Fund in

PRE-CAMBRIAN CRYSTALLINE ROCKS OF THE WASATCH MOUNTAINS, UTAH

by

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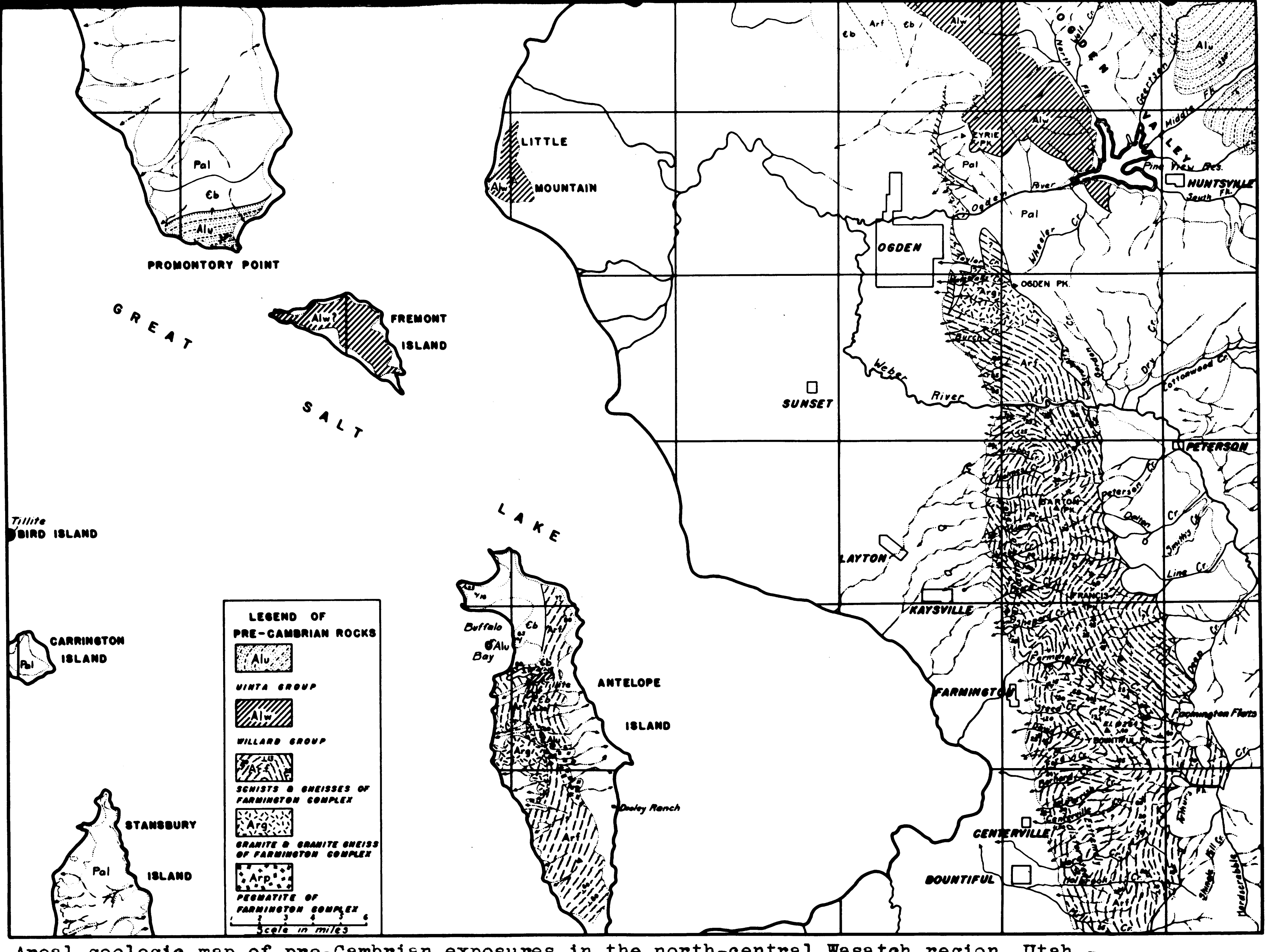

Areal geologic map of pre-Cambrian exposures in the north-central Wasatch region, Utah.-
By A. J. Eardley — Plate I

INTRODUCTION

Dr. A. J. Eardley of the University of Michigan suggested that the writer make a petrographic study of the pre-Cambrian crystalline rocks of the north-central Wasatch Mountains, Utah, to supplement the areal studies of the region made by Dr. Eardley. He was kind enough to furnish a collection of rocks and field data which made this study possible. The chief exposures of the old crystalline rocks are the main ridge of the Wasatch Range from Bountiful north to Ogden, and Antelope Island in Great Salt Lake (see accompanying map by A. J. Eardley). Small outcrops are found in Cottonwood Canyon northeast of Peterson, and at the base of the high peak east of Peterson. Very little petrographic work has been done on rocks of pre-Cambrian age in the Wasatch Mountains. For the area in which this study was made, the only known petrographic descriptions are those by F. Zirkel[1] made in the report of the 40th Parallel Exploration over sixty years ago.

The writer wishes to express his appreciation to the geology department of the University of Michigan for financial aid in the preparation of thin sections, to Professors T. S. Lovering and A. J. Eardley for critical reading of the manuscript, and to Dr. E. Ingerson of the Geophysical Laboratory for supplying incentive and assistance in making a petrofabric study of several of the rocks.

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1. Zirkel, F., U.S. Geol. Expl. 40th Parallel, v.6, 1876, pp 22-26.

GEOLOGY

Name, "Farmington Complex"

The name "Farmington complex" is chosen for the gneisses, schists, and igneous intrusions that are well exposed in the area, and the locallities of Farmington Canyon and Bountiful Peak are designated as the type sections. The rocks are thought to be of Archean age. The Willard group and Uinta group[1], thought to be of Algonkian age, are beyond the scope of the present article and are not treated. Inasmuch as the Farmington complex contains many lithologic types that have not yet been clearly related stratigraphically and structurally, it is felt that the word "complex" should be used in preference to "series", "group", or "formation".[2]

Metamorphic Rocks

The Farmington complex is composed essentially of metamorphic rocks. At various times igneous material was injected into the pre-existing rocks. Quartzites, arkosites, conglomerate schists, quartz-chlorite schists, mica schists, biotite injection gneisses, and granite gneisses are the common rock types to be found. The quartzites, arkosites, and conglomerate schists have been taken as strong evidence of the sedimentary origin of a considerable part of these pre-Cambrian rocks. They are thought to correlate approximately with the Vishnu schist of the Grand Canyon region[3].

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1. Names of younger pre-Cambrian formations to be introduced by A. J. Eardley.
2. Classification and nomenclature of rock units, Geol. Soc. Am., v.44, article 22, 1933, p 445.
3. Blackwelder, E., Summary of the pre-Cambrian rocks of Utah and Wyoming, Proc. Utah Acad. Sci., Arts, Letters, v.12, 1935, p153.

Igneous Rocks

Intimate intrusion of igneous material into the gneisses and schists has greatly increased the complexity of the history of these rocks. Primary gneisses, injection gneisses, granites, aplites, and pegmatites are all found within comparatively short distances of each other. Sills and lit-par-lit injections are the most common forms that the intrusions take. However, dikes and small stocks are present. The igneous material is of pre-Algonkian age because it is separated from Algonkian rocks[1] by an erosional unconformity. Little is known about the relative ages of the various intrusions. A small amount of evidence has been found that indicates at least that some of the igneous material was injected before the main period of metamorphism. This evidence will be discussed in detail under the petrofabric analysis of an injection gneiss.

STRUCTURE

Stratification

Another feature that supports the belief that many of these rocks are of sedimentary origin is the marked stratification which is so general throughout the region. Over most of the area where schists and gneisses are exposed, reliable strike and dip readings were recorded. The exact thickness of the Farmington complex is not known because no formational units could be traced for any extent laterally. It is safe to say, however, that at least a depth of 15,000 feet is exposed in the area under discussion. For the most part, the foliation is apparently parallel to the bedding planes.

1. The Uinta and Willard groups, A. J. Eardley, personal communication.

The fact that lit-par-lit injections, parallel to the general stratification, are so abundant, further substantiates this conclusion. Although the strikes and dips vary locally with the folding, the prevailing direction of strike of the foliation is north to northwest.

Folds

An open anticline trends about N 60° W through Bountiful Peak. It is flanked on both sides by open synclines, all of which plunge about 15-20° to the northwest. The structures of the Bountiful Peak area (see Plate I) are better revealed than elsewhere in the area. Trending through Weber Canyon the beds strike persistently to the northwest, the same as the axes of the folds of the Bountiful Peak area. Between Weber Canyon and Farmington Canyon is an area of very intricate structure. Although strike and dip readings were taken at numerous places and were apparently consistent enough with adjacent ones, they did not reveal the folds of the beds. The new CCC road from Bountiful to Bountiful Peak passes over an area of extremely distorted beds where the structure could not be made out in the brief time spent in the area. From Shepard Creek north to Holmes Creek across the mouths of the canyons is a zone of distortion in which the structure is very difficult to decipher. This may be a shear zone that originated during the Laramide Revolution[1].

Faults

A number of high-angle faults of small displacement were noted within the Farmington complex but their age could not be definitely

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1. A. J. Eardley, personal communication.

determined. The western face of the Wasatch Range in this section is a fault scarp of the Pliocene and Pleistocene Basin and Range deformation, and the small high-angle faults within the complex may be of the same age. Thrust faults of the Laramide Revolution are found within the area, chiefly at the mouth of and in Ogden Canyon. One or two of the thrusts pass into the schists and gneisses and are lost. The zone of distortion between Shepard and Holmes Creek may be a thrust fault of Laramide age. The thrusts resulted from approximate east-west compression[1].

PETROGRAPHY

Summary Of Rock Types And Distribution

The petrographic study has been made on twenty thin sections from as many different rocks. The specimens selected are representative of the important types found in the field. On the basis of the microscopic work, the various types have been divided into four groups denoting the origin of the rocks. These groups include the sedimentary rocks, silicic igneous rocks, injection gneisses, and the mafic igneous rocks. Only the metamorphic equivalents of these rocks are present now. Table I classifies the various rock types studied and gives the locallity from which the specimens came.

Metamorphosed Sedimentary Rocks

Megascopic Features:- The primary feature of the metamorphosed sediments is their stratification. This in conjunction with their mineralogical composition constitute the best evidence for a sedimentary origin. The quartz-sericite and quartz-chlorite

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1. A detailed study of the area by A. J. Eardley following Blackwelder's reconnaissance in 1910, is the basis for these statements.

Group	Slide No.	Name Of Rock	Location
Metamorphosed Sedimentary Rocks	5	Quartz-sericite schist	Bountiful Peak, northeast slope
	6	Quartz-chlorite schist	Bountiful Peak, northeast slope
	7	Arkosite	Bountiful Peak, east slope
	12	Quartz-chlorite conglomerate schist	Bountiful Peak, east slope
	11	Quartzite (pebble from 12)	Bountiful Peak, east slope
	14	Arkosite	Antelope Island, near top highest peak
Metamorphosed Acid Igneous Rocks	1	Gneissic hornblende granite	Ogden Canyon, mouth of
	2	Mylonite granite gneiss	Bountiful Peak, east slope
	3	Quartz aplite gneiss	Bountiful Peak, east slope
	13	Feldspathic pegmatite	Antelope Island, southeast highest peak
	22	Gneissic granite	Ogden Canyon, mouth of
	23	Gneissic quartz monzonite	Antelope Island, west highest peak
	27	Gneissic quartz monzonite	Waterfalls Canyon
Metamorphosed Injection Gneisses	9	Biotite injection gneiss	Bountiful Peak, east slope
	10	Biotite injection gneiss	Bountiful Peak, east slope
Metamorphosed Basic Igneous Rocks	4	Hornblende-labradorite gneiss	Bountiful Peak, east slope
	8	Hornblende-labradorite gneiss	Bountiful Peak, east slope
	15	Epidote-chlorite schist	Farmington Flats, ridge, east of
	28	Chlorite-sericite schist	Waterfalls Canyon
	29	Hornblende gneiss	Antelope Island, near top highest peak

Classes of microscopically studied rocks of the Farmington complex

Table I

schists, Nos. 5 and 6, were collected from two beds, one on top of the other, near Bountiful Peak. Both are grayish green in color, have a greasy luster, and have lost their original granular texture. A schistose structure pervades them, conspicuous in No. 6, because of the abundance of a platy chlorite, but less distinct in No. 5 which contains very little platy material visible to the eye. The quartz-sericite schist would be called a quartzite on the basis of its megascopic appearance.

The arkosites, represented by Nos. 7 and 14, are quite dissimilar. No. 7, from Bountiful Peak, looks like a quartzite and is composed of white bands containing mostly quartz, and brownish stained bands containing quartz and mica. No. 14, from Antelppe Island, has a dark greenish gray color due to an abundance of chlorite. Numerous light specks of altered feldspar stand out against the dark background. An indistinct bedding plane makes about a 35° angle with the schistosity of the specimen.

The most interesting and significant of the rocks that fall in this group is the quartz-chlorite conglomerate schist from Bountiful Peak, Nos. 11 and 12. The rock consists of elongated green quartzite pebbles in a groundmass of lenticular quartz and chlorite. The pebbles vary in size from 1/8 inch up to about an inch in diameter. The strongly schistose layers of the groundmass bend around the pebbles giving the rock as a whole a wavy appearance. The pebbles are in general elongated parallel to the plane of foliation.

Two types of rocks that are abundant in the area are the mica schist and a white quartzite. The mica schist contains alternating thin layers of a platy mica and small lenses of quartz. Weathering has produced a brown iron stain on the exposed surfaces (of this type of rock.) The white quartzite is thought to be a metamorphosed sandstone because it forms beds of uniform thickness that are conformable with the other old sedimentary beds[1]. The quartzite has a fused appearance and all indications of a granular texture have been obliterated. The rock seems to contain little else but quartz. No slides were prepared from these rocks.

Microscopic Features:- Under the microscope, the rocks of this group have many features in common. Mineral grains commonly have a thin zone of granulated material around them. Sutured boundaries are especially noticeable between the quartz grains. Undulatory extinction, moderate to strong, is universal in the quartz. Accompanying this feature, apparently, is the tendency for quartz to show incipient cracking and occasionally more intense shattering and granulation. Some of the mortar structure appears to belong to a different deformation than that which produced the strains and cracks in the quartz. Those rocks containing feldspar show similar features but much less intense. Mica and chlorite show warping. Schistosity is evident but not always well developed. It is revealed the best by mica and chlorite. However, petrofabric analysis proves that quartz has preferred orientations. Grain size is variable in the same specimen, ranging in all sizes up to a maximum diameter of about one millimeter.

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1. A. J. Eardley, personal communication.

The rocks of this group appear to have been somewhat recrystallized following an earlier stress period that produced some granulation at the grain boundaries. The main deformation was a low to medium grade of dynamic metamorphism. The cataclastic affects indicate that the rocks were under a comparatively light load. The strains in the quartz may have been produced during the main period of metamorphism. However, if recrystallization was complete, any straining of the quartz should have been relieved and it would be necessary to assume that the strains now present were produced either by a gradual diminution of the stresses during the main period of metamorphism or by some later deformation.

With regard to mineral composition, certain similarities are noted. All have quartz as their predominant mineral which is estimated to range from 40 to 80 percent. Fluid inclusions in the quartz are scarce. This feature is noted in the igneous rocks also, possibly indicating a scarcity of the gaseous phase in the original magma from which the quartz was derived. Chlorite in various stages of alteration from biotite is present in all rocks of this group. Small needles and grains of rutile are characteristically associated with chlorite. They have the white alteration product leucoxene on their surface. The rutile seems to develop as the biotite alters to chlorite and, therefore, suggests that the biotite was a titaniferous variety. Other minerals universally present and generally accessory are sericite, zircon, and apatite.

A quantitative mineral analysis of the six slides studied is summarized in Table II below. The percentages have been estimated with the exception of slide 6. In this case the relative amounts

	Quartz-sericite schist No. 5	Quartz-chlorite schist No. 6	Arkosite No. 7	Quartz-chlorite conglomerate schist No. 12	Quartzite No. 11	Arkosite No. 14
Quartz	80	68.7	70	50	60	40
Biotite (Chlorite)	5	24.4	5	40	30	45
Sericite	15	6.9	..	10	10	
Feldspar	..	...	25	..	..	15
Total	100	100.0	100	100	100	100

Quantitative mineral analyses of the metamorphosed sedimentary rocks.

Table II

were determined by micrometric analysis using a Wentworth recording micrometer. These figures, while only an approximation, are sufficiently accurate to denote the gènéral picture.

In addition to the above features that are common to all the rocks studied, other details are noted in the various slides. Recrystallized quartz having sutured grain boundaries and interstitial patches of sericite are particularly characteristic of the quartz-sericite schist, No. 5. The chlorite present is an unusual variety. It occurs in well developed crystals, is nearly colorless but has a slight greenish tint. Its interference color is first order light gray. The absence of magnetite and other iron minerals in the rock supports the belief that this is a low iron variety of chlorite. Small needles and grains of rutile are abundant in the chlorite. The quartz-chlorite schist, No. 6, is much like the preceeding one except that the amount of chlorite present is much greater. The chlorite contains a small amount of interbanded muscovite in very thin strips.

The arkosite, No. 7, differs from the preceding schists chiefly by the presence of the feldspars,-orthoclase, basic oligoclase of the approximate composition $Ab_{73}An_{27}$[1], and a little microcline. Clinozoisite in small grains and sericite occur as alteration products from the feldspars. Biotite has mostly altered to chlorite although epidote has formed in places and magnetite has altered to hematite and limonite. The other arkosite, No. 14, contains abundant green chlorite that seems to be intimately mixed

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1. All plagioclase feldspars mentioned have been determined by the Foquè method.

with fine sericite. The chlorite forms felted and highly folded masses. Magnetite is a plentiful accessory and is associated with the chloritic material.

The conglomerate schist from which slides 11 and 12 are cut is of unusual interest, not only because it affords excellent proof of sedimentary rocks in this early geologic time, but also because it contains pebbles that are themselves of sedimentary origin.

Most of the quartz in the pebbles varies between 0.05 and 0.1 millimeters in diameter and is angular to rounded in shape. This quartz is only slightly strained. A mixture of chloritic material and some sericite constitutes the cementing agent in the pebbles. The chlorite is responsible for the green color and inferior hardness of the pebbles, a knife easily scratching them. Small grains of rutile are abundant.

The groundmass of the conglomerate schist is composed of the same well developed chlorite with interbanded muscovite, mentioned in slide 6. The foliation is very pronounced. The quartz occurs in lenticular masses parallel to the foliation, each lens consisting of an aggregate of recrystallized grains.

<u>Petrofabric Analysis</u>:- Although the thin sections had not been made from oriented specimens, it was felt that the metamorphic history of some of the rocks could be profitably investigated by means of petrofabric analysis[1]. The general technique of fabric analysis as summarized by Knopf[2] was used.

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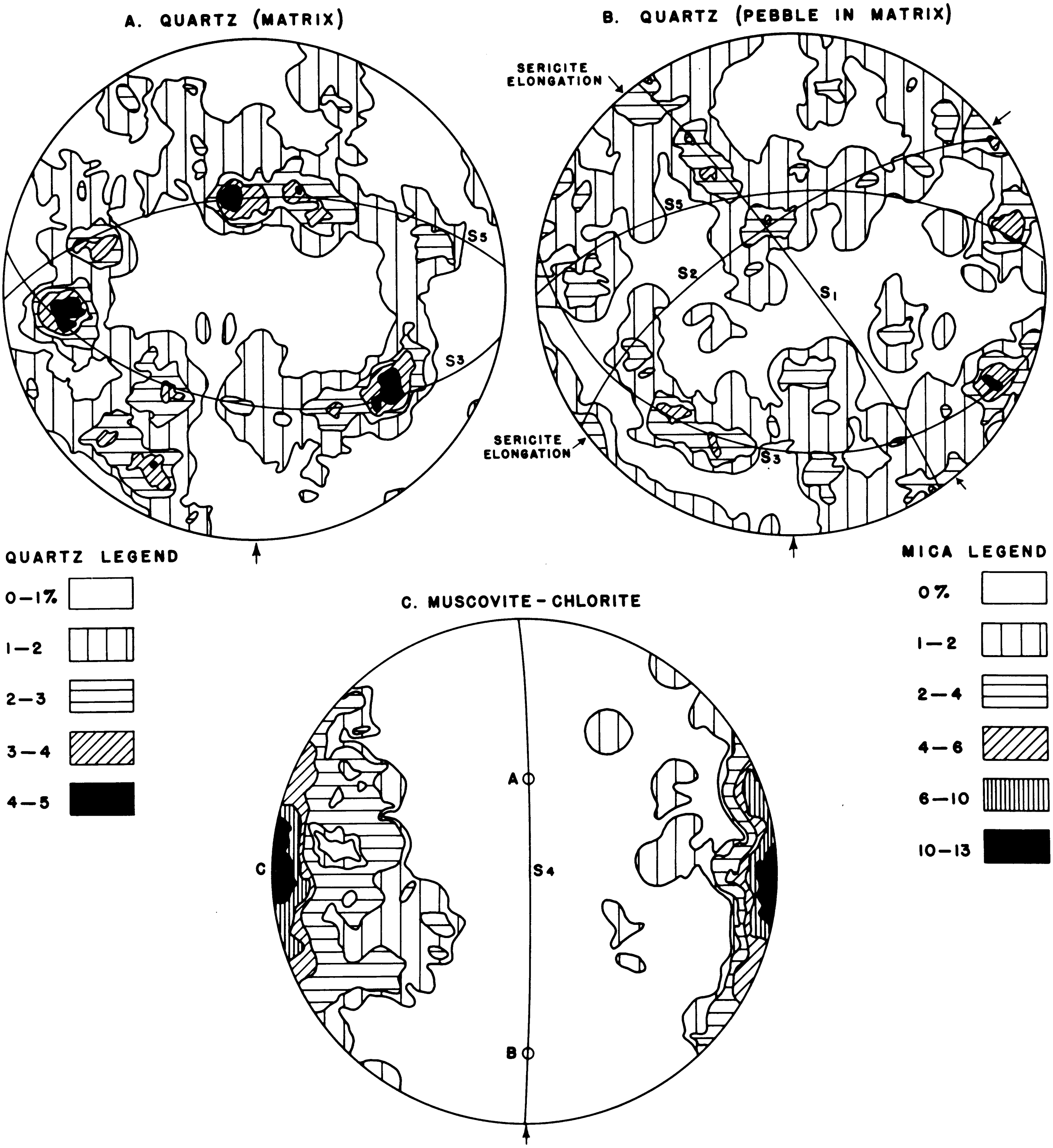
1. Suggestion by Dr. Earl Ingerson, Geolphysical Laboratory.
2. Knopf, E.B., Petrotectonics, Am. Jour. Sci., v.31, 1933, pp 443-470.

In the study of the conglomerate schist, two problems suggest themselves; one is the determination, if possible, of the number of times that the groundmass has been metamorphosed; the other is the investigation of a possible previous metamorphic history of the pebbles.

From the groundmass of slide 12, two orientation diagrams were prepared; one from 308 grains of quartz and the other from 149 grains of muscovite and chlorite (see Figure 1, A and C). The muscovite-chlorite diagram (Figure 1, C) clearly shows the pronounced orientation that is responsible for the foliation of the rock. The plane of foliation is represented by S_4, the great circle through the A and B petrofabric axes. The quartz diagram, (Figure 1, A) reveals two distinct girdles, S_3 and S_5, containing maximum concentrations.

S_5 represents a plane, nearly normal to S_4, the mica plane, in which the C-axes of the quartz grains are oriented like the spokes of a wheel. According to petrofabric theory, this orientation of the quartz grains is due to their rotation caused by shearing movement in the mica plane and parallel to the line of intersection of S_5 with it - the A fabric axis.

S_3 represents another plane, nearly normal to the mica plane and inclined about 65° to S_5, in which the C-axes of quartz exhibit the same radial pattern as in S_5. The orientation of the quartz grains in S_3 is theoretically due to movement in the mica plane approximately parallel to the line of intersection of it and the S_3 plane.



Petrofabric diagrams of the quartz-chlorite conglomerate schist from Bountiful Peak. A. 308 quartz grains in the matrix; B. 202 quartz grains in a quartzite pebble surrounded by matrix. The direction of elongation of the sericite in the pebble is indicated by the four arrows on the circumference of the circle; C. 149 muscovite and chlorite grains in the matrix. The measurements of the quartz and muscovite-chlorite grains are non-selective.

Figure 1.

Both quartz girdles are about equally developed, and, according to the usual interpretation, both seem to be related to movement in the S_4 plane of foliation. However, it appears mechanically impossible for both girdles to have been formed at the same time by a movement in only one direction in the S_4 plane. It is tentatively concluded, therefore, that movement occurred along two different directions in the S_4 plane. At the present time it can not be ascertained whether the movement alternated in these two directions during one period of deformation or whether two periods of deformations produced the two quartz girdles.

Following the study of the groundmass, a quartz diagram of a pebble in the conglomerate schist was made. The pebble selected was from slide 12 so that it had a fixed orientation in relation to the groundmass from which the other measurements were made. A diagram of 202 grains was prepared and the orientation of the sericite also carefully noted (see Figure 1, B). The structures in this diagram are so weak that considerable uncertainty is involved in picking them out. Only the most obvious S-planes have been indicated. Others may be present but their interpretation is left for future work to disclose.

What appears to be the S_5 girdle is located in the same position in this diagram as the one in Figure 1, A. The S_3 girdle is more uncertain. Definitely there is a band of concentration in the same general position as S_3 in Figure 1, A, but the uncertainty as to where to draw the great circle through the band deviates as much as 25° from the position in Figure 1, A. The two girdles S_1 and S_2

are thought to be evidence for a pre-conglomerate metamorphism of the pebble material. It was observed that the traces of these planes mark the direction of elongation of sericite flakes in the larger pebbles. No parallel structures are recognized in the groundmass of the conglomerate. It is noted further that the two directions of sericite elongation in the pebble deviate from the mica plane in the groundmass by varying amounts. This would be expected in a supposedly random orientation of the pebbles. Also, it was observed that very small grains of the pebble material, generally less than one millimeter in diameter, usually have their sericite all oriented parallel to the chlorite-muscovite foliation in the groundmass. This would be expected because such small grains could easily be affected by the forces which produced the principle foliation, whereas large pebbles would remain essentially unchanged except in the presence of a very intense force.

The quartz diagram needs to have its girdles intensified by the addition of considerably more data before reliable interpretations can be made, but it can be suggested in the light of present work that the rock from which the pebbles weathered was already slightly metamorphosed and that after the conglomerate was deposited the second and main phase of metamorphism occurred.

Metamorphosed Silicic Igneous Rocks

Megascopic Features:- The silicic igneous rocks are second only to the sedimentary group in abundance. Except for a small stock on Antelope Island and another east and southeast of Ogden, the intrusions are represented by countless sills and many cross cutting dikes throughout the area. Pegmatite is the most conspicuous of the rock types. It is usually rather coarse grained. In color it is somewhat variable and is either white, gray or pink, depending upon the color of the microcline present. In some places quartz occurs as a graphic intergrowth with the microcline. At the borders of pegmatite masses, muscovite and often a little biotite are found. Around the borders of the pegmatite masses are many small veinlets of quartz which intrude the country rock.

Intercalated in the metamorphosed sediments are strongly banded rocks that proved to be of igneous origin when examined under the microscope. Some of these are lit-par-lit injections of the igneous material into the pre-existing rocks. This type will be discussed below under the heading "Injection gneisses". However, some of these rocks are probably sills or flows of an igneous material different from the sills and dikes of the pegmatite.

The possibility that some of these igneous appearing rocks are migmatites must be considered also. J. T. Stark[1] has made a detailed study of pre-Cambrian rocks of the Sawatch Range, Colorado and reports that migmatites have been formed on a regional scale. The complex that he describes is similar to the Farmington complex of the Wasatch Mountains. According to Stark the areas around the granite and quartz monzonite stocks that intrude the old sediments have been granitized for some distance away from the stocks and the contact between igneous and sedimentary rocks obliterated for the most part. A porphyritic development of secondary feldspar and quartz is a characteristic feature of the migmatites he describes.

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1. Stark, J.T., Migmatites of the Sawatch Range, Colo., Jour. Geol., v.43, No. 1, Jan.-Feb., 1935, pp 1-26.

There is no evidence for a regional granitization of the old sedimentary rocks of the Farmington complex. Migmatites, if they occur, are confined to the narrow zone in contact with the small stocks that intrude the region. Microscopic examination of the rocks fails to reveal any evidence of replacement with the possible exception of one slide. This slide, No. 22, will be discussed later.

In general the layered silicic rocks are medium grained and have a light gray or pink color depending upon the feldspar present. All are gneissic with biotite layers forming the dark bands. This banding is not as sharp and regular as in the injection gneisses and appears to be a primary feature in some places.

Other small stocks may exist that were not discovered in the field work but the similarity of the Antelope Island, Waterfalls Canyon, and Ogden Canyon intrusions suggest that the common rock type to invade the old sediments was granite to quartz monzonite. Slides 1, 22, 23, and 27 represent specimens from the stocks. They are medium grained gneissic rocks with the gneissic banding only weakly developed for the most part. With the exception of No. 1, a gneissic hornblende granite, the specimens are flesh pink due to the feldspar and usually contain imperfect gray bands of biotite. No. 1 contains white feldspar with hornblende the predominant ferromagnesian mineral.

Microscopic Features:- As with the metamorphosed sedimentary rocks, the features common to all the igneous rocks will be grouped together and mention made of the individual slides that contain unusual features. In this group of rocks the results of metamorphism are chiefly cataclastic. The metamorphism was not intense enough to thoroughly recrystallize the rocks. However, sutured and intergrown boundaries of mineral grains are found in most of the slides but not much increase in grain size has occurred as the result of the recrystallization. This group of rocks has not been metamorphosed as much as the sedimentary rocks.

Grains range in size up to a maximum of about one millimeter in diameter. Besides the ragged and patchy texture in most of the slides that appears to be the result of a shattering and partial granulation of the rock preceeding recrystallization, a low grade dynamic metamorphism has produced strain shadows in quartz and feldspar, has bent the albite twinning planes and the mica, and has cracked and granulated the quartz slightly. This deformation may be part of the main period of metamorphism or one of later date. In most of the slides a slight development of gneissic banding is noted. This is observed in the tendency of the grains of the ferromagnesian minerals toward parallelism. Commonly a secondary microcline has developed from orthoclase.

The field occurrence is sufficient proof of the igneous origin of most of these rocks. In case of doubtful field relations the mineralogical compostion constitutes good proof of their igneous nature. Micrometric analyses were made on the slides with the exception of Nos. 2 and 13. Table III summarizes this data. The names given to the silicic igneous rocks in this report are based on this data as applied to Lindgren's classification which in turn is based on the orthoclase-plagioclase ratio.

	Feldspathic pegmatite	Quartz aplite gneiss	Gneissic hornblende granite	Gneissic granite	Gneissic quartz monzonite	Gneissic quartz monzonite
	No. 13	No. 3	No. 1	No. 22	No. 27	No. 23
Quartz	20	53.3	24.3	42.3	36.2	38.2
Microcline & Orthoclase	80	7.3	41.7	44.7	27.3	28.9
Albite	..	23.9	16.1	7.9	28.3	18.1
Biotite (Chlorite)	..	14.8	tr.	4.7	4.6	12.1
Hornblende	..	....	17.3	...	...	....
Accessories	tr.	0.7	0.6	0.4	3.6	2.7
Total	100	100.0	100.0	100.0	100.0	100.0

Quantitative mineral analyses of the metamorphosed silicic igneous rocks.

Table III

The primary accessory minerals are zircon, apatite, and magnetite. Titanite is found in slides 1 and 22. Alteration products are numerous, most slides containing chlorite altering from biotite, kaolinite and sericite from feldspar, epidote from biotite or hornblende, and hematite from magnetite. Some have rutile with its alteration product leucoxene developing in the chlorite.

The feldspathic pegmatite, No. 13, is composed largely of microcline with some orthoclase. A few small magnetite and hematite crystals are scattered through little veinlets of quartz that appear to belong to a later mineralization.

The mylonite granite gneiss, slide 2, has been classified in this group of rocks chiefly on the basis of mineral composition. It contains much microcline and the other minerals that occur in the igneous rocks. The rock was apparently in a shear zone and was reduced by shearing stresses nearly to the mylonite stage. Porphyroblasts of microcline, one millimeter or less in diameter, form the "augen". Interlayered finely ground quartz and stringy biotite, epidote, and chlorite are responsible for the sharp thin foliation bands seen in the hand specimen.

The quartz aplite gneiss, No. 3, differs little from the general description given for the rocks. Alteration products are very abundant. Plagioclase is about one-half altered to sericite and hematite replaces magnetite, which gives the rock a brown weathered appearance.

The gneissic hornblende granite, No. 1, from the mouth of Ogden Canyon is conspicuously different among the rocks of this group because of its abundance of green hornblende. Whether this hornblende was originally present or whether it is the result of a more intense grade of metamorphism of biotite is not known. A small amount of biotite is present and it recrystallized earlier than the hornblende. The rock is strikingly fresh in appearance. The gneissic granite, slide 22, from the same region contrasts strikingly with it. Biotite, mostly altered to chlorite, is the dominant dark mineral. Alteration of the various minerals is in an advanced stage. The feldspar is pink whereas it is white in slide 1. Pressure effects are very noticeable. Many of the microcline grains have been cracked and recemented with thin quartz lenses. Hematite fills the twinning planes of the albite and is scattered as a fine dust over the orthoclase. Microcline, some of it without the hematite dust, appears to be replacing the orthoclase. Patches of myrmekite are rather common in the slide. It is not known whether or not these two rocks represent the same intrusion, two different intrusions, or, whether No. 22 is a migmatite.

The gneissic quartz monzonite, No. 27, from the Waterfalls Canyon intrusion, southeast of Ogden, is similar to No. 22. Much more albite, magnetite, and hematite are present, however. The hematite dust is rather thickly concentrated on the albite and is sprinkled lightly on the quartz and microcline. The albite is altered extensively to sericite and may have a greater affinity for hematite for that reason than the quartz and microcline which are quite fresh. It is possible that the quartz and microcline are later replacement minerals. A few rather large patches of magnetite and chlorite occur in swirls.

The gneissic quartz monzonite, slide 23, from Antelope Island is the most distinctly banded of all the igneous rocks. Mineral orientation is more noticeable, also. Albite grains seem to be elongated with their twinning planes parallel to the plane of foliation, which is marked by the abundant chlorite. Extensive alteration reflects weathering or hydrothermal alteration, as in most of the other rocks.

Metamorphosed Injection Gneisses

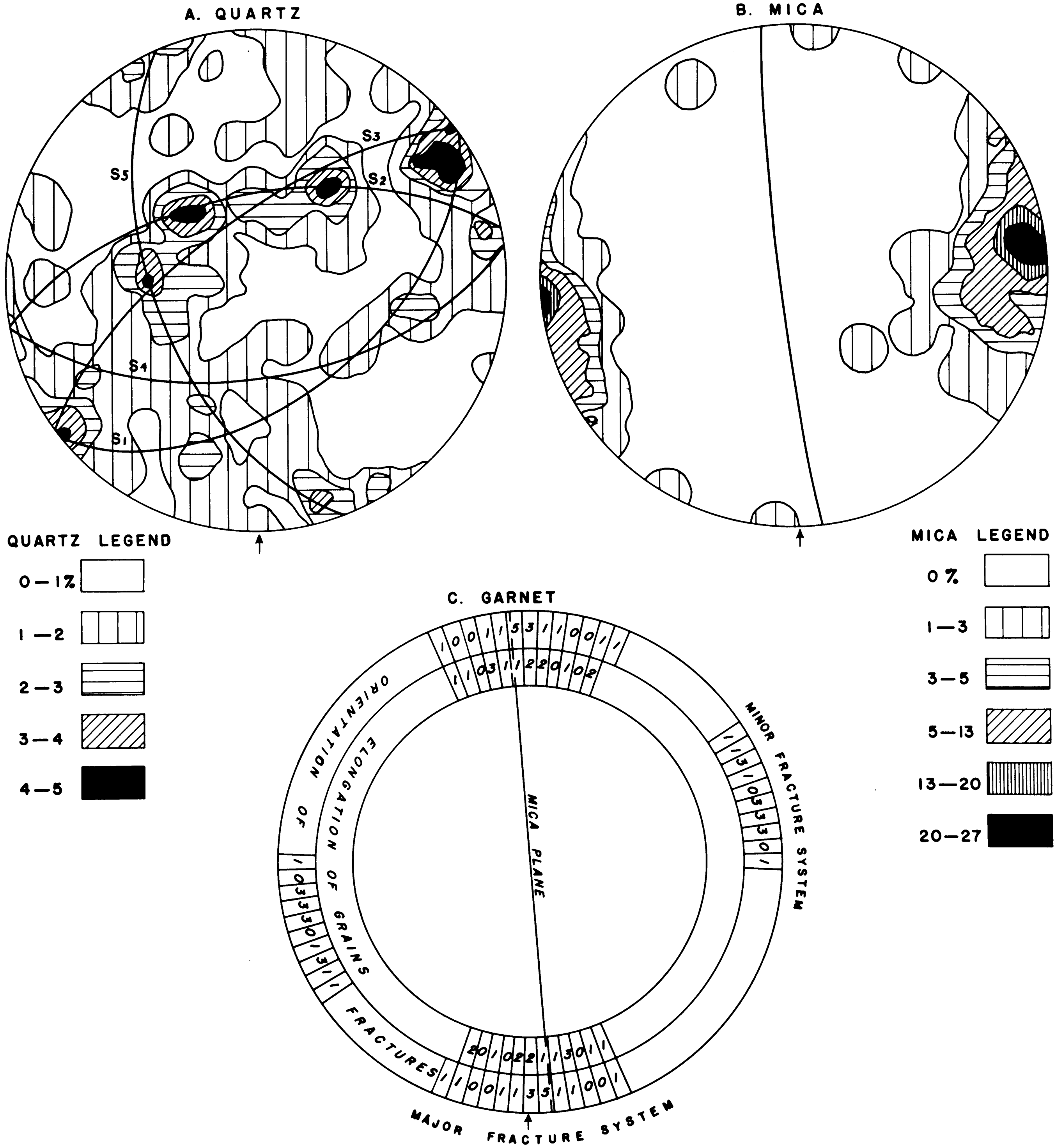
Megascopic Features:- The injection gneisses are closely related to the above group of rocks just described. However, because they are rocks of twofold origin, they are treated as a separate group. The hand specimen of No. 10, a typical representative, is remarkable for its banding. Black bands of biotite 1/8 to 1/2 inch in width alternate sharply with pink bands of quartz-feldspathic material of similar thickness. Individual bands exhibit uniform thickness for some distance. Commonly, small seams of the light material break across a thin biotite layer but this is not a feature readily noticed. The biotite layers contain small red-brown garnet crystals.

Microscopic Features:- Under the microscope the biotite of slide 9 is imperfectly oriented in contrast to the biotite of slide 10 which is nearly perfectly oriented. The dark bands that, seemingly, are mostly biotite, in the hand specimen, contain 50 percent or more of quartz and feldspar. The feldspar is of two varieties, microcline and oligoclase with a composition of about $Ab_{75}An_{25}$. Garnet is associated with the biotite. It has a faint pink color and is probably the almandite variety. The garnet grains are about one millimeter in diameter on the average. The usual accessory minerals are present. The rock is rather fresh with only a little alteration of biotite and the feldspars.

Recrystallization is in a more advanced stage than in the igneous rocks which have been studied but has not reached the stage found in the sedimentary rocks. The usual stress effects are present such as the strain and cracks in quartz grains, the bent albite twinning planes, and the cracks in the microcline which have been recemented with thin seams of quartz.

Petrofabric Analysis:- An important consideration in the interpretation of the history of the injection gneiss is the time of injection of the igneous material. For a datum plane in the time scale of the pre-Cambrian rocks, the so-called "main period of metamorphism", that has been referred to several times, is used. It was during this deformation that the pronounced foliation of the rocks was probably developed. The recrystallization of all the rocks in the Farmington complex is likely due to the same deformation. Since the injection gneiss has been recrystallized, the major deformation came after injection. Further evidence, either for or against this conclusion, was then sought by means of petrofabric analysis. It was noticed that the garnet grains are somewhat eliptical with their long axis apparently parallel to the foliation of the rock, also, that two main sets of fracture systems, nearly at right angles, traverse the grains. Using a mechanical stage, the axes of elongation and the two sets of fractures were measured on the sixteen grains in the slide. The results of these measurements are graphed in Figure 2, C. As was suspected, the axes of elongation and the major fracture direction tended to be parallel to the biotite foliation and the other set of fractures made an angle of about 65 to 80° with the foliation. Since the garnet must have been an early mineral formed by reaction of the injected material with the pre-existing rock, it must have been present before the main period of metamorphism in order to have been deformed by it.

Orientation diagrams of 134 biotite grains and 207 quartz grains were prepared, also. The biotite diagram (Figure 2, B) illustrates how well developed the orientation of that mineral is and establishes the AB plane of foliation. The quartz diagram (Figure 2, A) was prepared in an endeavor to find out if the injected material would show a pattern that could be linked up with that of the biotite, which supposedly represents the original rock. The difficulty is that two sets of quartz girdles S_1, S_2 and S_3, S_4 can be drawn through the maxima. S_2 of the first set and S_4 of the second set have the same fabric axes as the biotite; but, inasmuch as S_2 is much the stronger girdle, it appears that it reflects the main period of metamorphism and probably received its orientation from the same deformation as the biotite and garnet. Therefore, it is necessary to construct the girdle in the position of S_2 rather than in S_3, which does not have the same fabric axes as the biotite diagram. S_5 represents another possible girdle but its



Petrofabric diagrams of the metamorphosed injection gneiss from Bountiful Peak. A. 207 quartz grains; B. 134 mica (biotite) grains; C. 16 garnet grains, measured with a mechanical stage. Each compartment represents 1/100 of the circumference. The figures in the compartments denote the number of fractures or grain elongations that fall in each. The measurements of the quartz, mica, and garnet grains are non-selective.

Figure 2.

origin is unknown. Further petrofabric work is needed. The introductory study thus far made speaks very promisingly of the petrofabric method of study of the Farmington complex and the writer hopes to continue the work in detail.

Metamorphosed Mafic Igneous Rocks

Megascopic Features:- The rocks that have been grouped under this heading are the least known of the various types that were studied. They are not abundant and little has been done to determine their field relations to the other rock types. The writers' impression to date is that they are mostly conformable layers with the metamorphosed sediments and vary in thickness from one to ten feet. No dikes have been recognized. These dark beds could have been formed in any one of three different ways: 1, as a sediment with a high concentration of ferromagnesian material; 2, as a sill of mafic igneous material; or 3, as mafic lava flows and/or mafic pyroclastic material. Before further discussion of their origin is attempted, the microscopic characteristics will be presented.

Specimens Nos. 4 and 8, hornblende-labradorite gneisses, consist of alternate layers of hornblende and labradorite about one millimeter thick. The foliation is quite perfect in No. 4 and less so in No. 8. In appearance they closely resemble a diorite gneiss. Another hornblende gneiss, No. 29, looks like a hornblendite. It is black and rather fine grained with the hornblende crystals exhibiting a slight elongation in the same general direction.

The epidote-chlorite schist, No. 15, is a medium dark green, fine grained rock. Foliation is not noticeable.

In the region of Waterfalls Canyon is found a small, but apparently massive mafic intrusion. One specimen from the intrusion, No. 28, is a dark green, fine grained, chloritic rock. Another, from which no thin section was made, is a lighter green color and looks like a diorite. Unfortunately, lack of good material from this stock (?) prevents a good description and interpretation of it at the present time.

Microscopic Features:- The metamorphic features common to the known rocks of this group are much the same as those mentioned previously. All have been recrystallized extensively, the evidence for which is the interlocking and sutured grain boundaries and the euhedral and oriented development of hornblende and biotite. Foliation is characteristic but not always well developed. Those rocks containing the hornblende probably have been subjected to a medium grade of metamorphism while those containing essentially chlorite and epidote have undergone low grade metamorphism. Pressure was likely the dominant factor. Some later period of stress may be indicated by the strained and cracked quartz. Grain size is highly variable in each slide, some hornblende and biotite crystals attaining a length of about three millimeters. The mineral composition is summarized in Table IV. Slides 4 and 15 were measured with a stage micrometer. Nos. 8 and 29 were estimated by eye. No. 28 was omitted because it contains an intimate mixture of chlorite and sericite that is difficult to measure or estimate.

The accessory minerals and alteration products that occur in one or more of the slides are magnetite, hematite, pyrite, zircon,

	Hornblende-labradorite gneiss No. 4	Hornblende-labradorite gneiss No. 8	Hornblende gneiss No. 29	Epidote-chlorite schist No. 15
Quartz	21.9	tr.	tr.	1.0
Labradorite	26.0	40	..	...
Oligoclase	....	..	20	...
Hornblende	31.5	60	80	...
Biotite	19.6	tr.	tr.	...
Epidote & Clinozoisite	tr.	tr.	tr.	71.7
Chlorite	tr.	tr.	tr.	21.1
Titanite	tr.	..	..	5.7
Accessories	1.0	tr.	tr.	0.5
Total	100.0	100	100	100.0

Quantitative mineral analyses of the metamorphosed mafic igneous rocks.

Table IV

apatite, rutile, leucoxene, kaolinite, and calcite plus some of those listed in Table IV.

Slide 4 is unusual because of the presence of both quartz and acid labradorite. The labradorite has the approximate composition of $Ab_{48}An_{52}$. The presence of the labradorite along with so much hornblende and biotite suggests a mafic igneous rock as the original material. If the quartz is an original constituent, the parent material was probably a quartz diorite or a quartz gabbro.

A small amount of evidence for the later injection of quartz into a mafic igneous rock is obtained by a comparison of No. 4 with No. 8, both from Bountiful Peak. The latter is composed largely of hornblende and labradorite. The hornblende is the same green pleochroic variety as in No. 4 and the labradorite has nearly the same composition. However, only a small amount of biotite and quartz are present. The fact that the region has been intimately injected with igneous material, generally high in quartz, supports the belief that the quartz is the result of a later injection.

A sedimentary origin for these two rocks is difficult to imagine. Labradorite is not a mineral that would develop by the metamorphism of a sediment unless it were present at the start, which is an unlikely supposition.

A chemical analysis by weight, based on the micrometric analysis given in Table IV, has been computed for slide 4 (see Table V). It was necessary to assume chemical analyses for the hornblende and biotite. Those used have been included in Table VI in the appendix. The labradorite was calculated on the basis of its theoretical analysis. The computed analysis indicates the rock

	No. 4	No. 15
SiO_2	57.7	37.4
Al_2O_3	12.7	24.5
Fe_2O_3	2.8	4.8
FeO	6.8	3.5
MgO	7.4	3.1
CaO	6.0	19.7
Na_2O	2.2	0.1
K_2O	1.9	tr.?
H_2O	1.0	3.7
TiO_2	1.1	2.4
Total	99.6	99.2

Chemical analyses, percentage by weight, of a hornblende-labradorite gneiss, No. 4, and an epidote-chlorite schist, No. 15.

Table V

to be a diorite. However, if the injected quartz is subtracted, the analysis would show the composition of a gabbro. At present, not enough evidence has been collected to determine whether these mafic rocks are extrusive or intrusive in character.

No. 29, from Antelope Island, may have been a rock quite similar to the two just discussed. It is predominantly hornblende of a pleochroic brown variety. It contains little biotite or quartz, and the rest is mostly basic oligoclase, composition about $Ab_{71}An_{29}$. On the basis of its present composition, it must have been a mafic igneous rock of a type having a composition between that of a diorite and a gabbro.

The most unusual rock of this group is the epidote-chlorite schist, No. 15, from Farmington Flats. Epidote and clinozoisite, in about equal proportions, make up nearly 72 percent of the rock. The crystals of this material are elongated and have a rather well defined orientation. Interstitial chlorite in felted masses and euhedral to anhedral crystals of titanite constitute most of the rest of the slide. A few small patches of strained quartz are present.

A chemical analysis was computed from the micrometric analysis and is given in Table V. Because epidote and clinozoisite were measured together, it was necessary to assume an average chemical composition of the two for the calculation. The chemical compositions of the minerals used are listed in Table VI in the appendix.

On the basis of the present composition of the rock, it could have been formed by the metamorphism of a sediment consisting of calcareous, ferruginous, and clay material in the proper proportions[1]. Likewise a mafic igneous rock, such as certain gabbros high in CaO, could have been the parent material. Leaching or addition of material might have changed a rock of totally different composition into the present epidote-chlorite schist. For this reason it is impossible to prove that the parent rock was either a sediment or a mafic igneous rock. However, because this rock is so uncommon in the area and constitutes only a thin bed, and because the clinozoisite might readily have been derived from a basic plagioclase, while the epidote and chlorite were being derived from ferromagnesian material, the writer believes that the most probable origin of this rock is from a mafic igneous rock, intrusive or extrusive in character.

Slide 28, from the apparently mafic intrusion in Waterfalls Canyon, reveals little relating to the origin of the rock. The slide contains 70 percent, or more, felted chlorite with the remainder consisting mostly of sericite flakes distributed through the chlorite. A small amount of quartz and other accessory minerals are scattered rather uniformly through the slide. The field relations indicate that this mass of dark rock is an igneous intrusion. The physical characteristics suggest that the rock is a diorite.

HISTORY

Sedimentary Record

The history of the rocks of the Farmington complex is undoubtedly a long and complicated one; and, in light of the

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1. A. B. Peck, personal communication.

present study, only partially decipherable. The earliest fragment of the sedimentary record comes from the water worn pebbles in the conglomerate schist. Since the pebbles are metamorphosed sandstone, an older sedimentary rock than is known in the Farmington complex must have existed. It was probably slightly metamorphosed into a quartzite or quartzitic schist before weathering and incorporation, as pebbles, in the conglomerate schist of Bountiful Peak. The arkosites, however, were probably derived directly from some pre-existing igneous rocks, because the feldspar is so abundant. Nothing is known about the conditions of sedimentation or the relation between the various members of the old sedimentary series.

Igneous Record

The length of pre-Cambrian time is further brought out in the study of the igneous history. The thick sedimentary series is thoroughly injected by sills, dikes, possibly lava flows, and a few stocks. These intrusions and extrusions probably did not all occur at the same time, but may be of several different ages. However, some of the igneous rocks, such as the pegmatites, are found high in the sedimentary series, and must have been injected after the thick series had been deposited. During the erosion interval, marked by the unconformity between the rocks of the Farmington complex and the overlying pre-Cambrian rocks, some stocks and much pegmatite were exposed. A removal of several thousand feet of material probably was required.

Metamorphism

The complicated metamorphic history of the gregion is responsible more than anything else for the illegibility of the sedimentary and igneous records. On the basis of the petrofabric study, at least one period of metamorphism took place before the main period of metamorphism. However, it could not have been very intense. The most intense period of metamorphism probably took place toward the close of Farmington complex time. Igneous activity probably preceded and accompanied the metamorphism. Pressure and not temperature was the dominant agency of metamorphism. The magnitude of the pressure was not great enough to produce the typical stress minerals, but did produce some recrystallization and orientation of the minerals.

Several other deformations are known to have taken place since the main period of metamorphism. The post-Farmington complex rocks were weakly metamorphosed at the close of pre-Cambrian time, and the Laramide Revolution resulted in shear zones, but not regional recrystallization, as far as known. None of these deformations has obliterated the structure left in the rocks by the main period of metamorphism. The effect of the later deformations has been negligible, although slates and phylenites are developed in the pre-Cambrian rocks of Promentory Point and elsewhere in the region. Occasionally, if the rocks were in a shear or fault zone, fracturing and crushing has erased the older structure and textures. At the present time, the particular deformation that is responsible for the strain effects noted in all the slides is not known.

AN OUTLINE FOR FURTHER RESEARCH

The writer has been deeply impressed lately by the possibilities of petrofabric analysis as a tool in unraveling the complexities of pre-Cambrian geology. Fabric analysis reveals information about the history of rocks that would be difficult to get in any other way. If such a study were to be made in the area of this report, the first problem would be to separate all the patterns produced in the rocks by different deformations. The proceedure would be to work from the rocks that had been deformed only once to those that had been deformed twice and from those in turn to others metamorphosed a greater number of times. At each stage all the lineations would be plotted on maps with the hope that the regional picture might reveal the directions that the deforming forces were applied. The igneous rocks would then be studied in an attempt to correlate them with each other and with the old sedimentary rocks which they intrude. Such a detailed study as this should reveal much about pre-Cambrian history; although, at best, it would only bring to light the high spots in that vast stretch of time.

	Slide 4				Slide 15			
	Hornblende	Biotite	Labradorite	Quartz	Epidote & Clinozoisite	Chlorite	Titanite	Quartz
SiO_2	45.76	35.75	57.24	100	39.00	31.03	30.6	100
Al_2O_3	8.80	14.70	27.18		29.21	14.85	....	
Fe_2O_3	5.32	4.65	....		5.00	5.73	2.0	
FeO	11.23	14.08	....		0.60	17.42	....	
MgO	14.08	12.37	....		....	17.42	....	
CaO	10.62	0.17	9.07		24.00	0.36	28.6	
Na_2O	1.39	0.32	6.51		0.10	....	....	
K_2O	0.26	9.19	....		0.04	....	....	
H_2O	0.85	3.64	....		2.00	12.48	....	
TiO_2	1.43	3.16	....		0.05	....	38.8	
Total	99.74	98.03	100.00	100	100.00	99.29	100.0	100
Density	3.2	2.8	2.69	2.65	3.45	2.8	3.54	2.65

Mineral analyses, percentage by weight, used in the calculation of the rock analyses of the hornblende-labradorite gneiss, No. 4, and the epidote-chlorite schist, No. 15.

Table VI