibly the loss of mineralizers has made interstitial residual magma more viscous."

The fine-grained facies is thought to be formed by the final crystallization of the late-magmatic residual fluids. Evidence for its origin is noted in field exposures and in thin section. Mineral composition and texture suggest that the residual fluid was rich in silica, alkali, fluorine, carbon dioxide, and other volatiles. The porphyritic texture may be attributed to the presence of early-formed crystals which remained suspended in the residual solution or to faster crystal growth. The graphic texture of the matrix is due to simultaneous crystallization of quartz and orthoclase. The overall fine-grained texture is believed to be the result of a fall in temperature and a relatively high viscosity. The increase in viscosity is produced by the escape of the volatiles and the high silica content.

In the late- and post-magmatic stages, the original intrusion was affected by metasomatic alterations, which were reactions between residual solutions and the early-crystallized minerals. Lindgren (1933) has defined metasomatism as "the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregates."

In the Swisshelm Quartz Monzonite we have had a metasomatic alteration and replacement caused by solutions rising up from within the parent magma itself, and no foreign source needs to be postulated. The high concentration of the volatiles in the residual solutions is believed to be of great importance in the development of the various facies of the stock and in the contact metasomatism of the country rocks.

Although the order of the metasomatic alterations is not known, it includes the following processes: (1) alteration of biotite, (2) alteration of feldspars, and (3) desilication of the contact facies.

Alteration of biotite to chlorite is a common metasomatic feature. In some instances, this chloritization is accompanied by the appearance of secondary magnetite. Also, biotite is partly replaced by muscovite.

Alteration of feldspars includes the albitization of the orthoclase and the formation of muscovite, sericite, fluorite, possibly apatite, and calcite as secondary minerals. In all facies, the orthoclase is partly replaced by albite as a result of an introduction of soda. This replacement is believed to produce the perthitic texture. Although some of the common types, such as the film and vein perthites, may have originated by exsolution, others, such as patchy perthite, are believed to be formed by replacement. Muscovite, partly replacing orthoclase, is also a common metasomatic feature in the Swisshelm Quartz Monzonite. In the diorite contact subfacies, the orthoclase is almost completely converted to muscovite.

The plagioclase is commonly altered to sericite and partly replaced by muscovite, orthoclase, fluorite, and calcite. Partial sericitization of the plagioclase resulted in the liberation of some of its lime content. This calcium combines with some of the volatile constituents, such as fluorine, phosphate, and carbon dioxide, to produce fluorite, calcite, and probably apatite. The orthoclase replacement of plagioclase is considered a result of potassium metasomatism.

Desilication of the contact facies is a striking magmatic and metasomatic feature of the area. The origin of the diorite, monzonite, and syenite subfacies may be ascribed to a reaction between late magmatic residual solutions and the Upper Paleozoic limestone. During this reaction, it is believed that silica was partly transferred to the wall rock to form abundant calc-silicates. Conversely, some of the calcium may have migrated inward from the limestone to produce the common calcite and fluorite minerals in the contact facies.

The abundance of orthoclase in the syenite subfacies and its postulated conversion to muscovite in the diorite subfacies may be attributed to variations in the prevailing temperature and pressure along the contact. According to Hemley (1959), at either a constant temperature or a constant pressure, the conversion of orthoclase to muscovite may be ascribed to a decrease of either pressure or temperature. The assumed decrease would cause a shift from the orthoclase stability field to that of muscovite. The abundance of orthoclase in the syenite may be related to potash metasomatism.

Aplite, Pegmatite, and Quartz

Mineral compositions of aplite, pegmatite, and quartz correspond to those of the final stage of the parent magma with which they are associated. Therefore, they represent the late products of residual fluids formed by the crystallization of this magma.

Johannsen (1932) pointed out that "aplites are generally assumed to have originated from magmas similar in composition to those from which pegmatites came, but poorer in mineralizers and, consequently, more viscous. The two rocks evidently crystallized at approximately the same time, from the same source, and apparently under the same physical conditions."

The difference in texture between aplite and pegmatite may be attributed to the relatively higher degree of viscosity caused by the partial escape of volatiles from the aplite-forming residula solutions. The local graphic and porphyritic textures of aplite are similar to those characteristic of the fine-grained facies of the associated quartz monzonite. The graphic texture is thought to be produced by eutectic crystallization of the residual fluids. The porphyritic texture may be ascribed either to a faster growth of the phenocrysts or to a sudden cooling after the phenocrysts have grown to a certain limit.

Turner and Verhoogen (1960) have stated "... a late residual liquid (pegmatite magma) should be rich in quartz and alkali feldspar in proportions roughly corresponding to those in the low-melting range of the system orthoclase-albite-silica. That water and other volatile components -- phosphorous, fluorine, chlorine, sulfur, etc., and volatile compounds of these such as $SnCl_4$, $FeCl_3$, etc. -- should also become concentrated in the final residuum of granitic magma is also to be expected under certain conditions." The pegmatite coarse texture is believed to be the result of relatively low viscosity of the residual solutions caused by a high concentration of volatiles. The perthitic texture of pegmatite is similar to that of the enclosing quartz monzonite, especially the normal facies. It is thought that it has been generated in the same way either by exsolution or replacement.

Generally, the intimate association of aplite, pegmatite, and quartz veins demonstrates that they represent the magma residua and suggests that they were generated in essentially the same way. Their emplacement along joints and fractures suggests that these structural features have been developed during a cooling of the parent mass.

Inclusions

The origin of the inclusions in the Swisshelm Quartz Monzonite cannot be exactly determined at the present time. However, their field occurrence and petrographic study suggests that they are more related to the intrusive mass in which they occur than to the country rocks.

The biotite-potash feldspar-rich inclusions have a granoblastic texture and are composed of the same minerals which are present in the host rock. They contrast in having a higher content of K-feldspar, biotite, magnetite, and apatite. The higher potassium content could be attributed to a late-stage potassium metasomatism. The granoblastic texture with the relatively high concentration of apatite and magnetite may suggest a segregational origin for these inclusions (Grout, 1937).

The chlorite-plagioclase, biotite-plagioclase, and muscovite-plagioclase-rich inclusions are generally composed of the same minerals as the enclosing quartz monzonite. The chloritization of biotite, the local albitization of orthoclase, the muscovite, sericite, fluorite, and calcite replacements are striking metasomatic features. The associated pseudodiabasic, graphic, and perthitic textures in the biotite-plagioclase-rich inclusions are thought to be the result of a recrystallization and replacement process. The common crystalloblastic and the local porphyroblastic textures are a result of recrystallization of the original material. The mineral composition, the metasomatic features, and the high percentage of the plagioclase in these inclusions may be considered as criteria which suggest that they are cognate fragments of an earlier and more basic facies of the

Swisshelm Quartz Monzonite. Grout (1937) stated that "Cognate inclusions show much the same minerals (Pabst, 1928, p. 343) (Heyl, 1936) and the same late magmatic reactions (Bowen, 1922) as the minerals of the host, because the two are related and the fragments were still hot when included. A lack of such reaction in the inclusion is a strong sign that the inclusion is not cognate (Bowen, 1922)."

The muscovite-potash feldspar-rich inclusions are somewhat similar to aplite in mineral composition and texture. The quartz inclusions in the plagioclase porphyroblasts seem to be older than the host plagioclase crystals. According to Grout (1937) the absence of the plagioclase zoning, the sugary texture of the matrix, and the occurrence of zircon with unusual interference color and coarse grains may be considered as criteria of xenoliths of older aplitic rocks. But the presence of muscovite, sericite, fluorite, and calcite as metasomatic products may suggest that these inclusions represent cognate fragments of an early aplite facies included in the later Swisshelm Quartz Monzonite.

Metamorphic Rocks

The extensive metamorphism affecting the country rocks is of the contact type and may be attributed to simultaneous metasomatism and metamorphic differentiation. Ramberg (1958) suggests metasomatism when he states that "Magmas contain some substances which cannot enter completely the solid phases in the course of crystallization. Among such substances H_2O, C)$_2$, B, S, F, Cl, or some intercombinations of these and metals: FeF_3, SnF_4, FeF_2 (Table 15, p. 183). The mobile compounds must leave the magma chamber under or after crystallization, and they may perform metasomatism in the contact aureole."

Metamorphic differentiation is expressed by Turner and Verhoogen (1950) as follows: "Metamorphic differentiation covers collectively the various processes by which contrasted mineral assemblages develop from an initially uniform parent rock during metamorphism."

The intrusive mass of the Swisshelm Quartz Monzonite apparently gave off great quantities of hot, volatile-rich, residual fluids capable of penetrating the beds and causing changes in the texture and mineralogy of the country rocks. The characteristic crystalloblastic texture is due to simultaneous growth of all the component crystals.

The growth of garnet, hornblende, cordierite, feldspars, idocrase, and pyrite porphyroblasts is considered by Turner and Verhoogen (1960) and Ramberg (1958) as one of the most familiar results of metamorphic differentiation. Also, local segregations of pure marble and calc-silicate bands, lenses, and irregular masses seem to be striking features of metamorphic differentiation.

Ramberg (1958) stated that "The forces underlying the growth of a porphyroblast and the mechanism of this process are complicated in detail but rather easy to explain in principle. By changing P and/or T, a rock has become 'supersaturated' to certain small degree with reference to a mineral, say garnet. Under these circumstances, the probability of forming nuclei large enough to grow further (positively unstable nuclei) is small, whereas the very minute nuclei which form more frequently are negatively unstable phases and are likely to disintegrate. A further growth of the few growable nuclei decreases their molal free energy, thus establishing a centripetal free energy gradient, which causes the crystals to grow with a supply of material from the surroundings."

The poikioblastic texture of garnet, idocrase, cordierite, and feldspar porphyroblasts is regarded by Turner and Verhoogen (1960) to be the result of relatively rapid crystallization of the host mineral about sparsely scattered nuclei. The garnet zoning seems to reflect environmental variation in the physical conditions and chemical composition of the surrounding environment.

Field and petrographic studies indicate that the mineralogy of the metamorphic rocks may be attributed mostly to local variations in the initial composition and partly to introduction of magmatic materials.

The development of the calc-silicate in the dolomitic limestone and shaly sediments of the Upper Paleozoic Naco Group appear to be, in part, due to reaction between the parent rocks and the associated impurities and, in part, due to reaction between the initial sediments and iron-magnesium and silica-bearing solutions given off from the marginal magma. To the latter reaction, the desilication and probably the biotite-impoverishment and the calcite enrichment of the quartz monzonite contact facies have been ascribed. The pure marble was undoubtedly derived from limestone. Fluorite and pyrite are striking features of fluorine and sulfur metasomatism.

In the calcareous and arenaceous sediments of the Cretaceous Bisbee Group, the metamorphic silicates are believed to have formed by reaction between the pre-existing constituents under the influence of volatile-rich magmatic fluids.

The local development of the hornblende, instead of pyroxene, in the granofels in direct contact with the intrusive mass may be attributed to lower temperature or to high water pressure (Buddington, 1963) (Yoder, 1955); also, it may be due to local access of aluminum near the contact. In addition, Harker (1960) stated that "... it is not impossible, even where no fluoride is now to be detected, that it may have played a part as a 'mineralizer,' perhaps determining the formation of an amphibole rather than a pyroxene or idocrase rather than grossularite."

In general, the deposition of the contact-silicate minerals appears to be controlled mainly by the permeability of the country rocks and partly by fractures and bedding planes which have served as channel-ways to spread out the invading magmatic solutions.

CONCLUSIONS

From the previous discussion, the following conclusions may be drawn:

1. The Swisshelm Quartz Monzonite was formed in situ by differentiation and metasomatic processes.

2. The original magma (probably quartz dioritic in composition) was the source of the residual solutions that took part in the conversion of the rock to the present composition.

3. Initial differences in the concentration of the magmatic materials and in conditions of temperature and pressure have produced corresponding differences in texture and mineral composition of the Swisshelm Quartz Monzonite.

The abundancy of late-stage orthoclase, partial replacement of plagioclase by muscovite and orthoclase, and the development of the syenite contact subfacies are striking examples of potash metasomatism.

4. The fine-grained facies and aplite represent the late-stage accumulation of magmatic products and have the same mode of occurrence.

5. Beryl-bearing pegmatite is also a late magmatic product and was derived from an aqueous, volatile-rich residual solution.

6. During late- and post-magmatic stages the primary intrusion was extensively affected by reactions with the residual solutions.

7. Chloritization of biotite, albitization of orthoclase, sericitization of plagioclase, replacement by muscovite, fluorite, and calcite, beryl development, and desilication of the contact facies are prominent metasomatic features.

8. The more extensive alteration of the "altered facies" is thought to be produced by the greater concentration of the residual solutions remaining after the formation of the fine-grained facies.

9. The contact facies were formed by reactions between the magmatic derived solutions and the Upper Paleozoic limestones.

10. The inclusions in the Swisshelm Quartz Monzonite are believed to be of various origins: (a) local segregations, (b) cognate fragments of an early basic facies, and (c) cognate fragments of an early aplitic facies.

11. Metamorphism is of contact types.

a) Textural and mineralogical changes in the country rocks are attributed to simultaneous contact metasomatism and metamorphic differentiation.

b) The development of calc-silicates is due to initial composition and partly to addition of magmatic materials.

c) Fluorine and sulfur are the most common mineralizers capable of accelerating the chemical reaction of this metamorphism.

d) Rock permeability and fissures are the main controlling features for the diffusing volatile-rich magmatic solutions.

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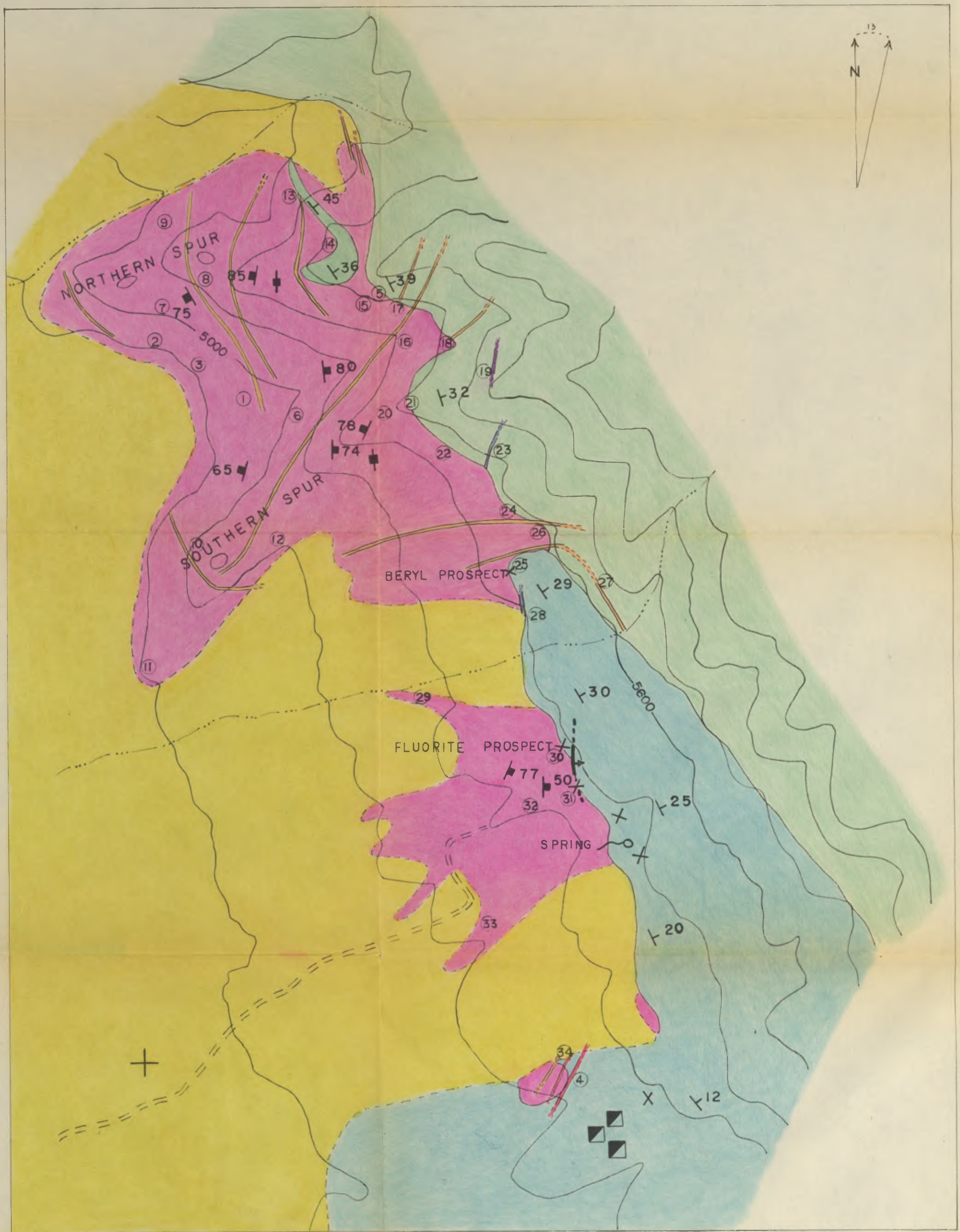
1 map

PLATE I

GEOLOGIC MAP OF SWISSHELM QUARTZ MONZONITE

SWISSHELM MOUNTAINS

COCHISE COUNTY, ARIZONA



EXPLANATION

	ALLUVIUM	QUATERNARY
	ANDESITE	POST LOWER CRETACEOUS
	LAMPROPHYRE	
	RHYOLITE	
	APLITE	
	QUARTZ MONZONITE	
	BISBEE GROUP	LOWER CRETACEOUS
	NACO GROUP	UPPER PALEOZOIC

CONTACT, DASHED WHERE APPROXIMATE
CONTOUR LINE
INTERMITTENT WASH
ROAD
FAULT SHOWING DIP AND STRIKE, DASHED WHERE APPROXIMATE
DIP AND STRIKE OF BED
DIP AND STRIKE OF JOINT
STRIKE OF VERTICAL JOINT
SHAFT
PROSPECT
SURVEYED SECTION CORNER
SPECIMEN LOCATION

0 — ¼ — ½ — 1 MILE

SCALE 8 INCHES = 1 MILE
DATUM MEAN SEA LEVEL
CONTOUR INTERVAL = 200 FEET

GEOLOGY BY H. D. DIERY
FEBRUARY, 1964