Basic Sills in Cottonwood Creek Canyon, Jefferson County, Montana

Dale F. Kittel

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BASIC SILLS IN COTTONWOOD CREEK CANYON,
JEFFERSON COUNTY, MONTANA

by
Dale F. Kittel

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science

Montana School of Mines
Butte, Montana
May, 1950
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# CONTENTS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>2</td>
</tr>
<tr>
<td>General Features of the Area</td>
<td>2</td>
</tr>
<tr>
<td>General Geology</td>
<td></td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
<td>4</td>
</tr>
<tr>
<td>Igneous Rocks</td>
<td>5</td>
</tr>
<tr>
<td>Structural Geology</td>
<td></td>
</tr>
<tr>
<td>Petrology and Occurrence of the Sills</td>
<td>6</td>
</tr>
<tr>
<td>Field Relationships</td>
<td></td>
</tr>
<tr>
<td>Petrography</td>
<td></td>
</tr>
<tr>
<td>Constituent Minerals Present</td>
<td>8</td>
</tr>
<tr>
<td>Alteration and Its Products</td>
<td>10</td>
</tr>
<tr>
<td>Textures</td>
<td>11</td>
</tr>
<tr>
<td>Classification</td>
<td>11</td>
</tr>
<tr>
<td>Origin and Age Relations</td>
<td>13</td>
</tr>
<tr>
<td>Summary and Conclusion</td>
<td>14</td>
</tr>
<tr>
<td>Appendix</td>
<td></td>
</tr>
<tr>
<td>Megascopic Descriptions of Hand Specimens</td>
<td>15</td>
</tr>
<tr>
<td>Petrographic Descriptions</td>
<td>18</td>
</tr>
<tr>
<td>Bibliography</td>
<td>21</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

Following Page

Plate 1. Index Map of the Cottonwood Creek Area .. 1
2. General Geologic Map of Cottonwood Creek Area .................................. 3
3. Map of Sills in Cottonwood Creek Canyon .. 4
4. Stratigraphic Section of Cottonwood Creek Canyon Showing Positions of the Sills .. 4
5. Photographs Illustrating Field Relationships of the Sills ......................... 6
6. Photomicrographs of Constituent Primary and Accessory Minerals ................. 7
7. Photomicrographs Illustrating Alteration Products .................................. 9
8. Chart Showing Petrographic Classification of the Sills by Johannsen's System ... 11
9. Photographs of the Sills in the Field ... 12
10. Photomicrographs Showing Examples of Microscopic Textures of the Sills ..... 14
BASIC SILLS IN COTTONWOOD CREEK CANYON 
JEFFERSON COUNTY, MONTANA

By Dale F. Kittel

ABSTRACT

A stratigraphic section of about 2600 feet of upper Beltian to lower Devonian formations exposed in Cottonwood Creek Canyon 11 miles east of Whitehall, Montana, contains about 20 igneous sills. These sills are from 5 to 20 feet thick, and grade from granogabbro to quartz basalt, except for one sill which is 165 feet thick, and is composed of granogabbro and red syenite. The whole sedimentary series is isoclinally folded, and the sills follow the bedding planes closely with localized crosscutting through the beds.

Alteration has affected the constituent feldspar and femic minerals of the sills in varying degrees, with the formation of calcite, epidote, sausserite, kaolin, and sericite as the principal products. The enclosing sediments have been slightly metamorphosed in some places.

The sills probably formed before the folding took place, and it is likely that they may be related to the Livingston volcanics found in this part of Montana. However, no basis for a direct corelation is available at the present time.
INTRODUCTION

A group of 17 closely spaced dark-colored sills parallel to vertical strata exposed in Cottonwood Creek Canyon have been studied by the writer in view of determining their petrologic and petrographic character, and also their relationship not only to the enclosing strata, but also to nearby sills, dikes, and volcanic rocks.

Although considerable literature has been published regarding the geology of the Whitehall region, to the writer's knowledge nothing has been published which deals with the igneous activity of the region, particularly in the Cottonwood Creek Canyon area.

Acknowledgment is made to H. M. Callaway, L. E. Echols, and P. Schapiro, who, with the writer, comprised the crew which mapped Cottonwood Creek Canyon and the adjacent area. Acknowledgment is also made to Dr. E. S. Perry and to Prof. F. S. Robertson of the Montana School of Mines, whose guidance aided the writer immeasurably in making full use of the data obtained from field and laboratory studies of these basic sills.

GENERAL FEATURES OF THE AREA

The Cottonwood Creek Canyon area lies generally in the south halves of Sections 29 and 30, and the north halves of Sections 31 and 32, in T. 2N, R. 2W. (See Plate 1.) It is about 11 miles east of Whitehall, Montana, which is about 32 miles east of Butte.
The climate of the area is quite arid, with an annual rainfall of about 15 inches, and temperatures range between 90° and -30° throughout a normal year. The average annual mean temperature is about 44°.

Sagebrush and greasewood are the most abundant forms of vegetation, although pine, fir, spruce, and aspen grow to a limited extent along the slopes and in the valleys.

The entire area is drained by Cottonwood Creek, which flows into the Jefferson River, which in turn joins the Madison and Gallatin Rivers about 40 miles east at Trident to form the Missouri River. The small intermittent streams which drain the area and flow into Cottonwood Creek form valleys in the less resistant sedimentary beds of the area.

Maximum relief of the area is about 2200 feet, with limestone forming the high ridges of relief. The elevation of Jefferson River nearby is about 4250 feet above sea level.

GENERAL GEOLOGY

The general geology of the Cottonwood Creek Canyon area is well exposed and relatively uncomplicated. A plane-table map of the outcropping formations is shown on Plate 2. Two unconformities exist in the exposed section: one between the pre-Cambrian Belt arkose or greywacke and the Flathead quartzite, and the other at the top of the section between the Cambrian Dry Creek shale and the overlying Jefferson limestone of Devonian age.
Sedimentary Rocks

The sedimentary rocks of this area are limestones and shales with the exception of the Flathead quartzite. The limestones are thick-bedded and fine-grained ridge-formers, while the shales are softer, thin-bedded valley-formers of medium thicknesses.

The basal Belt arkose or greywacke is the oldest of the exposed sediments in the area, being of pre-Cambrian age. Hand specimens appear to be shale, but prove to be arkose or greywacke upon microscopic examination. Its true thickness in this area is indeterminate.

The Wolsey shale is a sandy, thin-bedded shale which is rarely found outcropping because of its softness and lack of resistance to weathering. A gradational contact zone of variable width lies between it and the Meagher limestone. This zone contains alternating bands of shale, limestone, and igneous intrusives.

The Meagher limestone is well bedded in character, individual beds ranging from a few inches to two or three feet in thickness. Its upper half exhibits a mottled effect upon weathering. The contact between it and the Park shale is also characterized by alternating bands of shale, limestone, and stringers of igneous material.

The Pilgrim limestone overlies the Park shale, is massive in character, and contains excellent examples of intraformational conglomerate structure.

The Dry Creek formation is composed of variagated shales, four members of which lie between the Pilgrim and the
PLATE 3

MAP OF SILLS IN COTTONWOOD CREEK CANYON

SCALE 1:4000
0 500 FEET

LEGEND

Dj JEFFERSON DRY CREEK
Dc PILGRIM PARK
Mo MEAGHER WOLSEY
Q Flathead
P Pre-Cambrian
SILLS

Legend:

Dj
Dry Creek
Pilgrim Park
Meagher Wolsey
Flathead
Pre-Cambrian
Sills

Direction North

True North

Scale 1:4000
0 500 Feet

Legend:

Dj
Dry Creek
Pilgrim Park
Meagher Wolsey
Flathead
Pre-Cambrian
Sills

Legend:

Dj
Dry Creek
Pilgrim Park
Meagher Wolsey
Flathead
Pre-Cambrian
Sills

Legend:
Stratigraphic Section of Cottonwood Creek Canyon Showing Positions of the Sills.

<table>
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<tr>
<th>SILL</th>
<th>WIDTH</th>
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<tr>
<td>Dry Creek shale</td>
<td>4-13</td>
<td>4'</td>
</tr>
<tr>
<td>Pilgrim limestone</td>
<td>4-12</td>
<td>10'</td>
</tr>
<tr>
<td></td>
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<td>10'</td>
</tr>
<tr>
<td></td>
<td>4-10</td>
<td>5'</td>
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<tr>
<td></td>
<td>4-9</td>
<td>165'</td>
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<td>4-2</td>
<td>8'</td>
</tr>
<tr>
<td></td>
<td>4-1</td>
<td>21'</td>
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</table>

VERTICAL SCALE: 1 INCH = 250 FEET
Jefferson limestone formations along Cottonwood Creek Canyon.

The Jefferson limestone is about 1000 feet thick. Much of it exhibits a granular appearance on the fresh fracture, with an accompanying odor of sulfur dioxide.

**Igneous Rocks**

The basic sills which make up the igneous rocks of the area are generally granogabbros which have intruded along planes of weakness in the less massive sedimentary beds. With one exception they are relatively narrow in width.

**Structural Geology**

The main structural features of the area are the nearly isoclinal folds which produced an anticline and syncline shown on Plate 2. Although the anticline has been heavily eroded, the nature of the beds of which it is composed indicates that it is quite symmetrical, fairly large in size, and plunges steeply to the north. Extremely tight folding is evident at its nose.

The fault shown on the flanks of the anticline has an offset of about 150 feet, and is quite evident on the ridge which forms the east flank.

**PETROLOGY AND OCCURRENCE OF THE SILLS**

Plate 3 shows the relative positions of the sills in the stratigraphic section in Cottonwood Creek Canyon, whereas Plate 4 shows the same occurrences in the form of a stratigraphic column.
Field Relationships

The majority of the sills studied are relatively narrow, being less than 10 feet in width. Of the 17 shown on Plate 4, only 7 are more than 10 feet wide. With the exception of one relatively thick sill (4-9), all of these thicker sills occur in the lower half of the stratigraphic column in Wolsey shale and Flathead quartzite.

Sill 4-9 is the thickest sill in the area, measuring about 165 feet along the canyon wall. It is composed of basic gabbro which encloses a zone of acidic red syenite near the top of the sill. The red syenite varies in thickness from about 50 feet along the canyon wall to about 90 feet where it is exposed on the flanks of the anticline north of the canyon. Further studies of this syenite would probably show that it was formed as a result of magmatic differentiation during the cooling process which followed the intrusion of the sill in which it is enclosed. It appears to be the type of zoning which is described by Pirsson and Knopf (4;171), and said by them to occur in many parts of Montana.

The textures of the sills grade from extremely fine to coarse medium, and from porphyritic to non-porphyritic. The thinner sills tend to have a finer texture than the thicker ones, but order of occurrence in the stratigraphic column does not seem to bear any relationship to texture.

The magma which formed these basic sills followed the bedding planes of the shaley and slabby formations almost to
Plate 5

Photographs Illustrating Field Relationships of the Sills.

A. Crosscutting of a sill in the upper part of the Meagher limestone.

B. A closeup photograph of the same sill shown in A.

C. An extremely thin sill in the Wolsey shale which has followed small fractures to give a crosscutting effect. It has also metamorphosed the shale to a type of hornfels.

D. Contact of the red syenite and granogabbro of Sill 4-9. Note the chilled margins at the line of contact. x 2/3.

E. Limestone marble from near the top of the Jefferson formation. x 1/2.

F. Limestone marble from a sill contact in the upper part of the Meagher limestone. x 1/2.
Photographs Illustrating Field Relationships of the Sills.
perfection in most cases, although local crosscutting through beds is present in the Meagher limestone. Plate 5, A and B, illustrate this crosscutting, and Plate 5, C, shows the same effect, though on a much smaller scale; extremely small sills have intruded the Wolsey shale along bedding planes and have followed minute fractures which cross the very thin beds. The massive Pilgrim limestone contains no sills anywhere in its 300-foot exposure along the canyon wall.

Thin chilled margins at the contacts of the sills occur quite commonly. They are normally found in sills of this type, but their presence at both the upper and lower contacts proves conclusively that the sills are not extrusive flows of magma.

Metamorphism of the enclosing sediments by the sills is not a common occurrence. Local and mild metamorphism has converted small amounts of the limestone to limestone marble (Plate 5, E and F), and some Wolsey shale has been altered to a type of hornfels. The lack of metamorphism is not unusual in view of the fact that basic sills intruding basic sediments are not likely to produce a great deal of reaction in either type of rock, regardless of the temperature of the intruding magma.

PETROGRAPHY

Specimens were taken from each of the sills which crop out in Cottonwood Creek Canyon, and from many of the exposures of the sills in the anticline which lies north of Cottonwood
PLATE 6

Photomicrographs Of Constituent Primary and Accessory Minerals

A. A typical plagioclase grain. Crossed Nicols. x15.

B. A partially altered augite grain. Crossed Nicols. x15.

C. An augite grain under plane polarized light. x15.

D. Small grains of magnetite occurring with stringers of biotite. Plane polarized light. x15.

E. A pyrite grain in a microlitic groundmass. Crossed Nicols. x15.

F. A hornblende grain which exhibits twinning. Crossed Nicols. x25.
Photomicrographs of Constituent Primary and Accessory Minerals.
Creek. The positions of these specimens in the stratigraphic column are designated on Plate 4. Of the specimens taken, 10 were selected as representative for use in thin section studies; 5 thin sections were made from specimens taken in the general area, and 5 were made from specimens taken in the canyon proper. A qualitative study was then made to identify the constituent minerals present, textures, and the presence of alteration. Also, a quantitative study was made of the quartz, feldspar, and fennic content by means of a Wentworth traversing stage, and each thin section was classified by the Johannsen system.

**Constituent Minerals Present**

Most of the constituent minerals which occur in these basic sills are illustrated by means of photomicrographs on Plate 6.

Quartz was found to be present in all of the thin sections in amounts which ranged from less than 5 to 25 per cent. In most of the thin sections the amount is less than 10 per cent. Some subhedral and anhedral forms of it were observed, but nearly all of it is interstitial.

Orthoclase feldspar ranges in amount from 5 to 30 per cent. The grains range from anhedral to euhedral in form, with some crystals showing Carlsbad twinning. Several of the thin sections contain orthoclase as microperthite.

Plagioclase feldspar is abundant in all of the thin sections, but is not very plentiful in the red syenite. Classification as to type could not be made for the plagioclase in
three thin sections due to extreme alteration, but in all the others it was classified as labradorite. The albite-anorthite ratio ranged from 43:57 to 48:52. Carlsbad twinning was found to occur in most of the grains, which are subhedral to euhedral; combined Carlsbad-albite twinning is uncommon. Microlitic plagioclase was observed in the groundmass as shown on Plate 10. A.

Femic minerals comprise somewhat less than 50 per cent of the rock constituents in most of the thin sections. Subhedral augite is fairly common, but no other pyroxene was observed. Extinction angles for the augite range from 35° to 45°, 2V ranges from 65° to 75°, and the grains are generally stubby with a wide range of interference colors under crossed polarizing prisms. Minor amounts of amphibole occur as hornblende in some thin sections, with extinction angles ranging from 18° to 32°, a large 2V, and slight pleochroism in the green varieties. The grains are elongate, showing well developed prismatic cleavage. Biotite, occurring as plates or shreds is fairly common; it is brown in color, and is pleochroic from light brown to brown. In a few instances it displays a birdseye structure.

Four accessory minerals occur in these basic sills. They are magnetite, zircon, apatite, and pyrite. Magnetite is consistently present in all thin sections, the grains differing greatly in size, and ranging from subhedral to euhedral in shape. Its occurrence is in some cases the result of alteration of femic minerals, and in others it occurs as an accessory mineral. Zircon was found in only one thin section,
Photomicrographs Illustrating Alteration Products

A. Occurrence of pennanite, quartz, and feldspar together. P - pennanite (circled); Q - quartz; PF - plagioclase feldspar. Crossed Nicols. x60.

B. Sericitization of feldspar grains. Crossed Nicols. x60.

C. Kaolinitization of orthoclase and plagioclase feldspars. The small white grains are quartz. Plane polarized light. x60.

D. Calcite grain showing twinning striations. Crossed Nicols. x60.
Photomicrographs Illustrating Alteration Products.
wherein it occurs in biotite, surrounded by the characteristic halo which often serves to identify it. Apatite, occurring as minute colorless crystals in the felsic and feldspar grains, is present in nearly all thin sections. Porphyritic grains of pyrite occurring in a fine-grained matrix were identified in one thin section.

Alteration and Its Products

Secondary minerals in the specimens are many and varied, and are a result of alteration of the feldspars and the felsic minerals. Several of these alteration products are illustrated on Plate 7.

Two varieties of chlorite were identified; clinochlore occurs in abundance in nearly all thin sections as the green variety which exhibits low relief, parallel extinction, and is slightly pleochroic, while pennanite (pennine) was readily identified from its characteristic Berlin blue color under crossed polarizing prisms.

Sericite and kaolin also occur in abundance in the thin sections. A large percentage of the feldspar grains are heavily coated with sericite, which was identified by the characteristic pattern which it produces on the grains. Kaolin is readily identified by the cloudy effect which its presence produces on the feldspars (mainly orthoclase), and which obscures twinning and grain boundaries to a large extent.

Epidote was identified by its parallel extinction, fairly high relief, and its green color under plane polarized light.
Calcite occurs in many of the thin sections as phenocrysts. It commonly has the form of an augite grain from which it was altered. High and varied interference colors and twinning striations make this mineral easily identifiable.

The types of alteration present in the basic sills of Cottonwood Creek Canyon indicate that it must have resulted from deuteric processes. Those types which indicate this are albitization, chloritization, epidotization, sausseritization, and sericitization. While no one of these types is in itself indicative of deuteric alteration, the presence of several such types that are not usually found with ground water alteration indicates quite positively that deuteric processes were responsible for the alteration in these basic sills.

Textures

All of the thin sections studied reveal a hypautomorphic-granular texture which is usually also diabasic. The mineral grains range from extremely fine to medium in size, and grains of porphyritic calcite and pyroxene are present in some of the thin sections. Many examples of felty texture are displayed by plagioclase microlites, although most of the plagioclase occurs in an intergranular-diabasic type of texture.

Classification

Petrographic classification was made of seven of the thin sections studied. Because of the intense alteration of the plagioclase feldspars in the other three, accurate classification of them could not be made. Johannsen's system of
Families of Class 2, Order 3

1. Mesosilecite
2. Moyite
3. Quartz granite
4. Quartz granodiorite
5. Orthogranite
6. Calcigranite
7. Granogabbro
8. Quartz gabbro
9. Orthosyenite
10. Calcisyenite
11. Syenogabbro
12. Gabbro, Norite

Chart Showing Petrographic Classification of the Sills by Johannsen's System.
classifying igneous rocks was used. (2:27)

The results of the classification are shown on Plate 8. All of the sills were classified under Class 2, Order 3, (23), and it can be seen that all but one (the red syenite) fall under 237, which is granogabbro when of a phaneritic texture, and quartz basalt when of an aphanitic texture.

Megascopically, these sills appear to resemble almost exactly some granogabbros described by Johannsen (1:367), who states:

The rocks are generally moderately coarse-grained in texture, and dark-gray to almost black in color. Like quartz-gabbros and gabbros, the rocks appear darker megascopically than the percentage of dark minerals seems to warrant, on account of the dark color of the plagioclase.

The microscopic characteristics are also nearly identical to those of the same granogabbros. Concerning these characteristics, Johannsen further states:

The texture is typically hypautomorphic-granular, although the well developed twinning, common to the plagioclases, gives the rocks a more automorphic-granular appearance than it actually has. The essential constituents are basic plagioclase (labradorite to bytownite), a dark mineral, and some orthoclase and quartz. The latter two minerals usually fill the interstices between the others.

He also lists the femic constituents as pyroxene, occasionally hornblende, and rarely biotite.
PLATE 9

Photographs of the Sills in the Field

A. A photograph showing the stoping effect of a sill in the Flathead quartzite ($\xi_f$).

B. A body of Flathead quartzite which has become slightly metamorphosed from the sill which surrounds it.

C. An exposure of a sill in the Meagher limestone showing its tendency to weather spheroidally.

D. A sill in the lower part of the Dry Creek shale.

E. Photograph showing the differential weathering of a sill in the Meagher limestone ($\xi_m$).
Photographs of Sills in the Field
ORIGIN AND AGE RELATIONS

The age of the Livingston formation has been established as late Cretaceous, prior to the Laramide uplift of that time. This major disturbance faulted and folded the Livingston volcanics to a considerable extent.

Folding of the sedimentary beds of the Cottonwood Creek Canyon area also occurred during the Laramide uplift. These beds, which include strata of Cretaceous age, were intruded by the basic sills of the area prior to their folding. Therefore, the age of these sills is approximately the same as that of the Livingston formation; i.e., upper Cretaceous time prior to the Laramide revolution.

The Livingston formation and the basic sills can be related on a basis other than age only in a general way. The Livingston formation is composed of andesites, according to Jones (3:6), and they are therefore acidic. However, they are not highly acidic, and neither are the sills highly basic. Therefore, because there is no evidence that any of the intrusions and flows of the region occurred simultaneously, or that the sills in the lower part of the stratigraphic column occurred before those in the upper part, the assumption can be logically made that the basic sills of Cottonwood Creek Canyon and the Livingston formation are representatives of differentiated flows from the same magmatic source.
SUMMARY AND CONCLUSION

Certain conclusions can be made from the studies of the basic sills of Cottonwood Creek Canyon. They are:

1. With one exception, the sills are phaneritic granogabbros or their aphanitic equivalent, quartz basalt. The exception, a red syenite, is due to magmatic differentiation within a comparatively thick sill.

2. The age of these basic sills is approximately the same as that of the Livingston volcanics, which were laid down in late Cretaceous time before the Laramide uplift.

3. Further study in areas adjacent to Cottonwood Creek Canyon may lead to definite correlation between the basic sills studied by the writer, and other igneous intrusions which occur in the Whitehall region. From such studies a definite petrologic correlation with the Livingston volcanics may be possible.
PLATE 10

Photomicrographs Showing Examples of Microscopic Textures of the Sills.

A. A typical example of microlitic texture displayed in many of the thin sections by plagioclase. Crossed Nicols. x60.

B. Hypautomorphic-granular texture which is commonly found in most of the thin sections. Crossed Nicols. x60.
Photomicrographs Showing Examples of Microscopic Textures of the Sills.
Megascopic Descriptions of Hand Specimens

The descriptions given below are notations made during laboratory studies of the rocks. They do not include estimated percentages of the constituent minerals present because these percentages are given much more accurately in the petrographic descriptions which follow this part of the appendix. An asterisk preceding a specimen number denotes that a thin section study was made on that specimen.

*Specimen 4-1
This rock is a fine-grained gabbro of dark gray-green color. Dark green felsic phenocrysts which are probably altered pyroxenes are prevalent throughout the specimen, as well as patches of light green alteration products. Both types of alteration products have grains which average about 2 x 2 mm. Calcic plagioclase, which in part gives the gray-green color to the rock is present in large amounts. Sparse phenocrysts of calcite about 1 x 1 mm. can also be seen. Extremely small grains of quartz are present in minor amounts.

Specimen 4-2
This rock is a very highly altered fine-grained gabbro of very dark-green color. Because of the intense alteration of the constituent minerals, it is very difficult to distinguish them. Extremely fine-grained calcic plagioclase makes up most of the rock, with larger grains of altered felsic minerals (probably pyroxene) in abundance. Very fine grains of quartz are quite evident by the sparkling contrast which they exhibit to the drab background of the rest of the rock. Limonite stains and calcite are present.

Specimen 4-3
The rock has been altered to a high degree -- grains can be rubbed off the fresh fracture with the fingers. This specimen is a fine-grained gabbro with a texture very similar to Specimen 4-2, but is of a much lighter green color! The felsic minerals are not identifiable to exactness, but they are probably pyroxenes. The alteration of these pyroxenes takes the form of kaolin, limonite, and chlorite coatings. Masses of calcite about 2 x 2 mm. are present in fairly large amounts. Extremely small grains of magnetite, just visible
under a hand lens, are sprinkled liberally throughout the entire rock. Quartz grains of the same degree of fineness sparkle over the surface of the rock, but actually represent only a small per cent of the minerals present. Fine-grained green-stained plagioclase and probable small amounts of orthoclase make up most of the rock.

Specimen 4-4
This rock has been altered to the point of softness. It resembles Specimen 4-2 considerably in texture and color, although it appears to be slightly coarser-grained. Green-stained plagioclase makes up most of the rock, with a large amount of altered felsic minerals present as phenocrystal grains. Quartz is present in extremely fine grains. The presence of magnetite which is too minute to be seen with a hand lens was proved by use of a magnet. Calcite is far from being uncommon in the specimen, and limonite stains occur in numerous places on the rock.

Specimen 4-5
This rock is a very fine-grained gabbro containing minor amounts of quartz. Heavily altered phenocrysts of pyroxene which are stained dark brown are numerous. The general color of the rock is dark green, which grades to a yellowish green in some places. A minor amount of hornblende is present, and minute magnetite grains are liberally sprinkled throughout the entire rock. Calcic plagioclase is the major constituent mineral present. Limonite and kaolin coatings are common.

Specimen 4-6
This rock has not been altered to such a high degree as the specimens previously described. It is a very dark, blue-green, fine-grained gabbro. Calcic plagioclase is the chief constituent mineral present. Fairly large amounts of augite are present. Slender, needlelike grains of hornblende are common throughout the rock. Magnetite grains of a size which is visible to the naked eye occur commonly, and quartz is present in extremely fine grains. Alteration products are not very abundant, but some calcite is readily observed.

Specimen 4-7
This rock is a fine-grained to medium-grained gabbro, and is dark blue-green in color. It has undergone considerable alteration. Calcic plagioclase, which is the chief constituent mineral, ranges in grain size from extremely fine to about 0.5 x 0.5 mm. Augite grains about the same size are common, as are needlelike hornblende grains. Magnetite grains which can be seen by the naked eye are abundant. Extremely fine-grained quartz is present. Chlorite stains are present over the entire rock, and numerous calcite amygdaline can be seen.

Specimen 4-8
This rock is a highly altered, dark green gabbro which closely resembles Specimen 4-2, except that the mineral
grains are coarser and more evident. The chief constituent mineral, calcic plagioclase, is very fine-grained, but the coarser altered femic grains (about 1 x 1 mm.) show in marked relief on the fresh fracture. Biotite is present, as is magnetite and fine-grained quartz. A yellow-green stain covers much of the fresh fracture. Kaolin and calcite also occur in the specimen.

**Specimen 4-9**

Two specimens were taken from this extremely thick (165 feet) sill, one near the top, and one near the bottom. The two are nearly identical in character, except for slight variations in color and texture. The bottom sample has more gray plagioclase, which gives the specimen a lighter color, and is coarser grained than the specimen from the top of the sill. Both have calcic plagioclase as the chief constituent mineral, with liberal amounts of pyroxene grains ranging from fine to medium in size. Neither the femics nor the plagioclase show the high degree of alteration which marks most of the other sill specimens. Magnetite is liberally sprinkled as fine grains throughout the rock, as is extremely fine-grained quartz.

**Specimen 4-10**

This rock is a gray to blue-green gabbro of uniform medium-grained texture. Calcic plagioclase occurs in grains which are easily seen with the naked eye. The femic minerals, which are pyroxenes, range in grain size from fine to medium. Magnetite and quartz are present as minute, widely dispersed grains. A few grains of pyrite can be seen, and calcite porphyries are also present. Alteration has not affected this rock to the extent of staining it, although the calcite attests to its presence.

**Specimen 4-11**

This rock is a fine-grained, gray-green gabbro. Calcic plagioclase is the chief constituent mineral, and occurs as fine grains. The femic minerals occur as fairly coarse grains, and are not too evident. Small amounts of magnetite grains can be seen, and extremely fine-grained quartz occurs throughout the specimen. Kaolin coats parts of the fresh fracture, and is the only recognizable alteration product present.

**Specimen 4-12**

This rock is a fine-grained, gray-green gabbro. Calcic plagioclase is the chief constituent mineral, occurring in fine grains. Coarse-grained pyroxenes occur abundantly, and minute grains of magnetite are fairly common. Fine-grained quartz is liberally sprinkled throughout the specimen. Limonite and kaolin prove the presence of alteration, as does the green staining of the pyroxenes.

**Specimen 4-13**

This rock is a porphyritic, light gray-green basalt. The chief constituent mineral is fine-grained calcic plagioclase.
Phenocrysts of pyroxene make up much of the rock and magnetite is fairly common. Calcite, kaolin, and limonite all occur in considerable quantities as alteration products. In general appearance this rock is quite different from the specimens preceding it in these descriptions.

**Specimen 39A**

This rock is a medium-grained pink syenite. The chief constituent mineral is pink orthoclase feldspar. Hornblende is present in fairly large amounts, but appears to have been altered to a large extent. Plagioclase (probably sodic) is present in amounts which are about equal to those of quartz.

**Specimen 23**

This rock is a very fine-grained dark blue-green gabbro. Fine grains of calcic plagioclase are the chief constituent mineral, and pyroxene occurs in a considerable amount. Small amounts of magnetite in fine grains are visible, as is extremely fine-grained quartz. Alteration products are not evident, although the green stain of the pyroxenes indicates that the rock must have undergone alteration processes.

**Specimen 18**

This rock is a light greenish gray gabbro of fine to medium texture. The fine-grained green calcic plagioclase is the chief constituent mineral present. The pyroxenes are medium-grained, and have the green stain of alteration covering them. Magnetite and quartz are present in fine-grained, well disseminated amounts. Prominent limonite stains cover amygdalules in the rock.

### PETROGRAPHIC DESCRIPTIONS

**T. S. 4-1**

This specimen has a fine hypautomorphic-granular texture which is largely diabasic. Plagioclase microlites are common in the thin section. Anhedral and interstitial quartz comprises 13%, plagioclase (labradorite, Ab$_{48}$An$_{52}$) 42%, orthoclase 7%, and femic minerals 38%, of the rock constituents. The femic minerals consist of augite phenocrysts, hornblende, and magnetite.

The specimen has been intensely altered, with porphyritic calcite, epidote, clinohore, sericite, and kaolin as products. Green patches of altered femic minerals occur in forms suggestive of phenocrysts. No twinning is visible in the plagioclase, due to excessive alteration. Magnetite and apatite are present as accessory minerals.

This specimen was classified as quartz basalt.
T. S. 4-4

This thin section displays hypautomorphic-granular, diabasic, and microlitic textures. Percentages of constituent minerals present are as follows: interstitial quartz, 5%; orthoclase, 5%; plagioclase (labradorite, Ab47An53), 38%; femic minerals, 43%; and miscellaneous minerals (mostly calcite), 3%. Biotite is present as stringers, and calcite occurs as phenocrysts in which minute crystals of quartz are embedded. These phenocrysts have often taken the shape of pyroxene grains from which the calcite has been altered. Epidote and magnetite occur as accessory minerals. Alteration has not been intense in this specimen, with calcite and limonite occurring as the only products. The limonite has been deposited on the grain boundaries.

T. S. 4-9

This specimen is medium-grained, hypautomorphic and diabasic in texture. Quartz, which is present for the most part interstitially, comprises about 14% of the constituent minerals. Plagioclase (labradorite, Ab43An57) comprises 24%, orthoclase 21%, and femic minerals 41%. The femic minerals are hornblende and porphyritic augite, which is considerably altered, and which encloses small amounts of plagioclase crystals. Accessory minerals present are magnetite, zircon, and apatite.

Alteration products identified are clinochlore, sericite, kaolin, and calcite. Alteration has not been intense in this specimen.

This rock was classified as granogabbro.

T. S. 4-10

This specimen is medium-grained, and of hypautomorphic-granular texture. Interstitial quartz comprises about 5% of the constituent minerals, plagioclase (indeterminate) 48%, orthoclase 12%, and femic minerals 35%. The femic minerals consist of augite, with some hornblende and biotite in plate form. Accessory minerals are chiefly magnetite and apatite.

This specimen has been intensely altered with products as follows: Chlorite as clinochlore and pennanite (pennine), magnetite, epidote, kaolin, calcite phenocrysts, and large grains of pyrite.

Although the type of plagioclase is indeterminate, the rock was classified as probably granogabbro.

T. S. 4-12

This thin section displays a hypautomorphic-granular texture which is also diabasic to a large extent. The percentages of the constituent minerals identified are as follows: interstitial quartz, 9%; plagioclase (indeterminate), 62%; orthoclase, 9%; femic minerals consisting of augite and magnetite, 30%. Accessory minerals present are magnetite and apatite.
The specimen has been considerably altered, with the following products present: chlorite, as clinochlore and pennanite; sericite and kaolin, which coat the feldspar grains quite heavily; limonite on the borders of the feldspar mineral grains; and epidote. This sill was classified as calcisyenite.

**T. S. 39B**

An hypautomorphic-granular texture is displayed in this thin section, with a few phenocrysts of pyroxene present in the fine-grained groundmass. Constituent minerals identified are: interstitial quartz; microlitic plagioclase (labradorite, Ab43An57); augite; and small amounts of orthoclase. Because of the extremely fine texture of the specimen, a mineral count was impossible, and percentages of these constituent minerals were not obtained. Extreme alteration, which produced clinochore, kaolin, sericite, and limonite, coats both feldspar and feldspar grains heavily. Apatite is present as an accessory mineral.

**T. S. 23**

This thin section has a fine diabasic texture. A mineral count was impossible because of the extreme fineness of the texture, but the following constituent minerals were identified: interstitial quartz; microlitic plagioclase (labradorite, Ab48An52); and feldspar minerals consisting of augite, biotite shreds, and magnetite. Orthoclase is believed to be present, but could not be positively identified because of extreme alteration of the feldspars. Products of alteration present are sericite, kaolin, epidote, clinochore, and calcite phenocrysts. Apatite and magnetite were identified as accessory minerals.

**T. S. 18**

This thin section displays a medium hypautomorphic-granular texture. Anhedral and interstitial quartz comprise 6% of the constituent minerals, indeterminate plagioclase 30%, orthoclase 35%, and feldspar minerals 29%. The feldspar minerals consist of pyroxene or amphibole, but extreme alteration of them made their positive identification impossible. Accessory minerals present are magnetite and apatite. Secondary minerals consist of clinochore, kaolin, sericite, calcite, and limonite.

This specimen was classified as probably granogabbro.

**T. S. 43**

This thin section displays a medium hypautomorphic-granular texture, which is commonly diabasic. Constituent minerals present occur in the following percentages: interstitial and anhedral quartz, 7%; plagioclase (labradorite, Ab46An54), 40%; orthoclase, 16%; feldspar minerals consisting of augite and minor amounts of hornblende, 37%. Accessory minerals present are magnetite and apatite. Alteration products identified are clinochore, sericite, kaolin, epidote, magnetite, and calcite.

This specimen was classified as granogabbro.
