THE PETROLOGY AND GENERAL GEOLOGY
OF THE
KETTLE RIVER - TORODA CREEK DISTRICT
OF
NORTHEASTERN WASHINGTON

by

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A thesis submitted in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF WASHINGTON

1955

Approved by____________________

Department____________________

Date____________________

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PETROLOGY AND GENERAL GEOLOGY OF THE KETTLE RIVER-TORODA CREEK DISTRICT OF NORTHEASTERN WASHINGTON

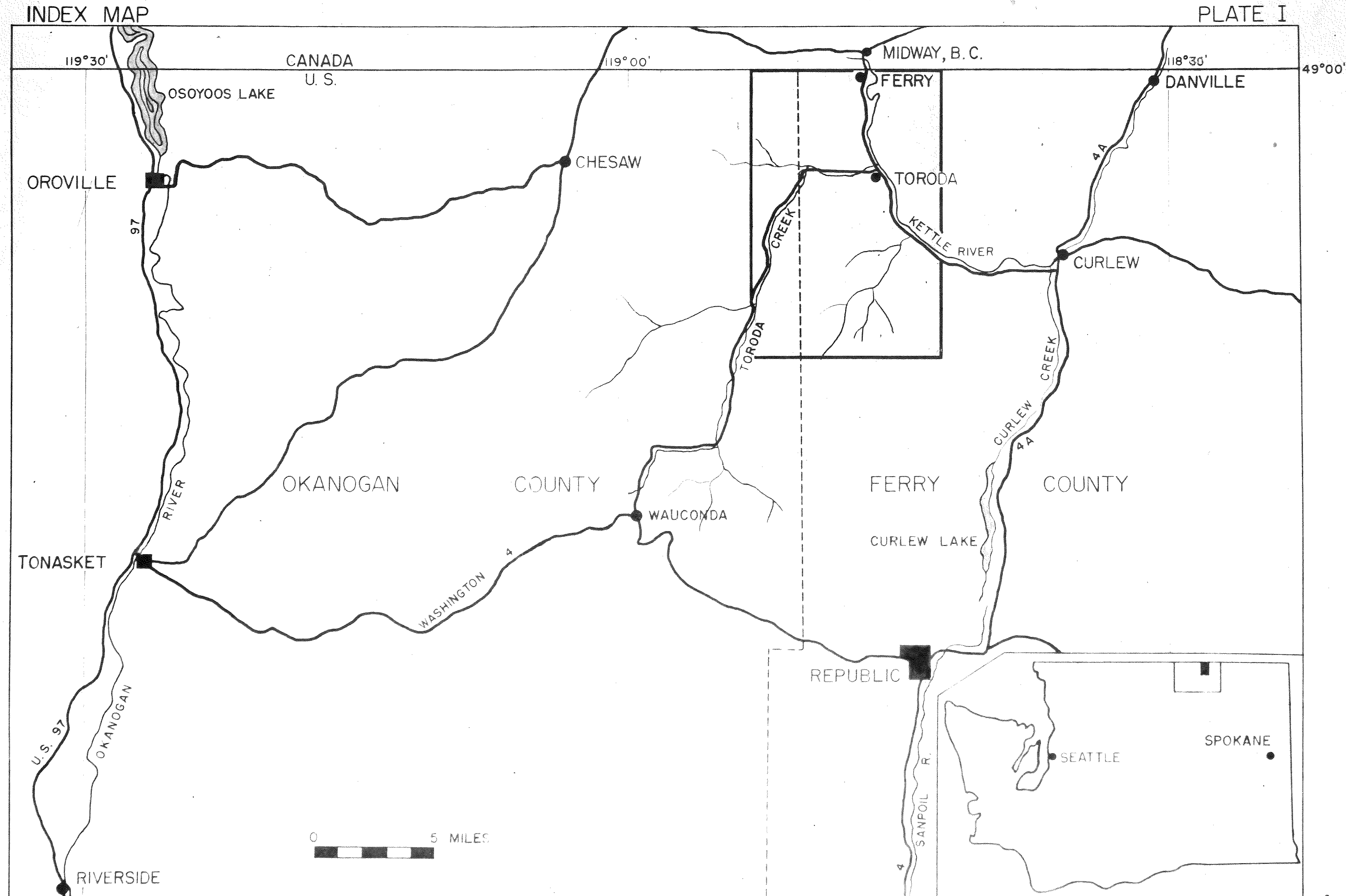
I N T R O D U C T I O N

LOCATION OF THE AREA

The Kettle River - Toroda Creek district is situated in northeastern Washington in Ferry and Okanogan Counties. Approximately one quarter of the area is in Okanogan and the balance is in adjacent Ferry County. The district is bordered on the north by the 49th parallel. Two county roads provide access to the area. Wauconda, 25 miles south of the Canadian boundary, is reached by means of the Toroda Creek road. The village of Curlew is located on the Kettle River some 10 miles east of the map area. Both of the above points are situated on excellent surfaced state highways. An index map delineating the general geographic relationship is shown on plate I, page 2.

PURPOSE AND METHOD OF INVESTIGATION

Relatively little is known concerning the geology of this portion of northeastern Washington. The purpose, then, was to map and describe the general geology. In addition a detailed petrographic and petrogenetic study of the rocks present was undertaken with the aim of ascertaining a part


INDEX MAP
PLATE I
CANADA
U. S.
119°30'
119°00'
118°30'
49°00'
48°45'
MIDWAY, B. C.
FERRY
DANVILLE
OSOYOOS LAKE
OROVILLE
CHESAW
TORODA
KETTLE RIVER
CURLEW
TORODA CREEK
CURLEW CREEK
CURLEW LAKE
97
4A
RIVER
OKANOGAN COUNTY
FERRY COUNTY
WAUCONDA
TONASKET
WASHINGTON 4
REPUBLIC
U.S. 97
OKANOGAN
SANPOIL R.
4
0
5 MILES
RIVERSIDE
SEATTLE
SPOKANE

of the geologic history of the district.

Base maps for the work consist of four seven and one-half minute topographic sheets prepared from aerial photographs by the U. S. Forest Service. Scale on the maps is approximately one to twenty-four thousand. Aerial photographs on the same scale were used in areas where forest cover was sparse or absent.

In 1904 the United States Geological Survey published a topographic map of the Republic quadrangle which includes the thesis area. This sheet is on the scale of 1-125,000 with a 100 foot countour interval. Fifteen minute topographic maps on the scale of 1-37,500 and with a contour interval of 50 feet were published for this district by the same agency in 1951. These are the Bodie Mountain and the Curlew, Washington, quadrangles.

Geologic field work was started in the late summer of 1949, continued throughout the summer of 1950, and completed during October and November of 1951. A total of approximately six months was spent in the field.

The mapped area is somewhat irregular in outline and includes approximately one hundred square miles. Of the total, nearly twenty-five square miles are located in northeastern Okanogan County with the balance in the northwestern part of adjacent Ferry County.

About 800 rock specimens were collected during the course of the work, and nearly 500 thin sections were made and examined by the writer.

PREVIOUS WORK

There are no published reports dealing with the geology of the area. Generalized information included on the geologic map of the state of Washington was supplied by the reconnaisance work of geologists of the State Department of Conservation and Development, Olympia, Washington. The geology of the "Boundary Creek Mining District", adjacent to the area on the Canadian side, has been discussed very briefly by R. W. Brock (1901, 1902, 1903). R. A. Daly (1912), in his geologic reconnaissance of the 49th parallel, briefly describes rock units such as the Midway volcanics and the Kettle River sdeiments which are also found in the area covered by the present report.

A rather complete description of the rocks of the Phoenix Camp has been given by O. E. LeRoy (1912, 1913). The Phoenix area lies a few miles north of the 49th parallel and is included in the Boundary Creek mining district.

J. B. Umpleby (1911), W. A. Broughton (1943), S. W. Zoldok (1947), and G. E. Goodspeed (1951) have supplied considerable information regarding the geology and ore deposits of the Myers Creek mining district. This district lies a few miles to the west of the map area.

Additional references dealing with surrounding areas are listed in the bibliography appended to this paper.

ACKNOWLEDGEMENT

The writer is deeply indebted to Professor Peter Misch for his advice and guidance in the preparation of this paper. The encouragement and kindly suggestions of Professor G. E. Goodspeed, Professor H. E. Wheeler, Professor J. D. Barksdale and other members of the University of Washington geology department are greatly appreciated.

Special gratitude is herein expressed to my wife, Julia B. Dobell, for her aid and encouragement during the preparation of this thesis.

G E O G R A P H Y

RELIEF AND DRAINAGE

The map area and the surrounding region are mountainous and rugged. Elevations in the upland area range from 5738 feet at Bodie Mountain to 4300 feet on Graphite Mountain. Elevations of the principle north-south trending ridge dominated by Bodie Mountain gradually decline from the previously mentioned figure down to approximately 5000 feet at the summit of Bamber Mountain.

A minimum elevation of 1800 feet is found on the Kettle River which flows in a southerly direction across the northeast corner of the district. The maximum relief in the area is 3938 feet.

The Kettle River is the master stream for a large region and one of the major tributaries of the Columbia. It occupies a flat, alluviated valley floor which is rarely more than one-half mile in width. The gradient on this meandering stream approaches 6.4 feet to the mile. Bar and swale topography on the flood plain gives a relief of ten to twelve feet. The present channel of the stream is some ten feet below the general level of the valley floor. Minor tributaries of the Kettle River include Catherine, Tenas Mary, Tonata and Henry creeks.

Locally the principle tributary of the Kettle River is Toroda Creek. This small stream enters the river from the west and drains a large area lying to the west and southwest. Unlike the comparatively placid Kettle River, the lower eight miles of the Toroda Creek course has a gradient of 75 feet per mile. Tributary to Toroda Creek are Nicholson, Resner, Harver, O'Conner and Graphite creeks.

CLIMATE AND VEGETATION

In this district the average year is one with hot, dry summers and cold, severe winters. Weather records from the Ferry County seat at Republic indicate a maximum temperature of 108°F. and a minimum of -31°F. Republic is located twenty-five miles southeast of the center of the map area and the data from that station probably is applicable since there are no great differences in topography or vegetation. Average annual precipitation is 14.27 inches with June being the wettest month (1.91 inches) and August and September the dryest months (.79 inches). Snowfall is generally light, with the greatest fall in December, January and February. The average annual number of days with snow cover is between 60 and 80. The average relative humidity in January is around 80% and in July it varies from 30 to 40 percent.

The prevailing winds throughout most of the year appear to come from the south and southwest. The local topography exerts some diversive influence in sections of the area. This is especially true in the canyons of the Kettle River, Toroda Creek and Nicholson Creek.

Although this region might be considered semi-arid there is, almost everywhere, a moderate forest cover. Distribution of the forests appears to be controlled in part by the topography. Usually, the heaviest stands of timber are found on the north, northeast and east slopes. This is perhaps due to the prolonged moisture supply resulting from slower melting of the snowbanks which accumulate on the leeward and shady slopes of the ridges.

The forests of the region consist principally of yellow pine, red and white fir, tamarack (larch) and spruce. Cottonwood and willow flourish along the larger valleys. Red birch, serviceberry, mountain ash and vinemaple are common species found in the smaller canyons and gulches. At higher elevations, especially along the relatively unforested southern and western slopes, the familiar quaking aspen is common. The aspen is a moisture-loving tree and almost invaribly marks the site of a spring or small tarn. Limited stands of red cedar and stunted juniper are occasionally noted within this area. In the zones where the soil mantle is deeper than usual, the normal cover of pine, fir and spruce gives way to dense stands of lodge-pole pine.

Although abundant in most of eastern Washington, the common sagebrush occurs only rarely in this district. Wild gooseberry, native flowers, and various grasses blanket the untimbered valleys and ridges. The blue and purple lupine, galardia, gillia and other wild flowers are a colorful addition to the landscape during the late spring and early summer months.

RESOURCES AND HISTORY

This semi-arid section of Washington supports a sparse population. In general, the lack of extensive areas of tillable land and the limited supply of marketable timber account for this situation. The residents are mainly engaged in small-scale mixed farming and cattle raising. Additional income is derived from the sale of timber, logging and the operation of small sawmills.

Evidence of much greater activity in past years is seen in the ghost townsites of Ferry and Toroda and in the abandoned roadbed of the railroad which parallels the Kettle River. This region was once part of the Colville Indian Reservation and was not open to settlement and development until early in the year of 1896. Population and prosperity reached a peak some twenty years later. Mining and prospecting within the area and in neighboring districts such as the Republic, Danville, Buckhorn Mountain, and the Canadian Boundary Creek Mining District contributed materially to this prosperity. Construction of the railroad gave impetus to ranching and logging activity. In later years the raising of horses, cutting of railroad ties and various logging operations partially substituted for the dying mining industry.

Soon after the start of the depression in the thirties, the railroad serving the area was abandoned and there began a gradual shift of population from the district. All that remains of the border town of Ferry is the thickwalled framework of the jail and the nearby railroad station and customs office building. Several ruined store buildings mark the site of the crossroads village of Toroda.

PETROLOGY AND STRATIGRAPHY

INTRODUCTION

The designation of the Pre-Attwood medium and high grade metamorphic complex as the oldest is based solely on its relations with overlying and surrounding rocks since no fossil evidence was obtained during the field investigation. A similar situation exists with respect to the Attwood[1] group of rocks. Fossil leaves found in the Kettle River formation by the present writer and by others indicate that it is probably of early Tertiary age. The Kettle River formation and the overlying Midway Volcanics were named and described by Daly (1912, Part I, pp 394-400).

Quaternary deposits consist of fluviatile and lacustrine accumulations associated with continental glaciation, and of more recent stream deposits.

The age relationships and possible lithologic correlation with rocks described by other workers in adjacent regions will be discussed more fully in succeeding sections of this paper.

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1. The name Attwood was applied by Daly (1912, Part I, p 378) to a group of low grade metamorphics which he described north of the 49th parallel. This group of rocks extends southward into the present area.

PRE-ATTWOOD MEDIUM AND HIGH GRADE METAMORPHIC COMPLEX

General Character, Distribution and Stratigraphy

The rocks mapped as Pre-Attwood in age include isochemical metamorphics, migmatites, granites and dikes and sills of intermediate composition whose emplacement preceeded or accompanied various phases of the regional metamorphism.

By far the most common rocks in the above group are the isochemically metamorphosed sediments. These are, in order of abundance, quartzites, amphobolites, impure quartzites, biotite schists, and lime-silicate marbles, granulites and gneisses. Some amphibolites intercalated with this group are of uncertain, perhaps igneous, origin. They will, however, be described with the isochemically metamorphosed sediments.

Although the dikes and sills of this complex show no evidences of chemical change through additive processes, and could thus be included with the isochemically altered rocks, the writer prefers to deal with them under a separate heading. These dioritic intrusives are not abundant and are not always metamorphosed to the same degree as the invaded rocks.

The migmatites consist of biotite gneisses and hornblende gneisses. Biotite and hornblende are their most frequent ferro-magnesium minerals, with the former being

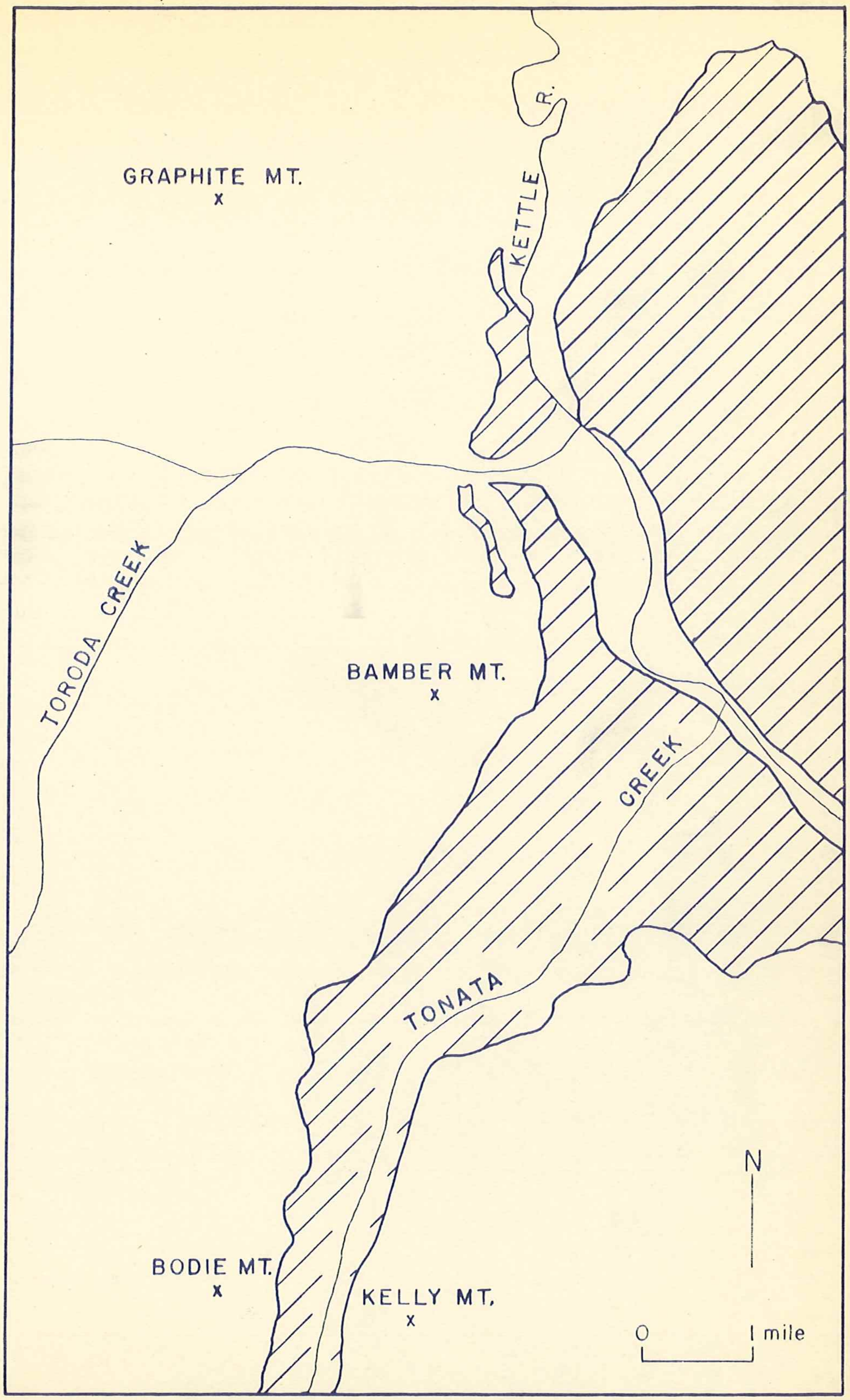


Figure 1. Distribution of the Pre-Attwood metamorphics.

the most abundant. These migmatitic gneisses are intercalated with and grade into the various isochemical metamorphics. The quantity of migmatitic material decreases upward in the section. With increasing depth in the section there is a gradual transition from the migmatitic type of rock to a gneissose granite. In turn the medium grained, often porphyroblastic gneissose granite passes gradually with depth into a directionless, medium-grained rock of granitic composition. In general, the pure quartzite mentioned earlier marks the upward limit of the migmatite zone. Exceptions to this include a biotite-bearing gneiss and a hornblende-bearing banded gneiss which are found above the quartzite, particularly on the west and southwest side of the Kettle River. The biotite gneisses locally grade upward into fine grained hornblende-bearing mylonites.

A generalized column showing the various lithologic units of the Pre-Attwood is given in table 1, page 15.

The Pre-Attwood complex forms one of the major rock units in the area. Approximately thirty-two square miles of this group of rocks were mapped in the district and equally extensive unmapped exposures lie to the east and south.

Table I

Succession of lithologic units composing the Pre-Attwood medium and high grade metamorphic complex. In decreasing order.

Cordierite-biotite schist
Amphibolite
Feldspathic quartzite
Diopside-bearing amphibolite
Quartzite
Marble
Lime-silicate rocks
Micaschists
Migmatites
Gneissose granite
Granite

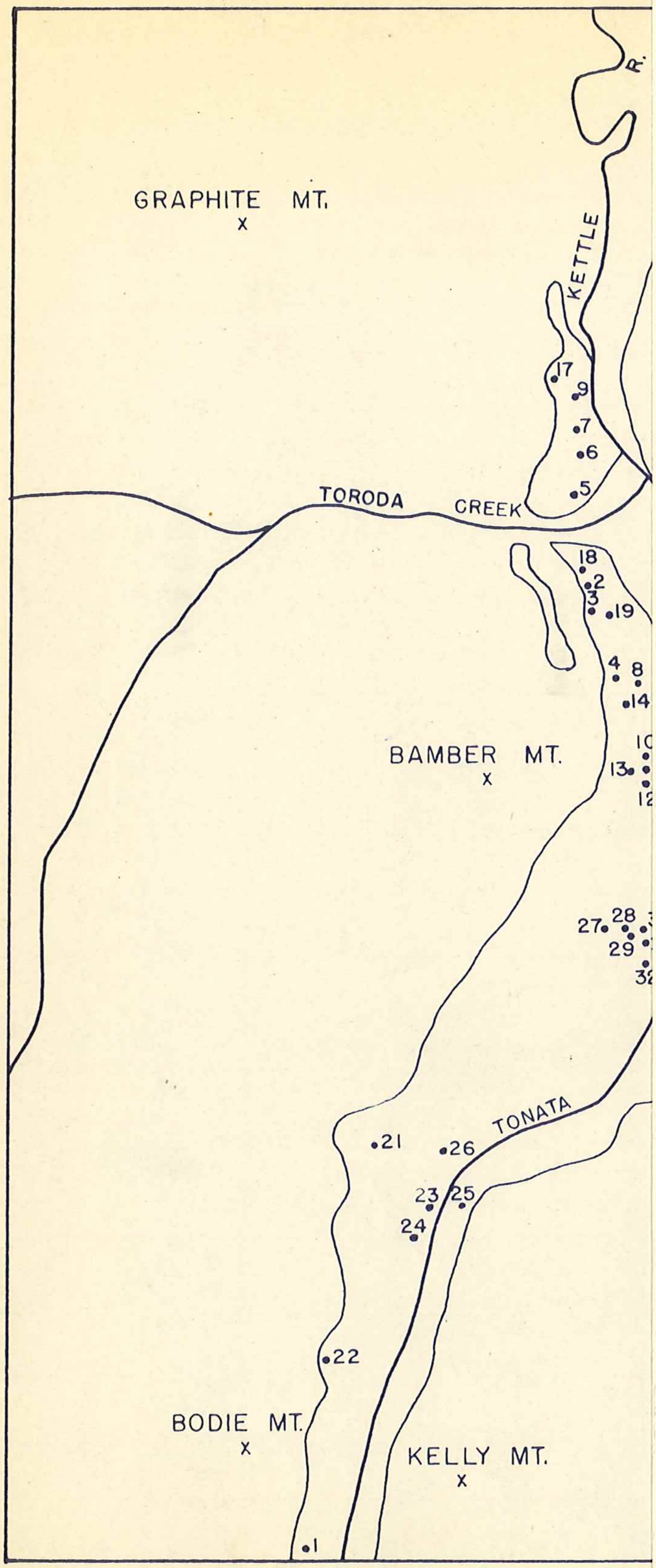


Figure 2 Sketch map showing the locations of the Pre-A
specimens referred to in the text.

Isochemically Metamorphosed Rocks

Micaschists

Introduction: For the purpose of discussion and description, rocks of this category have been divided into three groups: (I), garnet-biotite schists and tourmaline-garnet-biotite schists; (II), andalusite-bearing sillimanite-sanadine micaschists; and (III), cordierite-biotite schists. Table 2, page 42 shows the approximate modes of the pre-Attwood micaschists.

Description of the garnet-biotite schists (Group I): Excellent outcrops of biotite schist occur in the northwest quarter of the northwest quarter of section 2, T 39 N, R 32 E. In this locality 35 to 40 feet of schist forms a prominent black band on the face of a conspicuous escarpment. In other localities within the district they are much thinner and often pass laterally into more feldspathic or more quartzose rocks. The biotite schists are usually associated with quartzite (cf. below), and pass downward into migmatites.

Megascopically, the schists of this group range from course-grained, well-foliated types with 70% or more biotite to fine grained varieties, rich in felsic minerals and often somewhat indistinctly foliated. The mica-rich varieties often show considerable small scale folding and distortion in contrast to the general lack of similar features in the less micaceous types. Pods and elliptical lenses of quartz are not uncommon, especially in the crests of small scale folds.

Generally the schists weather to dark brown or rusty-red colors. Biotite-rich types such as the prominent 40 foot band mentioned above are very deeply weathered and it is difficult to obtain a satisfactory hand specimen. Unweathered samples are easily obtained from most other outcrops. When present, tourmaline, garnet, muscovite, quartz and feldspar can usually be detected with a hand lens. Anhedral dark red garnets up to 25 mm in diameter are common in the coarse-grained schists. Some crystal faces are developed on the garnets of finer grained rocks. Tourmaline is jet black in color and usually found in distinct trigonal prisms which range from 5 to 20 mm in length. These prisms lie in the foliation planes but are not present in sufficient quantity to define any lineation. Muscovite is often detected but is not an abundant constituent of these rocks.

In thin section, quartz is always present in amounts ranging from 25 to 70 percent. Grains are commonly somewhat sutured in outline and mutually interlocking or, in some sections, form a granoblastic fabric. Preferred orientation of quartz is not striking in these rocks although in sections cut parallel to the schistosity there is always an abundance of grains which remain at or near extinction position under crossed nicols.

The feldspar is calcic oligoclase or sodic andesine with minor orthoclase. Distribution of the plagioclase is irregular and patchy where it occurs with abundant quartz and uniformly disseminated biotite. In specimens showing irregularly alternating bands of quartz and biotite the plagioclase-rich zones may lie between the two or within the biotite bands. Although plagioclase is found in amounts up to forty percent, there are no definite indications of sodium introduction. Inclusions in the plagioclase are quartz, biotite, apatite and zircon. Inclusions of plagioclase, biotite and minor accessories are likewise not uncommon in the quartz. Where quartz and plagioclase occur together the texture is granoblastic. Availability of calcium and aluminum in the more argillaceous portions of the original sediment would explain the localization of the plagioclase. Potash feldspar showing carlsbad twinning and anhedral outlines is found in the tourmaline-bearing garnet-biotite schists (Sp 51.D.155A, B and C). No plagioclase is present in thin-sections of rocks from this location.

The biotite of these rocks is dark brown in reflected light and pleochroic from yellow to moderately dark brown under the microscope. In thin-sections cut normal to the schistosity the mineral appears as irregularly distributed parallel individuals with frayed or ragged outlines, and as interlocking sub-parallel flakes forming continuous bands. In sections cut parallel to the schistosity the plates have anhedral outlines and best display the inclusions of quartz, zircon, opaques or apatite. Specimen 51.D.75 contains approximately ten percent of muscovite which is intimately intergrown with biotite. The usual biotite schist includes only rare flakes of muscovite.

Porphyroblasts of tourmaline and garnet are found in specimen 51.D.155 and garnet alone is normally present in the common biotite schists of the district. Tourmaline is zoned, occurs in subhedral crystals up to maximum sizes of 8 mm in length by 4 mm in width and may be poikiloblastic. The inclusions are quartz and an opaque mineral. Pleochroism is very strong and changes from a pinkish-gray (e) to dark purple or blue (o). Zoning consists of several concentric bands of bluish-gray or blue color and is best seen in sections cut parallel to 0001. About 1% of the mineral is present and it may result from concentration of the boron content of the original argillaceous sediment (Turner, 1948, p 127). The garnet of this group of micaschists is invariably poikiloblastic with inclusions of quartz, biotite, an opaque mineral and an occasional grain of apatite or zircon. There is no alignment of the inclusions and clear borders are absent. Small scale, intricate folding of the adjacent rock material suggests that later deformation occurred after growth of the garnet had ceased. More conclusive evidence of post-garnet deformation is seen in fractured and slightly separated fragments of single garnet porphyroblasts. Such evidence of later cataclastic deformation was seen only in a part of the schists examined.

The garnet is faintly pink in thin-section and ranges from anhedral to subhedral in outline.

Minor constituents are apatite, zircon, magnetite and pyrite. Several specimens contain sparse anhedral grains of sphene. Magnetite grains are often altered to or rimmed with hematite. Apatite and zircon commonly occur as subhedral to euhedral grains. Pleochroic halos may or may not surround zircons in biotite. Fractures transecting the schistosity at various angles are healed with quartz or, less commonly, shreds of chlorite accompanied by irregular grains of magnetite.

Chlorite after biotite and sericite forming from plagioclase are retrogressive minerals indicating a period of low grade (epizonal) metamorphism. Discussion of this and other aspects of the metamorphic history of the Pre-Attwood micaschists of this district will be continued in the summary at the close of this section of the paper.

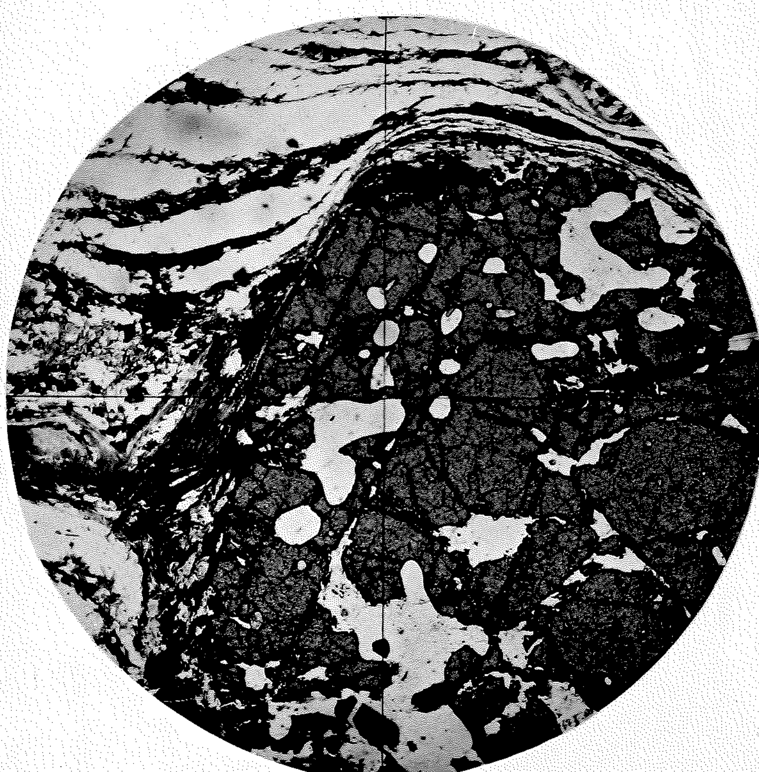


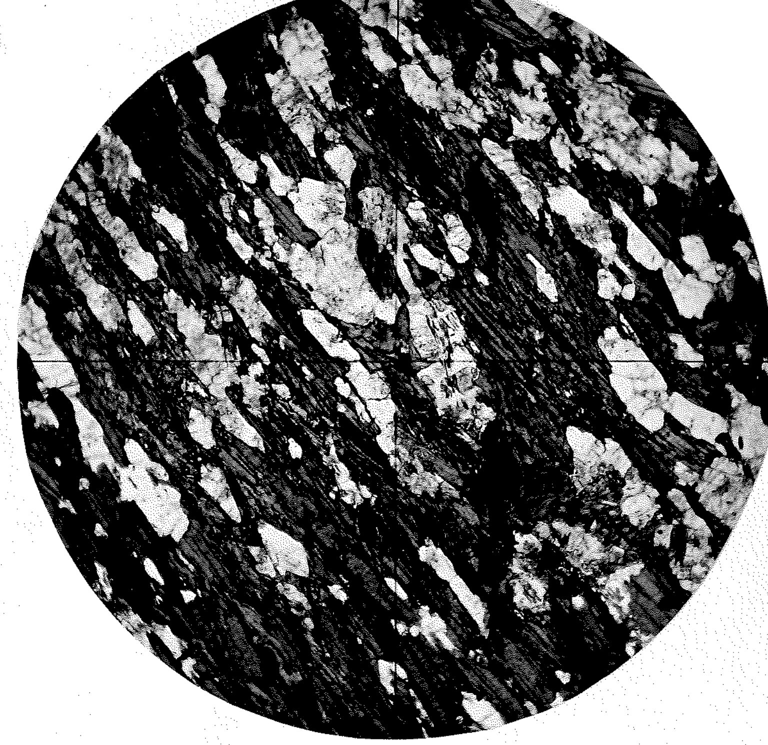
PLATE III

A. Typical garnet-biotite schist.

Specimen 51.D.48. Plane polarized light. X16.

B. Recrystallized quartzitic biotite schist. Dark Tourmaline with rounded quartz inclusions.

Specimen 51.D.155A. Plane polarized light. X16.



<u>Description of andalusite-sillimanite micaschists (Group II):</u> Micaschists with sillimanite, sanidine or andalusite are of limited occurrence in this district. They are interbedded with and grade into the biotite-garnet-tourmaline micaschists described above, and bear similar relationships to the lime-silicate rocks and thin beds of quartzite. These high grade schists also are found as bands in the migmatitic zone of the Pre-Attwood complex. The above-mentioned bands have the same attitude as the overlying schists, lime-silicate rocks and quartzites.

In hand specimen the rocks of this group are very similar to the micaschists described in section (I). Noticeable, however, is a tendency to be less distinctly foliated and more compact than other micaschists. The amount of quartz varies considerably in these schists. Those with abundant quartz tend to be fine grained, with the average grain size ranging from .5 to 1 mm. Other specimens are fairly coarse-grained with flakes of biotite attaining a size from 3 to 5 mm. Andalusite porphyroblasts up to 10 mm may be observed on cut surfaces but are difficult to recognize in rough hand specimens, since they do not form euhedral crystals and are not sufficiently large to form prominent "knots". Outcrops of these schists are stained various shades of brown or rusty-tan. Fresh specimens range in color from gray to an orange-brown. Intricate small-scale folding of the schistosity is a common feature that is often readily Detected.

detected in weatherd outcrops.

Quartz occurs in all rocks of this group, although, as indicated previously, there is local variation in the quantity present. Specimen 51.D.81F has less than ten percent whereas in specimen 51.D88A, quartz comprises at least seventy percent of the rock. It occurs in irregularly sutured or granoblastic grains found either in separate bands or as discrete grains associated with other minerals of the rock.

Biotite is the common mica although well-formed muscovite may be present in small amounts (specimen 51.D.88A, etc.). The common biotite is brown in thin-section with pleochroic colors ranging from paly yellow to dark brown. Biotite in specimen 51.D.77 is pleochroic from pale yellow (x) to reddish orange (z). In thin-sections cut normal to the foliation the biotite flakes are well-aligned and do not grow across the schistosity. Specimens with small scale folds show well recrystallized biotite forming "polygonal arcs", which indicate a late or postkinematic[1] period of recrystallizatization. Sections cut parallel to the foliation show enahedral flakes with many conspicuous embayments. Inclusions of zircon and quartz are present in the larger grains of biotite. Alteration of biotite to sericite is a common feature in some specimens of this group (specimens 51.D.80A, 64 and 84). In the specimens mentioned a larger percentage of the biotite appears

1. "Postkinematic" refers to processes which took place under static conditions after differential rock deformation had ceased. (Misch, 1949, Part I, page 211).

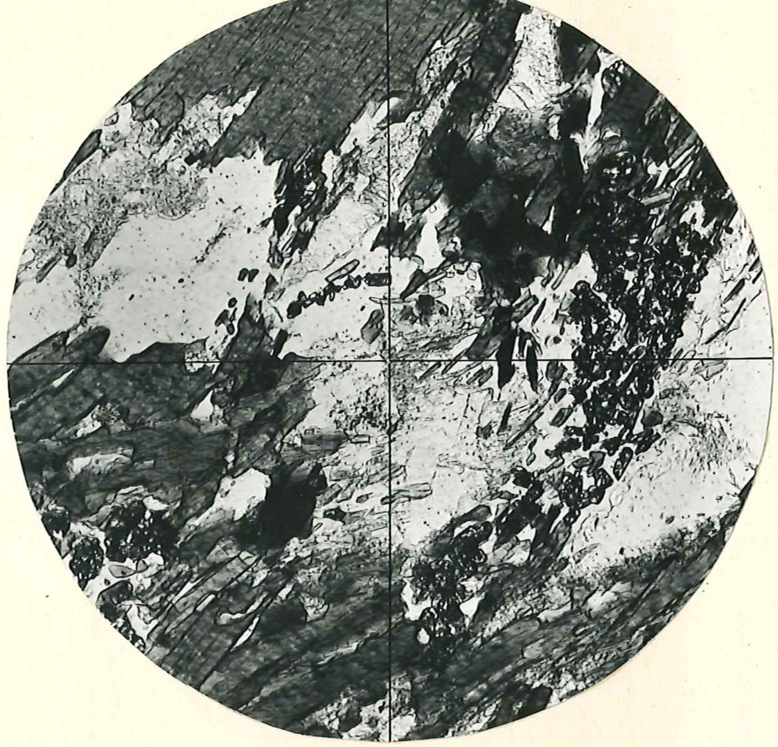
altered to sericite but as sericite also forms after the associated andalusite it is impossible to estimate the relative amounts derived from the two minerals. The origin of part of the sericite is further in doubt since yellow pleochroic haloes similar to those surrounding zircons in altered cordierite are also found. Haloes are not abundant in the remaining biotite, and no positive transitional relationships were noted. The sericite is faintly green in color and occurs as finely fibrous sub-parallel aggregates. Distinct flakes of white mica are found within the sericite masses. In specimen 51.D.88A the following relationships are observed. Biotite flakes which mark the foliation in the rock are partially altered to sericite and fine grains of an opaque mineral, probably magnetite. Well formed muscovite is found surrounded by the sericite or adjacent to and intergrown with biotite. The white mica often grows across the schistosity and would thus appear to be later than the foliation. Muscovite is also found in well-formed fresh flakes associated with quartz. It appears that two generations of muscovite are present: (a) that which occurs in parallel growth with biotite or with quartz and (b), muscovite forming from sericite and often growing across the foliation. The "b" generation of muscovite in specimen 51.D.88A may be contemperaneous with mica formed from the andalusite which is found in either rocks of this group (II). According to Turner (1948, page 118) this type of potash metasomatism may result from redistribution of materials present in the rock and need not indicate addition of potash.

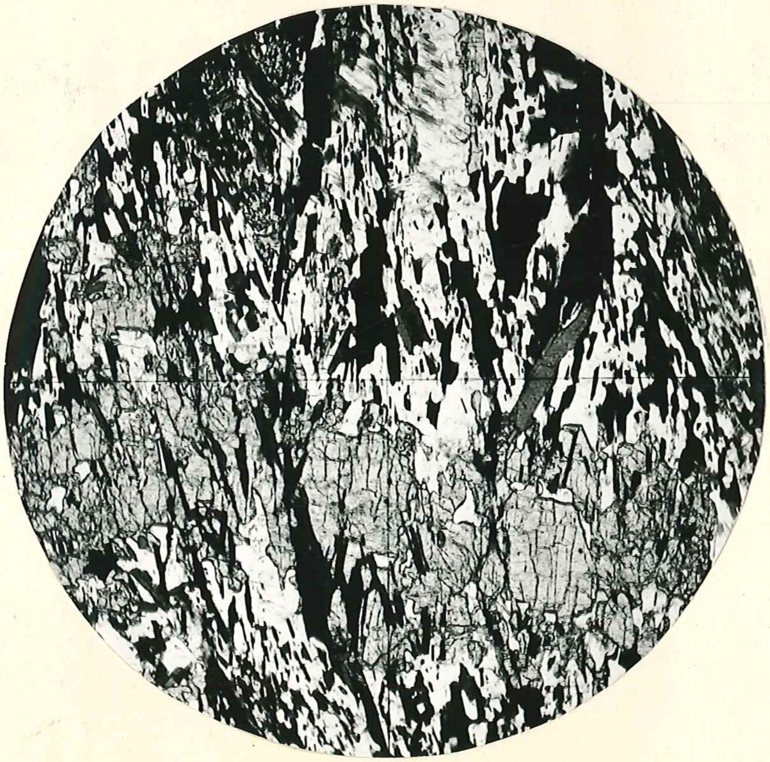
Plagioclase feldspar is absent in some specimens, and when present seldom constitutes more than five percent of the rock. In specimen 51.D.81F, sanidine and turbid orthoclase are intergrown with and appear to be replacing the plagioclase. Potash feldspars form a mosaic of grains associated with sparse quartz and sodic oligoclase. Sanidine is not found in all representatives of this group although potash feldspar is always present in amounts varying from five to thirty-five percent. Although sanidine is often considered a product of high grade contact metamorphism of argillaceous sediments, there is no field evidence that the sanidine in these group (II) schists has such a history. Misch (1949a) suggests that the mineral is stable under conditions of high grade regional metamorphism.

Sillimanite occurs in the form of well-developed needles and also as the fibrolitic variety. The better-formed mineral is common as aligned inclusions in quartz and feldspar, and appears to be older than radiating aggregates of fibrolite forming from biotite. The fibrolite often coalesces to form sheaves which display the cross fractures and birefringence of large prisms of sillimanite. The two varieties of sillimanite are believed to represent two phases of continued high grade synkinematic metamorphism. Specimens 51.D.88A and 51.D.77 show the mineral partially altered to sericite.

Andalusite is common as anhedral to subhedral porphyroblasts which often cut across the foliation planes. In thin-section the mineral may be pleochroic from colorless (x) to rose-red (z). The patchy distribution of this pleochroism within a single porphyroblast corresponds to blue-gray zones which are prominent under crossed nicols. These zones are irregular in outline and usually lie in the central part of the mineral. Although no symmetrical arrangement is seen, the zoning suggests the chiastolite variety of andalusite. Inclusions in the mineral are biotite, quartz, sanidine, orthoclase and sparse fibrolite. Muscovite and sericite are common alteration products. This late hydrothermal alteration is pronounced along 110 cleavages and less common in the marginal area of the porphyroblasts. The degree of alteration, however, varies with the locality of the specimen. Specimen 51.D.81F shows an early stage, whereas in specimens 51.D.84, 51.D.64, and 51.D.80A the andalusite is almost completely altered to mica. Genetically, the andalusite is a product of the postkinematic partial recrystallization of sillimanite-bearing micaschists which were derived from argillaceous sediments.

Minor accessories include zircon, sparse apatite and garnet. Thin-section 51.D.80A contains very small amounts (less than 0.5%) of sphene and allanite. Magnetite and sparse pyrite are the usual opaque minerals. As in other micaschists, chlorite commonly forms from biotite.





<u>Description of cordierite-biotite schists (Group III):</u> Schists with cordierite are found in two localities on the east side of the Kettle River. Aside from the cordierite, which they have in common, the rocks from these two areas differ mineralogically and are separated stratigraphically by a several thousand foot thickness of the various other members of the Pre-Attwood metamorphic complex. In the following paragraphs, micaschists with cordierite and sillimanite will be described under (a), and those with cordierite alone under (b).

(a) Cordierite-sillimanite micaschists crop out as a ten foot band in a small area in the center of the east half of section 1, T. 39 N, R. 32 E. Associated overlying rocks are biotite schists, thin lime-silicate bands, and quartzites. Underlying rocks are paragneisses and migmatitic types.

The megascopic appearance varies with the proportions of biotite, feldspar and quartz. Biotite-rich layers are dark in color, well-foliated, and easily split into slabs. Zones with abundant feldspar and quartz alternating with biotite bands have the interrupted foliation and general appearance of a gneiss. Cordierite and sillimanite were not identified in the hand specimens.

Quartz comprises a minimum of thirty percent of the rock. It is found as granoblastic grains which are either intergrown with cordierite and potash feldspar or form distinct quartz-rich bands. The mineral is a common inclusion in cordierite and feldspar.

Anhedral porphyroblasts of cordierite constitute approximately twenty-five percent of the schist in the thin sections examined. This amount is perhaps a little high for the rock as a whole since sections were often cut from the cordierite rich portions. The mineral occurs in rounded grains associated with quartz or as definite bands which crudely parallel the foliation. Various degrees of alteration to a yellow micaceous mineral (pinite?) and to well-formed flakes of muscovite is noteworthy. This alteration begins along the 010 cleavage or in fracture or parting planes, and progresses inward as a mass of scale-like fibers with moderate relief and pale yellow to greenish-yellow color. A slight amount of post-cordierite shearing parallel to the original schistosity apparently has provided easy access for hydrothermal solutions since the cordierite of these zones is extensively altered. However, the mineral always shows some degree of alteration also in those areas removed from the late fractures. Common inclusions in the cordierite are biotite, sillimanite, quartz, zircon, apatite, magnetite and rare potash feldspar. The unaltered portions of the mineral are colorless and no pleochroism was noted even in sections .04 to .05 mm thick. Pleochroic haloes surrounding zircon are prominent in grains cut parallel or nearly parallel to c. No halo is present when the x or y directions are parallel to the polarizer but with x in parallel position the halo is of a prominent yellow color. Several cordierite porphyroblasts show pronounced helecitic structures with the included folds marked by sillimanite and biotite. Cordierite in this group of schists appears to be a late mineral since all other minerals present do occur as inclusions. Helecitic structures and porphyroblastic habit further suggest that the mineral formed during a postkinematic period of recrystallization that may be contemperaneous with and within the same isograd as the andalusite described above in the group II schists. With the amount of cordierite set at approximately twenty-five percent of the rock, the author had some doubt whether this group should be considered isochemical. However, the presence of biotite inclusions is perhaps an indication that sufficient magnesia was available for the production of cordierite. Harker, 1939, page 235, suggests that cordierite plus biotite may form from the garnet, muscovite and quartz which were stable during an earlier synkinematic phase. This perhaps cannot be called upon to explain the present case since cordierite has replaced part of the biotite and no trace of garnet or early muscovite is seen.

Sillimanite is present in prisms and needles of sufficient size to produce normal interference colors. The mineral appears as fresh inclusions in potash feldspar and also as partially altered to fresh inclusions in cordierite.

The fibrolitic sillimanite has formed from biotite. No fibrolitic material is included in the feldspar but it is found together with well-formed crystals of sillimanite in cordierite. The age relation of the two forms is not clear though it appears that the prismatic mineral formed early in a period of high grade (katazonal) regional metamorphism and that continued deformation under sustained high temperature resulted in the production of fibrolite from biotite. Some support for the above conclusion is seen in the association of biotite, sillimanite and fibrolite in some thin sections. Early prisms of sillimanite are adjacent to biotite flakes which show varying degrees of alteration to fibrolite (section 51.D.100A).

The biotite is very dark brown in plane light and displays the usual yellow to brown pleochroism. It occurs in discontinuous bands with sillimanite and magnetite, and with quartz and potash feldspar. These bands are often completely enclosed in cordierite. Flakes of biotite are also scattered through the quartz or quartz-feldspar bands. Muscovite and sericite are late hydrothermal products which have formed from potash feldspar, cordierite and, to a limited extent, from fibrolite. Flakes of muscovite up to 0.3 mm in greatest dimension are observed in cordierite-potash feldspar grain boundary zones. Muscovite and sericite are also commonly formed along the cleavages of the feldspar.

Microcline and sparse sanidine are both present in rocks of this group. The microcline occurs as anhedral granoblastic grains associated with and including quartz. Other included minerals are sillimanite and biotite. Fractures and cleavage traces are prominent and marked partially by sericite or small flakes of muscovite. The sanidine grains lack the faint turbidity and prominent cleavages of the microcline. Feldspar was formed late in the synkinematic phase. It has been replaced in part by the postkinematic (?) mineral cordierite.

Minor accessories present include apatite, zircon, magnetite and, rarely, pyrite. Of these minerals apatite and magnetite are the most common. Euhedral crystals of apatite often include zircon or grains of magnetite. Magnetite of pre and post-cordierite ages appears to be present. The second generation occurs as anhedral, usually elongated grains which may have formed from iron released during the replacement of biotite by cordierite.

The retrograde minerals present include chlorite, sericite, muscovite and the micaceous alteration product (pinite?) of cordierite. Chlorite is not common but where present it has formed from biotite. The origin of the sericite and muscovite has already been discussed in preceeding paragraphs.

(b) The second occurrence of cordierite in the Pre-Attwood complex is in micaschists which crop out on the north slope of Catherine Creek valley. Catherine Creek drains a large area in the northeast corner of the district and is a minor tributary of the Kettle River.

A thickness of around one hundred feet of the cordierite bearing micaschist is visible in some outcrops while others appear much thinner and show interbedded amphibolite bands. Unconformably overlying the cordierite-biotite schists are the impure quartzites and black phyllites of the Attwood formation. Rocks underlying the schist are amphibolites and a mafic-rich diorite sill.

Megascopically this uppermost member of the Pre-Attwood rocks presents an unusual appearance. Weathered specimens show rounded or ellipsoidal light-colored spots ranging from one-eighth to two inches across. The spots are closely-spaced in a matrix of quartz and biotite and often weather out as knots on surfaces parallel or nearly parallel to the schistosity. In other outcrops the spots appear less resistant to weathering agents and form shallow depressions. On fresh fractures the outlines of the knots are difficult to distinguish due to lack of color contrast with the grayish-green biotite. Although biotite is plentiful, the rock is more compact and has less tendency to split along foliation planes than the usual schist.

Thin-section examination reveals that the knots are poikiloblastic segregations of cordierite. The mineral shows no tendency to form euhedral crystals and seldom occurs as twins.

Each of the "spots" is composed of several intergrown grains forming what might be termed glomeroblastic aggregates. Inclusions present are quartz, muscovite, biotite and zircon. Bright yellow pleochroic haloes are common around the zircon. Some sections show the cordierite partially altered to a mica-like product which lacks the yellow color noted in the cordierite alteration product mentioned under group III (a) above. In other sections no alteration is found. Cordierite has formed at the expense of biotite.

The biotite of these rocks has a peculiar greenish-brown color in thin-section. Pleochroism ranges from colorless (x) to greenish-brown (z). In areas where cordierite is absent an occasional flake of biotite grows across the schistosity. This partial recrystallization may have occurred under the same static conditions which produced the cordierite. Muscovite is less common than biotite and appears to be contemperaneous with it. The fine flaky micaceous mineral (pinite?) which has formed from cordierite may be distinguished from early mica on the basis of size and distribution. Early mica occurs in biotite-rich areas whereas the smaller pinite flakes are restricted to the cordierite porphyroblasts.

Quartz is a major constituent in all thin-sections. It is equigranular and evenly distributed throughout the rock. There seems to be no preferred orientation and no concentration into bands or ellipsoidal masses. Quartz is the most abundant inclusion in the cordierite knots as well as in the biotite and feldspar.

Not more than five percent of the rock is composed of plagioclase. Some sections contain no feldspar but where present it is calcic oligoclase. The subhedral porphyroblasts range in size from a few tenths up to two millimeters in greatest dimension.

Minor accessories include the usual grains of magnetite, apatite, zircon and sparse pyrite. Chlorite after biotite is occasionally noted but as a rule is much less abundant than in the usual Pre-Attwood micaschist. The micaceous alteration product of cordierite has been mentioned above.

The origin of the cordierite "knots" in these group III (b) micaschists is doubtful. Replacement of biotite by cordierite, partial recrystallization of the groundmass biotite and the imperfect foliation of the rock as a whole suggests a late, high-temperature static metamorphism. There is some possibility, however, that the heat necessary may have been supplied by nearby intrusive bodies. The diorite sill which underlies the micaschist is several hundred feet thick; but since it is slightly schistose, the suggestion that its emplacement is unrelated to the appearance of statically formed cordierite seems logical.

<u>Summary and conclusion</u>: On the basis of the foregoing descriptions the metamorphic history of the Pre-Attwood complex, as indicated by the micaschists, may be subdivided into the following phases.

I. Synkinematic metamorphism under at least cooler high-grade conditions. High temperatures and movement continued with fibrolite forming from biotite.

II. A postkinematic period of recrystallization which involved the micas in particular and, to a certain extent, all other minerals. Andalusite and possibly the cordierite formed. Warm medium-grade temperatures prevailed.

III. A low temperature metamorphism resulting in retrogressive chlorite, sericite, "pinite" and muscovite.

IV. Post-chlorite phase or phases of faulting and shearing. Late fractures cemented with silica or, more rarely, carbonate.

MICASCHISTS

lusite-sillimanite schists						Cordierite-biotite schists		
80A	81F	81H	84	88A	169	100	127	130
20	15	10	55	75	40	30	60	70
--	--	--	--	--	--	20	--	--
5	10	--	2	5	--	1	--	--
--	5	35	3	--	--	--	--	--
5	5	t	--	--	30	--	--	--
15	1	t	4	10	--	--	10	5
30	30	40	30	5	25	20	20	10
--	--	--	--	--	t	--	--	--
--	2	10	--	2	1	8	--	--
5	30	--	5	--	--	--	--	--
--	--	--	--	--	--	20	10	10
--	--	--	--	--	--	--	--	--
t	t	t	t	t	t	t	t	t
t	t	t	t	t	t	t	t	t
t	--	t	--	--	--	--	--	--
t	t	t	t	t	t	t	t	t
--	--	--	--	--	--	t	t	--
15	t	5	t	t	2	t	t	t
--	--	--	--	--	--	--	--	--

TABLE 2

APPROXIMATE MODES OF PRE-ATTWOOD MICASCHISTS

	Garnet-biotite schists										Andalusite-sillimanite schists								Cordierite-biotite schists		
SPECIMEN*	44	48	63	75	155A	155B	165	166	167	168	64	77	80A	81F	81H	84	88A	169	100	127	130
MINERALS																					
quartz	40	15	35	70	55	40	20	55	50	25	55	50	20	15	10	55	75	40	30	60	70
microcline	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20	--	--
sanidine	--	--	--	--	--	--	--	--	--	--	10	5	5	10	--	2	5	--	1	--	--
orthoclase	--	--	--	--	--	20	--	--	--	--	--	--	--	5	35	3	--	--	--	--	--
plagioclase	25	30	35	5	--	--	45	5	10	40	--	--	5	5	t	--	--	30	--	--	--
muscovite	t	t	t	10	t	t	t	t	--	--	5	5	15	1	t	4	10	--	--	10	5
biotite	30	35	25	15	40	35	30	35	20	30	25	30	30	30	40	30	5	25	20	20	10
garnet	--	--	--	--	2	1	--	1	2	t	t	--	--	--	--	--	--	t	--	--	--
sillimanite	--	--	--	--	--	--	--	--	--	--	--	2	--	2	10	--	2	1	8	--	--
andalusite	--	--	--	--	--	--	--	--	--	--	3	3	5	30	--	5	--	--	--	--	--
cordierite	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20	10	10
tourmaline	--	--	--	--	2	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
apatite	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t
zircon	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t
sphene	t	t	--	t	--	--	t	--	--	--	t	--	t	--	t	--	--	--	--	--	--
magnetite	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t	t
pyrite	--	--	--	--	--	t	--	--	--	--	--	t	--	--	--	--	--	--	t	t	--
chlorite	t	20	5	t	t	t	t	t	20	5	t	t	15	t	5	t	t	2	t	t	t
epidote	--	--	t	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

*All specimen numbers preceded by 51.D.

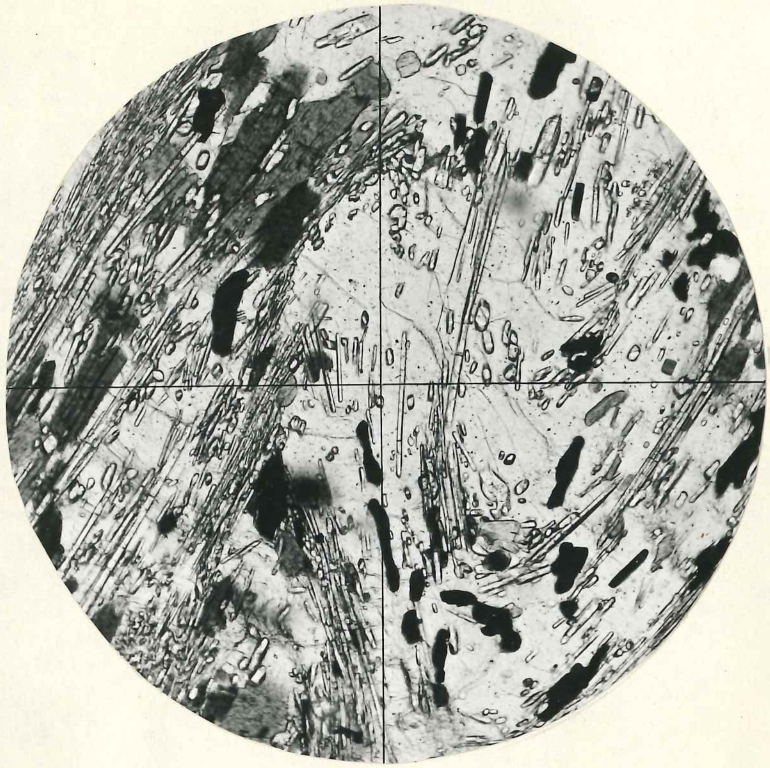
PLATE V

A. Cordierite-biotite schist. Hilicitic structure shown by sillimanite, biotite, apatite and zircon included in cordierite.

Specimen 51.D.100A. Plane polarized light. X50.

B. Cordierite-biotite schist. Cordierite partially altered to pinite (?). Apatite, magnetite, quartz and biotite. Zircon surrounded by pleochroic halo.

Specimen 51.D.100B. Plane polarized light. X50.



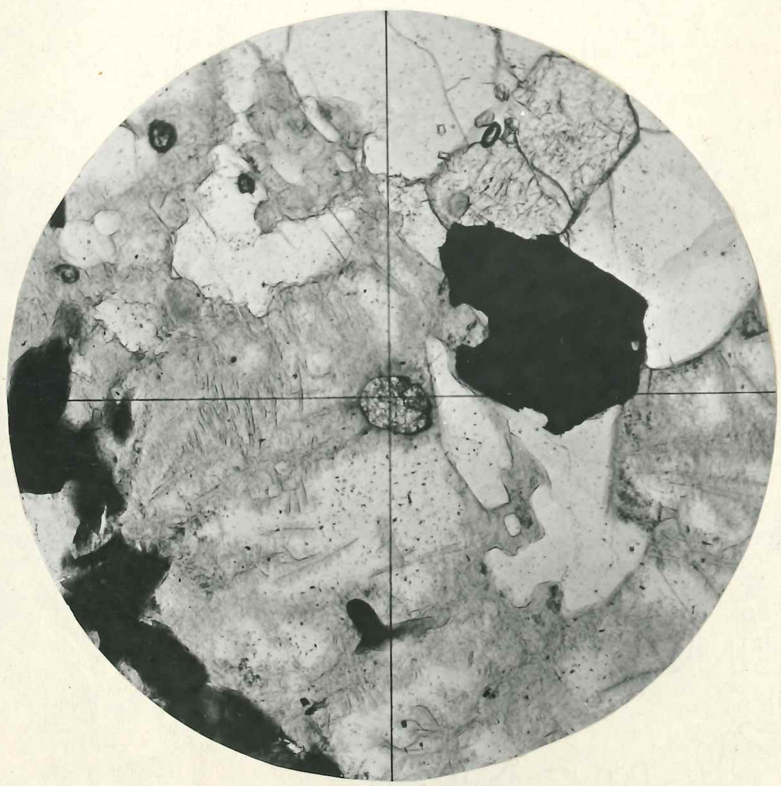
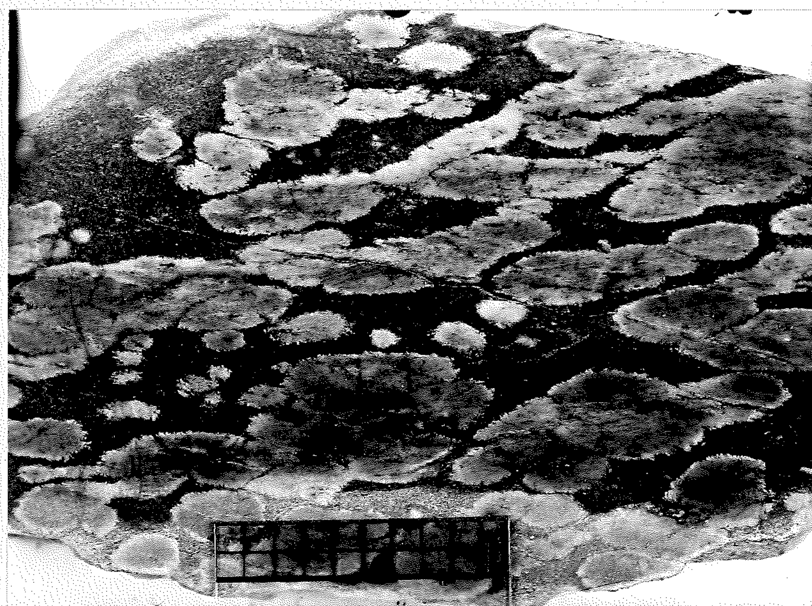
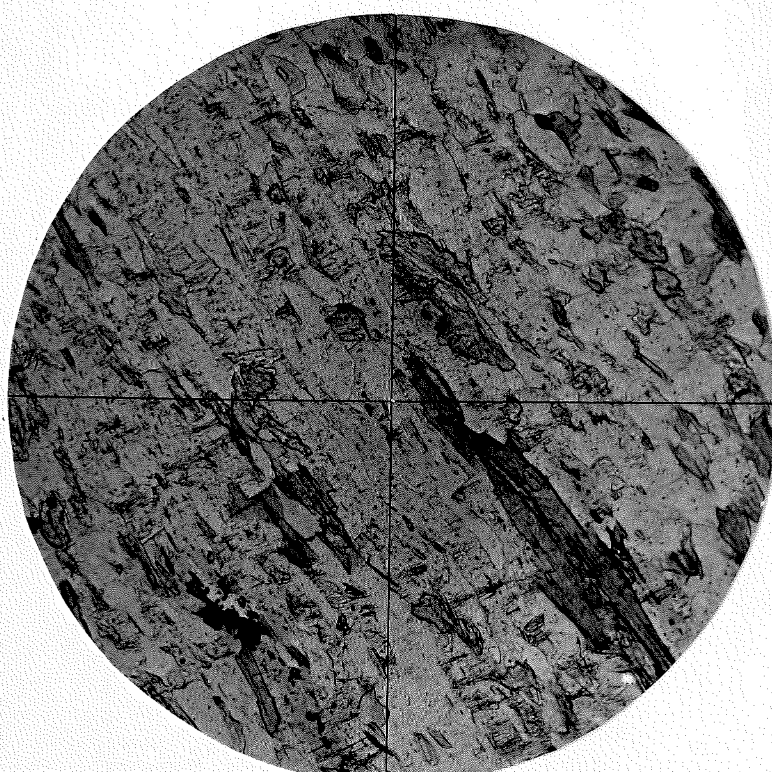


PLATE VI

A. Cordierite-biotite schist. Polished slab showing cordierite porphyroblasts.

B. Cordierite-biotite schist. Photomicrograph of a thin -section from A (above) showing inclusions of quartz, biotite, muscovite and zircon in poikiloblastic cordierite. The latter shows faint cleavage traces.
Specimen 51.D.127. Plane polarized light. X50.





Marble and Lime-silicate Rocks

Occurrence: Carbonate and lime-silicate rocks of Pre-Attwood age crop out in limited areas of the southeast part of the mapped region.

Stratigraphically these rocks underlie the tan quartzite described on page 65. They are associated with biotite schists, graphite schists and granitized or partially granitized micaschists. The marble occurs as lenses which range from ten to fifty feet in thickness and one to five-hundred feet in length. Included within the marble are four to twelve inch thick lime-silicate bands which have been pinched off into aligned boudinage-like segments (see figure 3). Other lime-silicates occur as transitional bands between marble and biotite schists or as thin, discontinuous layers alternating with micaschists, impure quartzites, granulites and granitized rocks.

Granular rocks with varying amounts of quartz, feldspar, diopside and graphite are well exposed in cuts and outcrops on the west side on the Tonata Creek road about seven miles southwest of Toroda townsite. Stratigraphically these granulites underlie the tan quartzite and marble and are associated with micaschists and impure quartzite, and with other lime-silicate rocks. The maximum observed thickness of the various granulitic rocks of similar character are not observed at the same horizon in other localities.

Mineralogic variations include a graphite-rich granulite at one extreme and a diopside-feldspar rock with sparse graphite at the other extreme as well as intermediate types. Table 3, page 53, shows the approximate modes of the Pre-Attwood lime-silicate rocks.

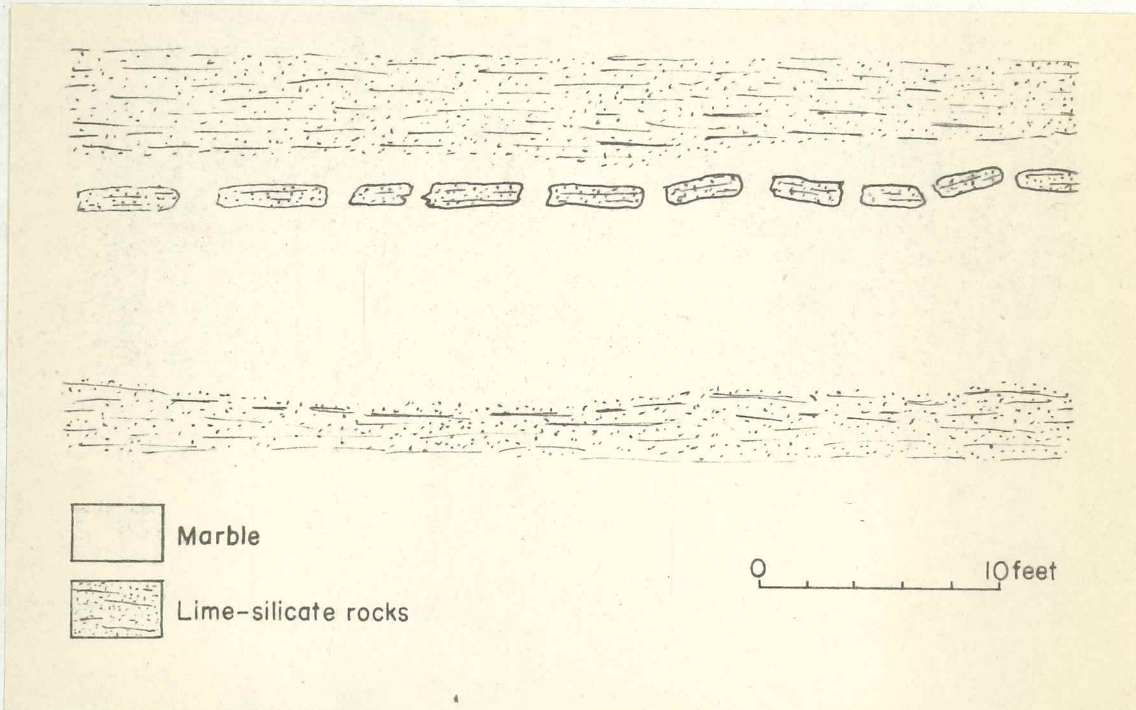


Fig. 3. Boudinage structures in marble exposed near Louis Creek.

Marble: In hand specimen the marble is normally finely crystalline and varies from white to blue-gray in color. Banding or linear structure in specimen or outcrop is absent except in transitional zones between the marble and adjacent rocks. The chalky-white appearance in weathered outcrop and violent effervescence in dilute hydrochloric suggest a low magnesium content.

Under the microscope the carbonate grains average one millimeter in greatest dimension. The inter-penetration of anhedral grains results in a mosaic texture. Lamellar twinning of calcite is common. Rare grains of apatite and laths of muscovite were noted in several sections, and others contain scattered grains of diopside.

Lime-silicate marble: Rocks of this type are well exposed in cuts on the government road to Radar Mountain. Other outcrops are found on the Tonata Creek road which skirts the east slope of Radar Mountain. No exposures of this impure marble were noted at a corresponding horizon on the north side of the Kettle River valley.

A concentration of mica and other relatively insoluble minerals together with a pitted appearance and brown color make the rock distinctive in a weathered outcrop. Fresh exposures, such as those in road cuts, clearly display the banded nature. The attitude of this banding corresponds to the local dip and strike of associated micaschists and quartzite.

The banding of the granulitic rock is marked by thin layers of dark mica and diopside. Calcite, in grains 2 to 3 mm across, usually constitutes eighty to ninety percent of the rock.

Other minerals determined under the microscope include spinel, chondrodite, muscovite, calcic plagioclase and apatite. Spinel is emerald-green in color and occurs very sparsely as rounded grains .5 to 1 mm in diameter. Anhedral grains of chondrodite comprise up to 2% of the area in some thin-sections. The mineral shows strong pleochroism from nearly colorless to a bright yellow. Muscovite appears as scattered flakes lying between carbonate grains. The dark mica which marks the banding in the marble appears to be phlogopite. The plagioclase, An_{70}, is very sparsely distributed throughout the rock. Other constituents include rare grains of zircon, sphene and apatite.

Gneissose lime-silicate granulites: Granulitic rocks of gneissose appearance are observed in transitional zones between marble and micaschists or as thin intercalations within impure quartzites or micaschists. The thickness in either occurrence seldom exceeds one foot and commonly is but 1 to 6 inches. Outcrops displaying these granulites occur on both sides of the Kettle River approximately 1.5 miles southeast of the townsite of Toroda. They are also found in cuts along the Radar Mountain government road about one-half mile west of its intersection with the Tonata Creek road. Gneissose lime-silicate rocks to be described in the following paragraphs include (a) hornblende-diopside granulites, (b) diopside-wollastonite granulites, and (c) diopside-scapolite granulites.

(a) Granulites with hornblende (9.14.50.7 and 8) are restricted to the previously mentioned transitional zone between schist and marble. The gneissose structure is marked by the hornblende. The concentration of hornblende is probably related to the composition of the sediments. In addition to the amphibole, quartz and diopside may be identified in hand-specimen. Associated minerals noted in the thin-sections include small amounts of calcic labrodorite (about An_{70}) and sparse apatite, sphene, magnetite and zircon. The amounts of hornblende and diopside vary with the proximity of the specimen to the adjacent rocks. Hornblende is more abundant near the micaschists and gives way to diopside with the increase of calcium and decrease in alumina as the pure marble is approached.

(b) Granulites with wollastonite and diopside are intercalated with impure quartzites or with micaschists. In hand specimen the gneissose appearance is due to alternation of light green diopside and epidote with wollastonite. Minerals present in addition to the foregoing include quartz, calcite, zoisite, garnet and an occasional grain of sphene and apatite. Unlike in the hornblende-diopside granulite described above, there is conclusive evidence of retrogressive metamorphism visible in thin-sections of this rock. Calcite is pseudomorphous after wollastonite and epidote appears to have formed from diopside. Quartz apparently is later than epidote and was probably introduced. The relationship of zoisite to the original mineral assemblage is uncertain. The mineral occurs as isolated grains in quartz and also intergrown with epidote. Zoisite may have formed at the expense of calcic plagioclase although, as indicated above, there is no thin-section evidence suggesting such an origin. Garnet, diopside, wollastonite and possibly calcic plagioclase formed the original mineral assemblage and indicate metamorphism under high grade or katazonal conditions. Epidote, zoisite, and calcite are considered retrogressive and indicative of later metamorphism under medium grade temperature.

(c) Scapolite-diopside granulites occur as lenses and thin pods associated with the hornblende-diopside rocks described above (a). Scapolite granulites with very sparse diopside are also found intercalated with impure quartzites at the mouth of Louie Creek, a minor tributary which flows south into the Kettle River about two miles downstream from Toroda townsite. In this locality the total thickness of the scapolite layers is around ten feet. In other localities the thickness seldom exceeds a few inches.

In hand specimen these rocks have a banded appearance due to the variation in amounts of diopside, scapolite and light colored minerals. The scapolite is gray and the diopside varies from light to dark green in color. Texture is granular and the average grain size is 1 mm.

Additional minerals visible in thin-section include quartz, plagioclase, sparse epidote and scattered subhedral grains of apatite, sphene and zircon. The plagioclase is calcic labradorite and is largely restricted to bands containing small amounts of diopside, sphene and rare scapolite.

Epidote occurs in transitional zones between the plagioclase and adjacent diopside and scapolite-rich bands. Interference colors of the upper second-order indicate the calcium content of the scapolite is high. As in the other granulites, the texture is granoblastic.

The appearance of scapolite suggests metamorphism at a lower temperature than that effecting the wollastonite-diopside bands (b). However, scapolite may have formed in place of calcic plagioclase and thus be a stable constituent of the high grade zone (katazone) of metamorphism. Wollastonite in the lime-silicate rocks (b) and sillimanite in adjacent micaschists attest to the degree of metamorphism in this portion of the Pre-Attwood series.

Diopside-bearing quartz-graphite granulite: The graphitic rocks are grey to black in color and thus contrast strongly with the overlying light colored marble. Thin quartz-rich layers alternating with dark layers give a pronounced banded appearance. The attitude of the banding parallels the strike and dip of associated metamorphics. Small-scale folds or swirls are noted in some outcrops. Hand specimens have a slabby appearance and there is a definite tendency toward splitting along the graphite-rich layers.

Texture in thin-section is granoblastic with average maximum grain of the quartz about .5 mm. Quartz anhedra in the light colored bands are much larger with average greatest dimension around 3 mm. Graphite flakes seldom exceed .2 mm and are generally approximately .1 mm long. In sections normal to the schistosity, the randomly oriented graphite particles are concentrated into bands or layers which parallel the foliation. Sections cut parallel to the schistosity and within a graphite-rich band display no lineation of either light or dark constituents. Small amounts (1 to 5%) of diopside are present. Inclusions in the poikiloblastic mineral are graphite and sparse quartz, apatite or sphene. Grain size averages .15 mm and reaches a maximum of 3 mm.

A variety of the quartz-graphite granulite described above is represented by specimen number 51.D.60. In this rock pale green diopside in grains up to 10 mm in length occurs in distinct bands. The thickness of the bands ranges from a few millimeters to ten centimeters. Under the microscope the diopside appears as porphyroblasts with abundant inclusions of quartz and graphite.

Diopside-feldspar granulite: Outcrops of this granulite are weathered to a yellow-brown color and thus contrast with the gray color of associated quartz-graphite rocks. Hand specimens are crudely tabular although the all-over appearance of a fresh surface is that of a granular-textured rock. In a cut slab or thin section, however, the distinct banding produced by diopside alternating with feldspar and quartz is apparent.

Examination of thin-sections indicates that nearly equal amounts of diopside and quartz comprise eighty to ninety percent of the minerals present. Orthoclase, calcic andesine, labradorite and biotite, named in order of abundance, are the remaining major constituents. Some specimens contain andesine or labradorite in the diopside-rich bands, and, in others, the pyroxene is associated with and replacing biotite.

Diopside occurs in anhedral grains ranging in size from .1 to 2 mm. Skeletal forms and grains in optical continuity are common. Inclusions in these poikiloblasts are quartz, feldspar, sphene and, in some sections, biotite. The biotite is strongly pleochroic with the range from nearly colorless to a reddish-brown. This mineral may form as much as five percent of some sections and where present occurs in transitional zones between diopside-plagioclase bands and quartz-potash feldspar bands. The foregoing relationship suggests that the original sediment may have been a shale with alternate thin beds of marl and quartz-rich argillaceous material.

Minor constituents are sphene, garnet, apatite, zircon, and graphite. The latter is common as inclusions in all major minerals and is especially abundant in the biotite rich areas.

<u>Summary</u>: With respect to the metamorphic grade, it appears that the association diopside-calcic plagioclase may be considered high grade. Micaschists and lime-silicate

rocks from the same general area contain sillimanite, and wollastonite, spinel and chondrodite respectively, and thus confirm that the above granulites are products of high grade metamorphism.

TABLE 3

APPROXIMATE MODES OF PRE-ATTWOOD LIME-SI

	Lime-silicate marble		Diopside-hornblende granulite		Diops
SPECIMEN*	90	90A	9.14.7	9.14.8	9.7.1
MINERALS					
calcite	90	90	--	--	10
diopside	3	5	20	20	30
hornblende	t	--	40	15	--
wollastonite	--	--	--	--	t
quartz	--	--	20	30	10
scapolite	--	--	--	--	--
plagioclase	1	1	15	35	--
orthoclase	--	--	--	--	--
phlogopite	2	2	--	--	--
muscovite	--	--	--	--	--
chondrodite	--	1	--	--	--
spinel	--	t	--	--	--
garnet	t	t	--	--	5
epidote	--	--	--	--	30
zoisite	--	--	--	--	5
chlorite	t	t	--	--	--
sphene	t	--	1	t	t
apatite	t	t	t	t	t
zircon	t	--	t	t	--
allanite	--	--	--	--	--

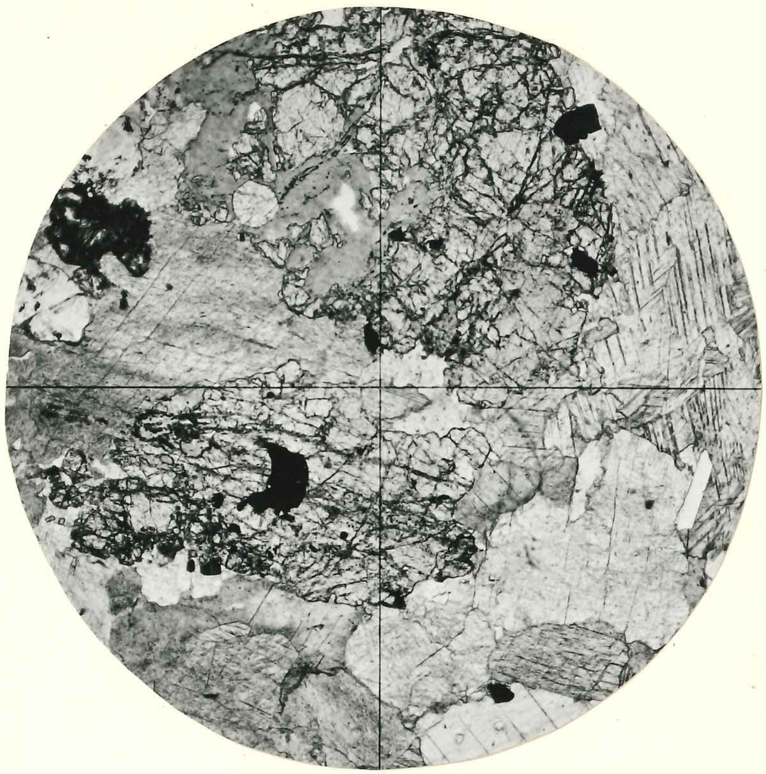
*Specimen numbers as 90 are preceded by 51.D. Numbers as 9.7.1 shoul

TABLE 3

APPROXIMATE MODES OF PRE-ATTWOOD LIME-SILICATE ROCKS

	Lime-silicate marble		Diopside-hornblende granulite		Diopside-wollastonite granulite				Diopside-scapolite granulite	
SPECIMEN*	90	90A	9.14.7	9.14.8	9.7.1	9.7.1A	9.14.9	81E	9.14.6	51.D.165
MINERALS										
calcite	90	90	--	--	10	15	30	10	--	t
diopside	3	5	20	20	30	35	10	40	45	10
hornblende	t	--	40	15	--	--	--	--	--	--
wollastonite	--	--	--	--	t	30	10	40	--	--
quartz	--	--	20	30	10	10	5	--	1	5
scapolite	--	--	--	--	--	--	t	--	40	75
plagioclase	1	1	15	35	--	--	2	t	10	1
orthoclase	--	--	--	--	--	--	--	--	--	5
phlogopite	2	2	--	--	--	--	--	--	--	--
muscovite	--	--	--	--	--	--	--	--	--	--
chondrodite	--	1	--	--	--	--	--	--	--	--
spinel	--	t	--	--	--	--	--	--	--	--
garnet	t	t	--	--	5	t	35	5	--	--
epidote	--	--	--	--	30	--	t	t	t	--
zoisite	--	--	--	--	5	5	t	--	--	--
chlorite	t	t	--	--	--	--	--	--	--	--
sphene	t	--	1	t	t	t	t	t	t	t
apatite	t	t	t	t	t	--	--	t	t	--
zircon	t	--	t	t	--	t	t	--	--	--
allanite	--	--	--	--	--	--	--	--	t	--

*Specimen numbers as 90 are preceeded by 51.D. Numbers as 9.7.1 should be read as 9.7.50.1



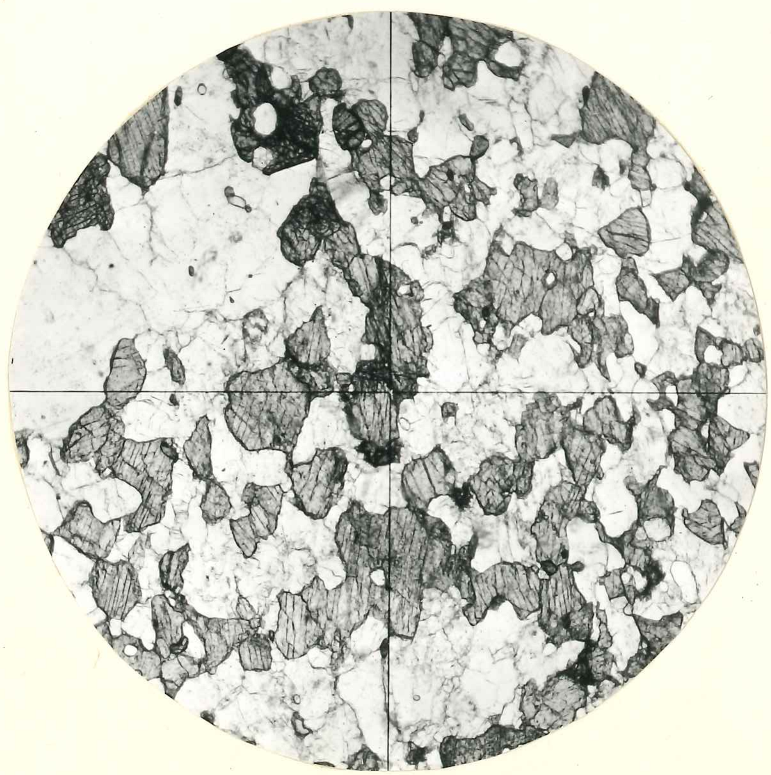


PLATE VIII

A. Quartz-graphite granulite from upper Tonata Creek. 95% of opaque particles are graphite.
Specimen D.2.6A.49.1A. Plane polarized light. X16.

B. Diopside-bearing quartz-graphite granulite from upper Tonata Creek.
Specimen 51.D.60A. Plane polarized light. X16.

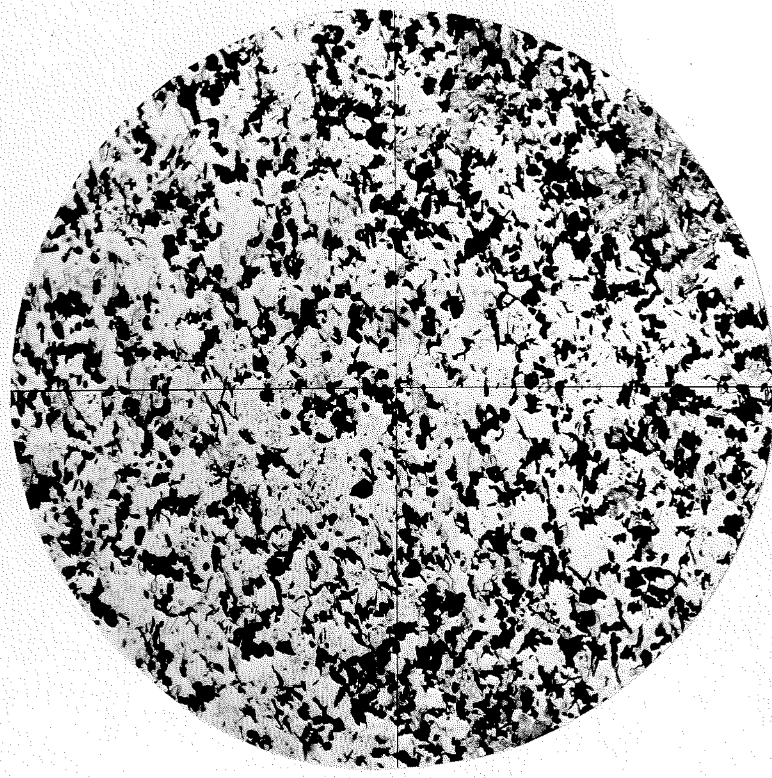
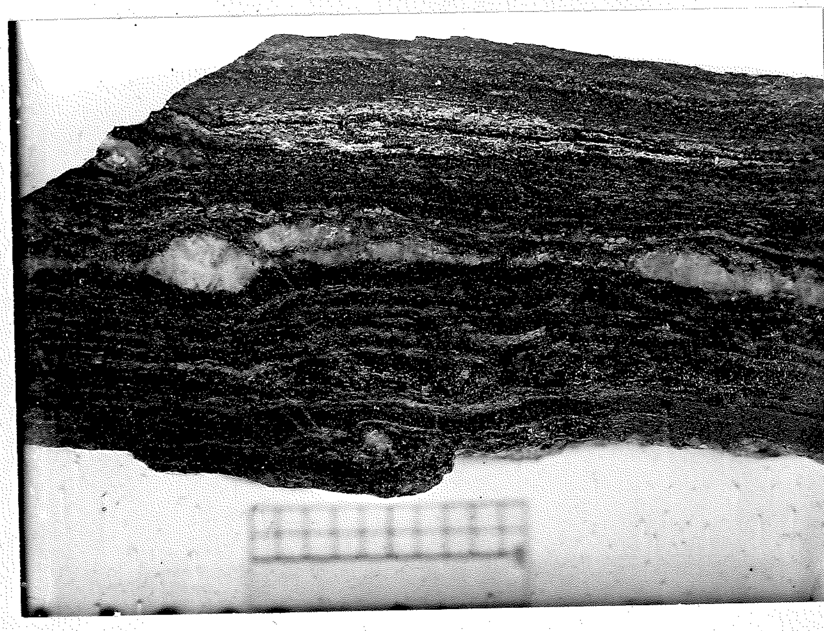


PLATE IX

A. Foliated quartz-graphite granulite from upper Tonata Creek. Light-colored pods are quartz.
Specimen 51.D.62A.

B. Biotite-rich portion of diopside-feldspar granulite from upper Tonata Creek. In northeast quadrant of field, diopside replaces biotite.
Specimen 51.D.62C. Plane polarized light. X50.



Quartzites

Occurrence: The slightly schistose quartzites crop out in prominent cliffs on both sides of the Kettle River, a half mile to a mile south and southeast of the Toroda townsite. Excellent exposures are also found on the easterly slope of Radar Mountain and vicinity. Radar Mountain is located on the northwest side of Tonata Creek in about the geographic center of the area.

The thickness of the main body of quartzite varies within the area but averages two hundred feet. Some outcrops include thin, intercaluated, garnet-bearing biotite schists or an occasional band of lime-silicate rock. Other exposures display conformable feldspathic layers which vary in thickness from a few inches to five feet. The passage into overlying amphibolites is usually rather sharp although 10 to 20 inch beds of quartzite are sometimes included in the lower portion of the amphibolite. In contrast, the lower limit of the principal quartzite unit is poorly defined. For several hundred feet the underlying biotite schists, marble, lime-silicates and migmatites are intercalated with quartzite layers which range from a foot to twenty feet in thickness.

In the field the quartzite almost always forms excellent outcrops despite the numerous joints and the faint tendency to part parallel to the weakly marked schistosity (and bedding) planes. The rock commonly weathers to or is stained a limonitic brown or orange-brown color.

Description: Freshly broken specimens of quartzite are white, light tan, or faintly pink in color. A sugary-grained appearance suggests well-defined grains. Examination with the hand lens fails to disclose any trace of former clastic textures. Some specimens contain very small amounts of brown or white mica. Scattered grains of magnetite were present in all rocks examined, and pyrite was occasionally observed. The rock breaks with a subconchoidal to irregular fracture and shows a slight tendency to split into parallel slabs. Weathered specimens often display a faint planar structure, but this structure is barely recognizable in the case of freshly broken rocks except where more than the usual amount of mica is present.

In thin section the texture of the quartzites is crystalloblastic with the quartz grain boundaries intricately sutured and interlocking. There is a definite elongation and parallelism of the grains. Occasionally quartz-filled fractures transect the schistosity. Minerals present in addition to the quartz include very minor quantities of mica, rutile, zircon, magnetite and hematite. The xenoblastic quartz distinctly shows undulous extinction under crossed nicols. An individual elongated grain often presents a banded appearance due to the variation in extinction. These bands are parallel to the schistosity of the rock and this fact suggests that deformation outlasted crystallization in the first phase of regional metamorphism. An alternative view point would relate it to a later period of deformation (see section on metamorphic history, page 88). There is distinct preferred orientation of the quartz since in a given field at least one half of the grains are at or near extinction position. A very small amount of well-formed muscovite and rare biotite is found in the usual clean quartzite. Rocks in transitional zones between quartzite and biotite schist show a gradual increase in biotite content. The rutile present is dark yellow-brown in color and commonly euhedral. The rare zircons occur as well-formed prisms with simple (111) pyramidal terminations. Magnetite in rectangular shapes is often partially altered to hematite.

Paragneisses

Introduction: Isochemically metamorphosed rocks which may be calssified as paragneisses are of limited occurrence in the district since most of the gneissic rocks have large amounts of feldspar and sparse biotite and are considered to be migmatitic. Characteristic paragneiss specimens were, however, obtained from outcrops on the east and southeast slopes of Bamber Mountain. Associated rocks include mica-schists, quartzites, and an occasional lime silicate band.

Description: The usual paragneiss is a compact, medium-grained rock with a tendency to split into slabs which are roughly parallel to the foliation. In some specimens nearly equal amounts of biotite and feldspar have been segregated in such a manner that an all-over gray, yet banded, appearance has resulted. In other specimens the banding is produced by the biotite alone since the feldspars, which average one millimeter in diameter, are evenly distributed throughout the rock. Fractures which cross the schistosity are re-cemented and may be marked by iron-oxide stains or bleached feldspar. Weathered surfaces are brown to buff in color.

In thin section the texture is crystalloblastic. Feld-spar grains normally do not exceed two millimeters in greatest dimensions and average perhaps one millimeter. In some specimens (D.9.14.50.15) the feldspar grains show some tendency toward elongation parallel to the schistosity in the manner of augen. In other sections the grains are rounded and appear to have grown without pronounced directional control. From thirty-five to forty percent of the average paragneiss consists of calcic oligoclase. Quartz, biotite, hornblende, zircon, sphene and apatite may occur as inclusions in the plagioclase. Potash feldspar occurs in irregular aggregates occupying intergranular or intersititial positions. The amount present is perhaps ten percent though it is difficult to ascertain even in sections treated with sodium cobaltinitrite.

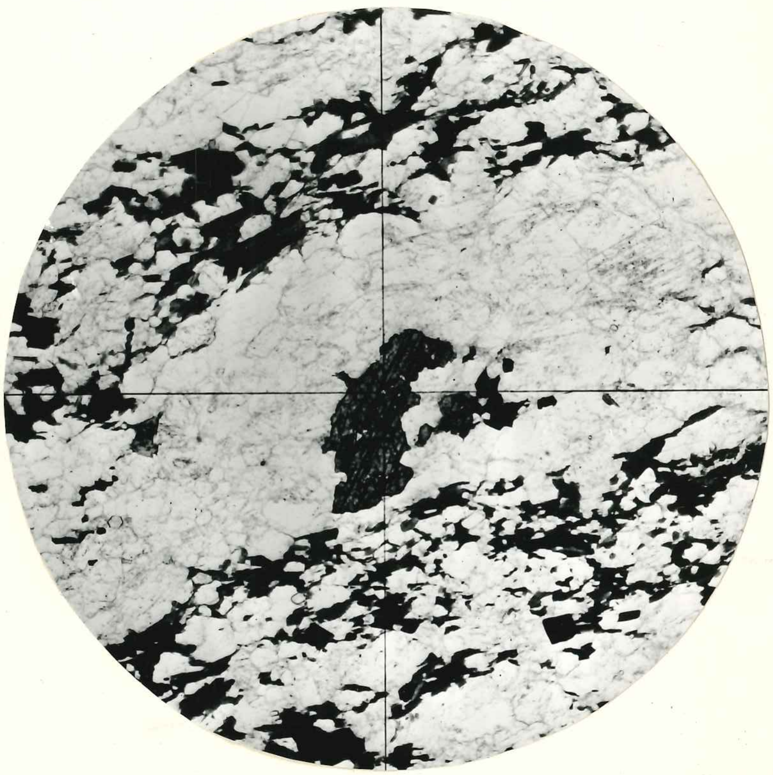
The percentage of quartz varies from ten to thirty-five. It occurs in elongated or rounded grains included in or lying between feldspars. Undulatory extinction is common in the larger intersititial grains but, as might be expected, is absent in the quartz occurring as inclusions in plagioclase.

Mafic minerals include biotite and hornblende. The occurrence of green hornblende together with rather abundant calcic oligoclase suggests that the paragneisses were derived from argillites fairly rich in calcium. The amphibole is intergrown with and may be partially replaced by biotite. The mica is deformed and bent around the plagioclase porphyroblasts indicating that deformation and some crystallization continued after the optimum of biotite growth. In the micaschists (see above0 this late synkinematic phase was marked by production of fibrolite. Failure of fibrolite development in the paragneisses is perhaps a result of insufficient aluminum, more economical use of aluminum in fedlspar, or of low temperature.

Minor constituents include the usual euhedral prisms of apatite as well as sparse zircon, magnetite and sphene. The sphene is anhedral, often shows good cleavage and may have inclusions of euhedral zircon. In section 51.D.39 the sphene is definitely confined to certain layers or zones parallel to the foliation. This relationship suggests compositional differences in the original sediments or some type of small-scale metamorphic differentiation.

Chlorite has formed from biotite and hornblende. Minor amounts of sericite occur along plagioclase cleavage planes and grain margins. Minute fractures crossing the foliation of the paragneisses are filled with chalcedonic quartz and with sparse epidote derived from hornblende. In a one to two millimeter-wide zone parallel to these late fractures the feldspar is clouded with kaolinitic material.

Summary: The mineral assemblages of the paragneiss group are not distinctive as far as determination of metamorphic grade is concerned. More reliable is the association of these rocks with the micaschists of known metamorphic history (see page 41). The interstitial position of orthoclase and partial biotitization (?) of hornblende are two features which suggest the introduction of minor amounts of potash-bearing solutions. Evidence is this respect is not clear enough to warrant inclusion of these rocks among those displaying rather conclusive evidence of potash-metasomatism.



Amphibolites

Introduction: Approximately ten square miles of amphibolite and amphibolite-derived rocks crop out within the northwest, north and northeast limits of the Pre-Attwood terrane.

Amphibolites overlie and are sometimes separated from the tan quartzite (see page 64) by a succession of micaschists, migmatites, and thin beds of quartzite. The thickness of these intervening units varies from around one-hundred feet on the east side of the Kettle River to nearly twice that amount on the west side of the river. Occasional layers of clean, schistose quartzite up to two feet in thickness are intercalated within the lower twenty feet of the amphibolite. The best-defined body of amphibolite is approximately 300 feet thick. It is overlain by seventy to ninety feet of a schistose quartzo-feldspathic rock whick is in turn succeeded by a second series of amphibolites the thickness of which was not determined. Overlying the second amphibolite is the cordierite-bearing biotite schist described on page 37. The upper portion of the first amphibolite and parts of the second show varying degrees of feldspathization and will thus be discussed in another section of this paper.

Difference in appearance, field relations, and mineralogy indicate that the amphibolites may be divided into two groups.

Group (I) consists of diopside-bearing amphibolites with intercalated thin beds of tan quartzite. These rocks are para-amphibolites which may have been derived from a sandy-argillaceous dolomite. The presence of diopside suggests metamorphism under conditions of the warmer medium-grade or high grade zone. Amphibolites of group (II) contain abundant augen and streaks of feldspar. Some specimens are distinctly gneissic in appearance. Diopside is not present. Certain microscopic features suggest that some of these rocks were derived from either crystal tuffs or porphyritic flows of intermediate composition.

Table 4, page 79, shows the approximate modes of the two groups.

Description of the diopside-bearing amphibolites (Group I): In hand specimen the usual rock is fine-grained, dark green in color, and distinctly schistose in structure. Locally, light green streaks of diopside and pods of quartz vary the appearance. In the narrow contact zone surrounding a granodiorite mass the amphibolite is somewhat hornfelsic, lighter green in color, and is cut by thin (1 to 2 mm) epidote-filled fractures. Light green layers in the rocks from this zone are usually epidote rather than diopside. Some specimens from the contact area also show pytgmatic bands of feldspar which may be related to the granodiorite. Other specimens, from both the east and west sides of the Kettle River, include conformable one-half to two inch bands of quartz, garnet and feldspar. In these bands there are scattered blades of hornblende and streaks of garnet which are usually aligned with the distinct schistosity of the specimen. Epidote is not present in rocks showing this second type of feldspathic banding.

Weathered specimens usually are rusty-brown to black although, as the granodiorite contact is approached, a brown to light green color is common.

In thin-section hornblende is present in amounts ranging from thirty-five to sixty-five percent. Individual grains are xenoblastic and often include apatite, plagioclase or magnetite. In sections cut normal to the schistosity (s) the hornblende seldom diverges from a position of near-parallelism with the foliation. Sections cut parallel to the schistosity indicate that on a microscopic scale, at least, lineation is not prominent. The arrangement of the hornblende prisms in such sections is extremely irregular. The mineral is pleochroic from pale yellow or green to a greenish-blue. Under crossed nicols the bright colors of the lower second order as usual. The common alteration product of the hornblende is chlorite. Specimen D.2.13.49.1 from the contact zone of a granodiorite mass shows at least fifty percent chlorite, and many other sections not affected by contact action show at least traces of chlorite after hornblende. Other alteration products include calcite and epidote.

Plagioclase is present in amounts ranging from thirty to forty-five percent of the rock. Composition of the feldspar varies from calcic oligoclase to calcic andesine, the latter being more common. The feldspar commonly forms a mosaic of nearly equidimensional grains distributed among the hornblende laths. Average grain size of the andesine is approximately .2 mm in most of the amphibolites. The less common oligoclase is usually untwinned and often occurs in grains up to 1 mm in greatest dimension. Epidote and sericite are found as alteration products of feldspar, especially in areas adjacent to the granodiorite mentioned above.

Diopside is restricted to the lower portion of this amphibolite and usually constitutes from 3 to 5 percent of the rock. An exception is found in specimen 51.D.1580 where the mineral represents 32% of the total. The diopside is very pale green in plane light although this color is often obscured by a gray colored turbidity which appears to be an incipient stage of alteration. It occurs as anhedral grains ranging up 1.6 mm in diameter. Together with the associated plagioclase, sphene and sparse quartz, it forms distinct bands or pods. Diopside and hornblende are found together when these bands are very thin (1 to 2 mm). The two minerals also occur in transitional zones between diopside and hornblende-rich bands. Sphene is the most common inclusion in the diopside although sparse granules of quartz and plagioclase were noted.

The average amphibolite of this group contains very little quartz. Amounts up to approximately five percent are found in sections of amphibolite collected from areas with intercalated quartzites (cf. above). Diopside-bearing amphibolites from the west side of the Kettle River display an occasional one to two inch pod of quartz which, together with that occurring as grains scattered throughout the rock, may constitute five percent of the whole.

Minor constituents include sphene, allanite, apatite, zircon, magnetite and pyrite.

<u>Description of amphibolites (Group II)</u>: The rocks of this group are described separately on the basis of mineralogy rather than occurrence as well defined and separable stratigraphic units. Several lenses or pods, which may be followed for several hundred feet along the strike, are included in the schistose leucocratic rock mentioned earlier and thus may be exceptions to the above statement.

Group (II) amphibolites are schistose to gneissose in appearance. Feldspar occurs in thin streaks or as rounded and drawn-out augen. Hornblende is generally unaltered and very dark green colored in a fresh specimen. The feldspars in weathered outcrops are chalky in appearance and conspicuous against the rusty-brown color of the amphibole.

In the thin-sections examined, hornblende constitutes forty to sixty-five percent of the rock. It occurs as well-defined anhedral blades up to 3 mm long. Average size is perhaps .5 mm. The distinct pliochroism shows a range from greenish-yellow to bluish-green colors. Inclusions in the occasional poikiloblastic hornblendes are commonly feldspar, opaques or rare quartz. Pennine, epidote and perhaps the small granular masses of carbonate are alteration products of the hornblende.

Plagioclase appears in thin, short streaks and as augen-like aggregates which may reach 10 mm in length but average one half of that amount. The plagioclase of the streaks and that which is of random occurrence among the amphibole grains is calcic andesine. The augen-like feldspar is calcic oligoclase. Some of these ellipsoidal masses vary in structure from a singly twinned or untwinned porphyroblast to an aggregate of sutured grains of varied orientation. Others have the appearance of fractured phenocrysts surrounded by bands of granulated feldspar. The oligoclase is usually somewhat turbid and full of hornblende, an opaque mineral, and occasional quartz inclusions.

Minor constituents present are sphene, apatite, zircon, and magnetite. Some carbonate occurs as a filling in late fractures. Several fractures in one sample were filled with pennine and an occasional "second generation" grain of sphene.

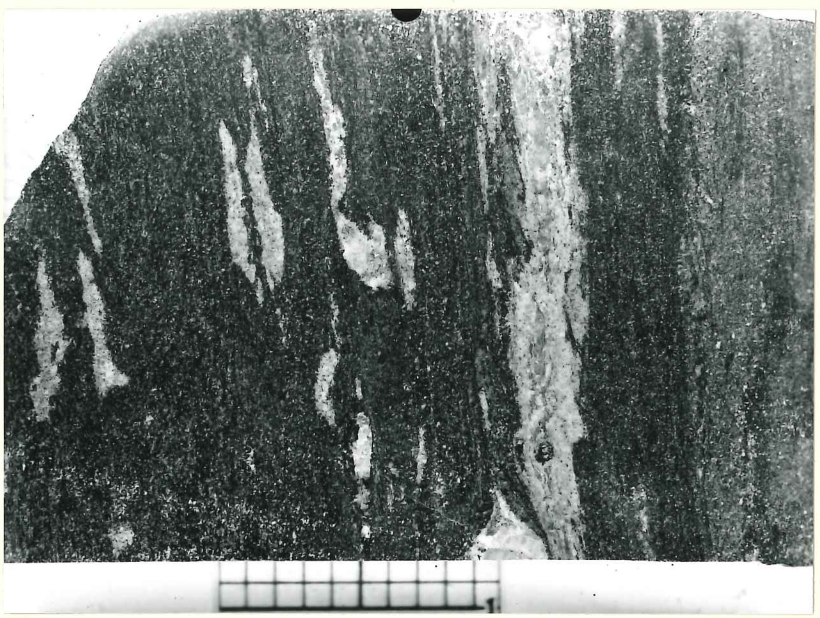
SPECIMEN*	15
MINERALS	
hornblende	5
diopside	
quartz	
plagioclase	4
orthoclase	
epidote	-
sphene	
apatite	
zircon	
opaques	
carbonate	-
chlorite	
sericite	-
allanite	-
	4

TABLE 4

APPROXIMATE MODES OF PRE-ATTWOOD AMPHIBOLITES

	Diopside-bearing Amphibolites (GROUP I)										Amphibolites (GROUP II)							
SPECIMEN*	158A	158B	158C	9.5.1A	2.10.2	2.10.1	9.5.3	9.5.6	22	2.10.4	19B	128	9.15.2	9.16.1B	144	9.8.4	106	105
MINERALS																		
hornblende	50	55	35	60	45	5	45	65	60	55	50	65	55	50	65	70	48	40
diopside	3	4	32	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
quartz	1	t	2	5	t	2	5	--	t	--	--	--	t	1	t	--	--	--
plagioclase	45	40	30	30	50	45	45	35	40	30	50	33	40	44	33	30	50	60
orthoclase	t	t	t	t	t	t	t	t	--	--	t	t	t	t	t	t	--	--
epidote	--	--	--	--	2	1	1	--	t	5	--	t	--	1	t	t	--	t
sphene	1	1	t	t	t	--	--	t	t	t	--	1	1	t	1	t	1	t
apatite	t	t	t	t	t	t	t	t	--	t	t	t	t	--	t	--	t	--
zircon	t	t	t	t	--	t	--	t	--	--	--	t	t	t	--	--	--	t
opaques	t	t	t	t	t	t	1	1	t	t	t	t	t	t	t	t	t	--
carbonate	--	--	--	t	t	t	--	--	--	t	--	--	--	1	--	--	t	t
chlorite	t	t	t	t	t	45	2	t	t	5	--	t	--	1	--	t	t	--
sericite	--	--	--	t	--	--	t	t	--	--	--	t	--	1	--	--	--	--
allanite	--	--	--	--	--	--	--	--	--	t	--	--	--	--	--	--	--	--

*Specimen numbers such as 158A are preceeded by 51.D. Specimens such as 2.10.1 should read 2.10.49.1. Specimen numbers such as 9.5.6 should read 9.5.50.6



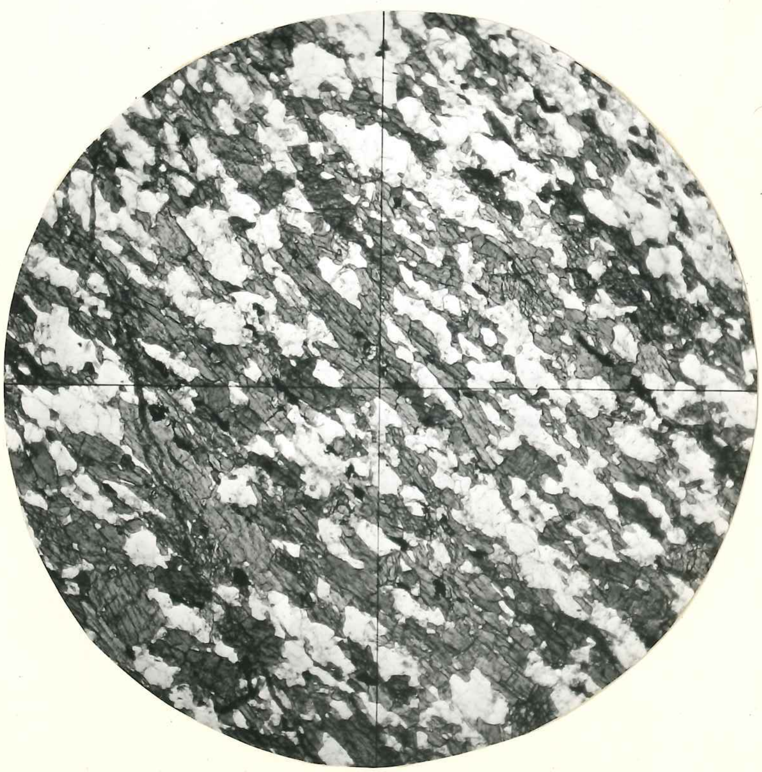
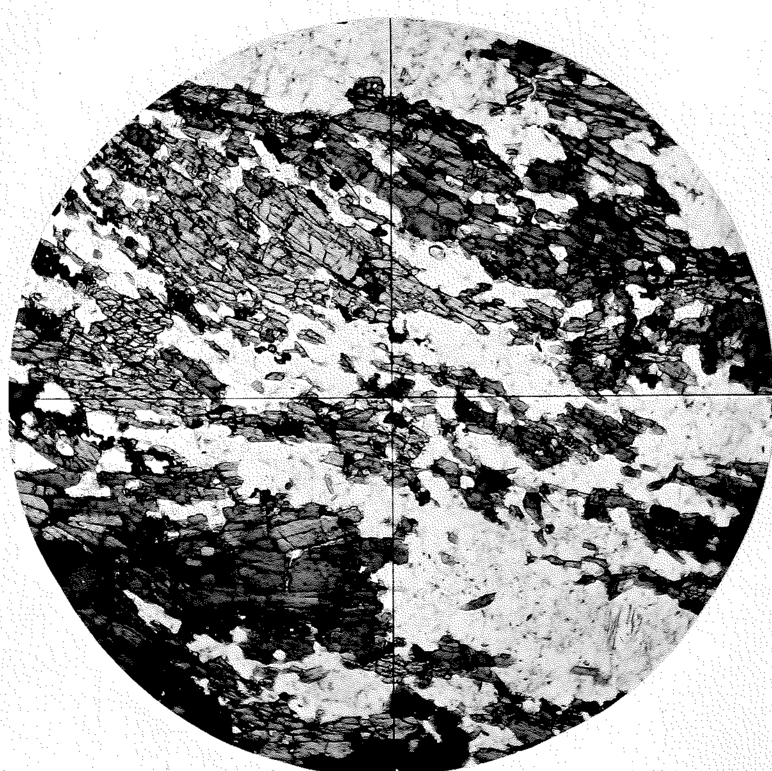


PLATE XII

Photomicrograph of average Group II amphibolite.
Specimen 51.D.128. Plane polarized light. X16.



Feldspathic Quartzites

Occurrence: Feldspathic quartzites crop out as prominent knobs and cliffs on the west wall of the Kettle River canyon for a distance of two miles north of its confluence with Toroda Creek. The maximum thickness was estimated at 150 feet. The underlying rocks are the migmatitic upper portions of the diopside-bearing amphibolite (group I). A second amphilbolite (group II) conformably overlies the feldspathic quartzites. The samp impure quartzites crop out in a similar stratigraphic position on the east side of the Kettle River.

Description: In outcrops the rock is light-colored and thus distinctly contrasts with the adjacent amphibolites. A definite schistose structure is marked in part by discontinuous, thread-like grayish-green bands. In addition, dark green hornfelsic textured material forms on to four inch thick bands which seldom are continuous for more than a few hundred feet along the outcrop. Joints crossing the schistosity are abundant. In a few areas dark gray and black veinlets 2 to 5 mm wide crosscut and parallel the schistosity.

In hand-specimen the average rock is medium-grained and is light greenish-gray in color. An occasional pod or lense of aphanitic textured material has the appearance of a slightly schistose hornfels. The surface of a sawed specimen when treated with hydrofluoric acid shows that feldspar constitutes at least 40% of the rock. The remaining major mineral is quartz. Several specimens were stained with sodium-cobaltinitrite and the results indicate that no potash feldspar is present. Quartz and plagioclase occur in elongated, sutured grains mutually intergrown. There is no notable tendency toward segregation into bands composed dominantly of one or the other.

The dark-green hornfelsic appearing bands display no traces of foliation in hand specimen. Except for the color, the rock has the aphanitic appearance and subconchoidal fracture of a dense basalt.

In thin section an all-over crystalloblastic texture is common to these rocks. In detail, the texture of the dominant rock type is a sutured mosaic and, the occasional finer grained, leucocratic areas, as well as the dark-green bands, are granoblastic.

The plagioclase is sodic oligoclase. It is usually untwinned and partially altered to sericite. Some thin sections show the mineral altered or replaced by granular, sparse carbonate in addition to the sericite. Quartz-rich zones consist of sutured intergrowths of variously oriented individuals. Undulatory extinction is common. Some grains show parallel lines of vacuole inclusions.

Scattered wisps of chlorite and rare flakes of partially chloritized biotite are responsible for the light-green tint of the hand specimen. There is no relict hornblende present, and it appears likely that the chlorite has all formed from biotite.

Hornblende appears to have been the major constituent of the occasional dark green bands. Rare anhedral grains of the mineral are seen, but for the most part it has altered to chlorite and carbonate. The numerous fine opaque grains may be secondary magnetite. Epidote and plagioclase are minor constituents of the dark bands. The feldspar occurs as rounded equidimensional grains which are clouded with alteration products. The composition was not determined due to the small size and lack of distinct twinning. Epidote is xenoblastic and lies among flakes of chlorite and carbonate.

Minor constituents noted in the main rock type include an occasional grain of epidote in addition to sphene, zircon and apatite. Fractures are often filled with epidote and quartz.

The thin, gray to black stringers crossing and paralleling the traces of schistosity are replacement veinlets of tourmaline and quartz. Evidence for such an origin consists primarily of bridges or septae of the sodic oligoclase which cross the veinlets with no evidence of fracturing. The width of the replacement veins varies from 2 to 5 mm. A crude zonal arrangement is noted. The tourmaline-rich central area is flanked on both sides by quartz with sparse, scattered grains of tourmaline. Subhedral prisms of tourmaline occur but most grains show no development of crystal faces. The mineral is strongly pleochroic from pink (e) to dark olive-green (O). Most grains are zoned. High indices and strong pleochroism indicate that the tourmaline is an iron rich variety. Except in areas where the veinlets parallel the schistosity, there appears to be no fracture or other structural control of the replacement process.

Summary: On the basis of the stratigraphic relations and the composition of the present rock it is presumed that the original rock was a sediment rich in quartz, feldspar and arillaceous material.

The amphibolites (groups I and II) with which the feldspathic quartzites are intercalated, have been metamorphosed under at least warmer medium-grade and possibly under cool high-gradeconditions. The alteration of biotite to chlorite indicates that the impure quartzites have also been subjected to a later period of low-grade metamorphism. A nearly complete alteration of the mica to chlorite, together with sericitization of oligoclase suggests that some areas of these rocks lie within the outer contact aureole of the nearby granodiorite.

Summary of the Isochemically Metamorphosed Rocks

The rock types included in this category and described in the foregoing pages comprise quartzites, micaschists, amphibolites, marble, lime-silicate granulites, quartz-graphite granulites and quartz-feldspar granulites. With the possible exception of certain amphibolites, all of these rocks are former sediments.

Mineral assemblages present in the micaschists and the granulites suggest that the high grade zone of regional metamorphism was attained. The degree of metamorphism is not always clear in the amphibolites. Minerals present in the stratigraphically lower amphibolites (Group I) include diopside and sparse calcic andesine and thus may lie within either the warm medium-grade or the high-grade zone. Since the schists and lime-silicates underlying the diopside-bearing amphibolites contain sillimanite and wollastonite it is highly probable that this group of amphibolites lies within the same isograd. The Group II amphibolites lack diopside and are not closely associated with rocks containing high temperature minerals. Possible medium grade temperatures are suggested.

All of the above rock types show some evidences of retrogressive metamorphism. Chlorite has formed after hornblende and biotite. Diopside is often altered to an unidentified yellow-green or brown mineral. Epidote is secondary after hornblende and calcic plagioclase. Zoisite has replaced and carbonate has formed pseudomorphs after wollastonite. Sillimanite and andalusite may be partially altered to muscovite. It appears that these retrogressive effects may be related to a second period of metamorphism. The Attwood formation which unconformably overlies the Pre-Attwood, has been subjected to synorgenic metamorphism under warmer low-grade conditions. At this time, the underlying older rocks were subjected to the temperatures and, locally, to the mechanical deformation which affected the Attwood formation.

Migmatites

Introduction

The term migmatite is used here to name rocks in which megascopically visible areas of granitic material are distributed throughout a metamorphic host rock. In the Kettle River - Toroda Creek district migmatites are represented by Pre-Attwood gneisses, and two subdivisions of these migmatitic gnesses are recognized. They are characterized by the predominance of biotite and of hornblende, respectively. The following description is based on this distinction.

Biotite-Gneisses

Distribution: Gneisses with varying amounts of biotite crop out on both the north and south slopes of the Kettle River valley east and southeast of Toroda townsite. Good exposures are also located along the course of Tonata Creek, particularly in the Radar Mountain area.

Biotite gneisses occur at irregular intervals throughout approximately two thousand feet of the isochemically metamorphosed sediments which underlie the diopside-bearing amphibolites (group I). The maximum observed thickness of individual gneiss bands in this area is twenty feet; bands ranging from a few inches up to three feet in thickness are numerous intercalations within micaschists, lime-silicates, quartzite and marble. Biotite-bearing migmatites are also found near the base and again near the upper limit of the diopside-bearing amphibolites.

Migmatitic gneisses become increasingly common with stratigraphic depth, and thus the base of the obviously sedimentary portion of the Pre-Attwood complex is poorly defined. The transitional zone between the isochemically metamorphosed sediments and the underlying more or less directionless granitic rocks displays gradations between a banded gneiss and granitic gneiss. Biotite schists adjacent to biotite migmatites often include sparse pods and discontinuous bands of feldspar (cf. figure 4).

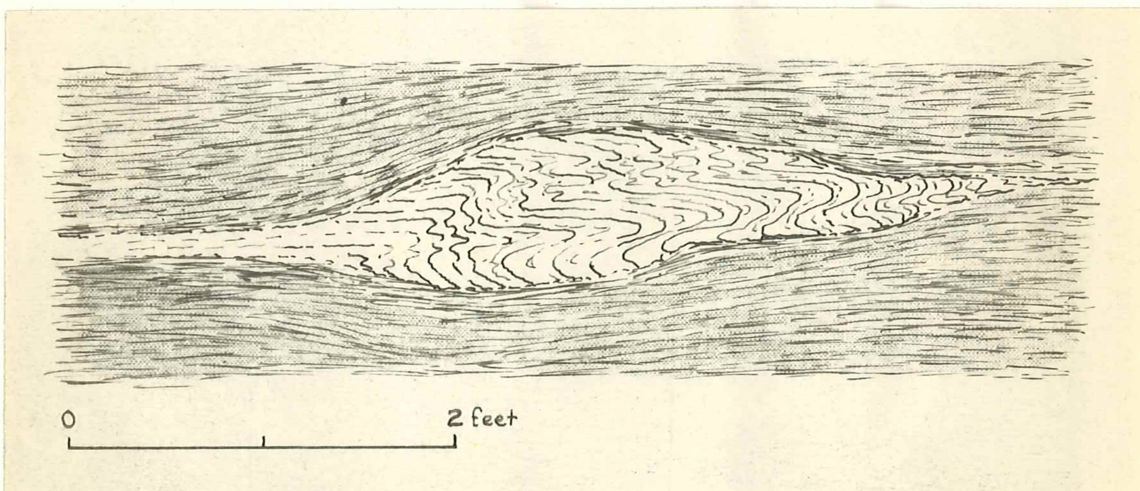


Fig. 4. Feldspathized area in micaschists adjacent to biotite-migmatite zones on the Tonata Creek road. Folding in feldspathic zone suggests some mobilization and disharmonic motion of the migmatite.

<u>Description</u>: In hand specimen the rocks are of varied appearance due to the range in amount and distribution of

quartz, biotite and feldspar. A common type shows an even, sparse distribution of aligned biotite flakes in a feldspar-quartz groundmass. Augen of feldspar up to a centimeter in maximum dimension form bead-like strings which parallel the foliation. Staining with sodium-cobaltinitrite indicates that by far the greatest percentage of the augen are plagioclse and that potash feldspar is largely restricted to an interstitial position although scattered larger porphyroblasts may occur. Intricate folding on a hand specimen scale was noted in several outcrops.

A second common type of migmatite is gray to black in color due to an abundance of biotite. Irregular bands, pods and lenses of coarse feldspar are prominent, and additional fine-grained feldspar and quartz occurs with the biotite. A variation of this type consists of one to two inch bands of dominantly leucocratic minerals alternating with biotite-rich bands of about equal thickness.

Certain migmatites near the base of the diopside-bearing amphibolite consist of feldspar, minor amounts of quartz, and scattered wisps and thin bands of biotite which mark the foliation. Porphyroblasts are 1.5 to 2 cm in size. Stained specimens indicate that they are plagioclase. Aside from them, the rock as a whole is fine to medium-grained. The ratio of potash feldspar to plagioclase varies. Hornblende takes the place of part or all of the biotite in the transitional zones between migmatite and amphibolite.

Rocks in the transitional zone between the migmatites and the underlying granitic mass are distinctly foliated, though coarser grained than the usual biotite migmatite. Aside from the grain size, these rocks are characterized by subhedral porphyroblasts of potash feldspar which may be two inches in greatest dimension. Their elongation parallels the schistosity marked by discontinuous flakes of biotite and concentrations of feldspar.

All of the above types weather to a buff or rusty brown color. Hand specimens and talus blocks are generally roughly tabular. Unevenly spaced jointing at approximately right angles to the foliation and parallel to the strike is common in many outcrops.

The microscopic texture of these rocks is crystalloblastic. Major constituents are quartz, plagioclase, potash feldspar and biotite. Minerals usually present in small or trace quantities include sphene, muscovite, magnetite, garnet, zircon, apatite and hornblende. Alteration, retrogressive and other minerals include chlorite, sericite, epidote, muscovite and fibrolite.

As indicated in the megascopic description, plagioclase is more common than potash feldspar. It is calcic oligoclase and is present in all biotite migmatites in amounts ranging from 30 to 55%. Porphyroblasts have distinctly granulated borders, may be poikiloblastic and are often twinned according to the albite, carlsbad and pericline laws. Inclusions in these larger grains are biotite, quartz, apatite, sphene or zircon. The maximum dimension is always in the direction of the foliation and seldom exceeds a centimeter. The usual plagioclase of the rocks is around 1 to 2 mm in size. The grains are sometimes subhedral, but more often they are extremely irregular in outline. In some specimens the oligoclase grains show zoning. In a single thin-section only part of the plagioclase may be zoned, though the compositions may be similar and textural relations with associated minerals the same. Plagioclase may be altered to sericite along cleavage traces or in the more calcic cores of zoned anhedra.

Potash feldspar is less abundant than plagioclase in the usual migmatite. Exceptions include rocks with at least 60% orthoclase. In rare cases orthoclase is absent. The orthoclase frequently appears in an intergranular position as elongated, very erregular anhedra which parallel the foliation planes. Porphyroblasts of orthoclase and microcline also occur but are not common. Some poikiloblastic grains have a maximum size of approximately two inches in coarse grained migmatites. The larger grains are often subhedral and may or may not parallel the schistosity. Carlsbad twinning is present and extinction angles indicate that the feldspar is microcline. The average size of the potash feldspars is about 1 centimeter. Inclusions are quartz, oligoclase and biotite, as well as minor constituents such as sphene and apatite.

The amount of quartz ranges from 15 to 45%. The mineral appears as discrete grains distributed throughout the rock or in thin bands paralleling the structure. Texture in the bands is mosaic, and the grains associated with feldspar-biotite areas are extremely irregular in outline. Undulous extinction is common.

Biotite is pleochroic from pale yellow to dark brown. In thin sections cut at right angles to the foliation the mineral shows preferred orientation and does not grow across the schistosity. The mica does, however, show evidence of recrystallization in the polygonal arcs of small-scale folds in certain of the migmatites. Apatite, magnetite and zircon are common inclusions in biotite. Pleochroic haloes occur around the zircons. The mica usually shows some degree of alteration to chlorite.

Small amounts of hornblende appear at the margins of migmatitic bands which are intercalated in the lower portion of the diopside-bearing amphibolite (Group I). The mineral forms irregular laths which are pleochroic from pale to dark green. Alteration to chlorite is much more pronounced than in the biotite of adjacent rocks. The chlorite is pennine.

Apatite, sphene, zircon and garnet, in the order named, are common minor constituents. Magnetite is usually present. The anhedral to subhedral sphene is often associated with biotite. Garnet is pale pink in color, and when poikiloblastic contains inclusions of magnetite and quartz.

Hornblende-Gneisses

Distribution: Hornblende-bearing migmatites crop out on both sides of the Kettle River in the vicinity of Toroda. However, the most extensive outcrops are found on the east side of the river. Those on the west side are limited to a narrow band extending a mile north and half a mile south of Toroda Creek.

Stratigraphically the hornblende-bearing gneisses occupy two horizons. The first of these lies above and grades downward into the diopside-bearing amphibolite (Group I), while the second appears near the base of and in various lenses and pods within the Group II amphibolite. The two amphibolites are separated by several hundred feet of a leucocratic quartz-feldspar rock containing minor amounts of chloritized amphibole.

Description: The migmatites associated with the diopside-bearing amphibolites (Group I) and those related to Group II amphibolites are discussed in the following paragraphs under (a) and (b) respectively.

(a) The megascopic appearance of these rocks varies with the amount and distribution of feldspar and amphibole. In some specimens feldspar is the dominant constituent and thin hornblende streaks accentuate the gneissose structure. In others, the hornblende is very abundant and feldspar appears in streaks and bands or as randomly distributed augen.

Typical specimens are illustrated on plates XV and XVI, pages 110 and 112. Sparse garnet and biotite occur in some outcrops. Fractures across the foliation are commonly filled with carbonate or epidote.

In thin-section the rocks are crystalloblastic. Hornblende appears as elongated anhedral laths with frayed terminations. It is pleochroic from yellow-green to blue-green and may have inclusions of apatite, magnetite or sparse quartz. Alteration to pennine is common. In some sections sphene is associated with this chlorite and appears to be secondary. Epidote forms from hornblende, and also appears as a fracture filling.

The plagioclase of these rocks is sodic andesine and it occurs as porphyroblasts which average 6 to 8 mm in maximum dimensions, or as much smaller anhedral grains distributed throughout the rock. The larger feldspars are often augen-shaped and aligned with the foliation. However, some subhedral feldspars grows across the foliation. The plagioclase seldom exceeds 10% of the volume of the rock, and as far as textural relations are concerned there is no suggestion of metasomatic addition.

The amount of potash feldspar varies from specimen to specimen. The maximum is approximately 50 percent and an average is 35 percent. In the leucocratic variety of hornblende-migmatite, the orthoclase, quartz and scattered plagioclase form a mosaic of more or less equidimensional grains.

The rather rare banded gneisses have discontinuous streaks and knots of orthoclase paralleling the schistosity. These streaks may range up to an average of 5 mm in width. Flakes of hornblende included in the orthoclase retain the attitude of adjacent amphibole-rich bands. Porphyroblasts of orthoclase are twinned, have distinctly irregular and crenulated borders, and may be poikiloblastic. Inclusions are quartz, plagioclase and hornblende.

Quartz is rare in the banded gneiss mentioned in the preceding paragraph. However, it is present in most hornblende-bearing rocks, and in the leucocratic variety it comprises a maximum of 40 percent of the rock. The mineral is commonly xenoblastic in light colored areas, in contrast to less irregular forms in the amphibole rich zones. Undulous extinction is common. In sections cut parallel to the foliation, there is no noticeable preferred orientation.

Chlorite, sphene, carbonate and epidote are retrogressive minerals formed from hornblende. Some hornblende migmatites include sparse biotite which is also partially altered to chlorite. There is no indication that this biotite has formed from hornblende. Sericite after plagioclase is common.

Euhedral zircon and apatite are common minor accessories. In one thin-section (D.9.4.50.6), several grains of allanite were noted.

(b) The migmatites associated with the Group II amphibolites have a distinctly different megascopic appearance than the rocks described in (a) above. They are usually fine-grained, and the light colored minerals tend to be uniformly distributed throughout with only random flakes or bands of hornblende and sparse biotite marking the foliation. Outcrops may be either predominantly migmatitic with minor stringers of the amphibolitic host rock, or the reverse relationship may exist. Porphyroblasts of calcic oligoclase are not prominent and when present are 2 mm in maximum average size. Aside from the hornblende and occasional biotite the constituents often form a sugary-textured rock. However, sufficient directional elements are present to give most hand specimens a rough tabular form.

The texture in thin-section is crystalloblastic and there is a wide range in all-over textural pattern, apparently due to the degree of recrystallization accomplished post-kinematically. In some specimens (D.9.17.50.5, 51.D.103, etc.) the equidimensional plagioclase grains are partially sheathed by hornblende and biotite flakes and are separated into elongated lenticles which may be bordered by finer grained, almost mortar-like quartz and feldspar. Other specimens (D.9.17.50.2, 51.D.125) have the equi-granular appearance of complete post-kinematic recrystallization. Variations between the two extremes are common.

The plagioclase averages calcic oligoclase and forms xenoblastic to hypidioblastic grains up to 2 mm in length.

Lenticles or flaser-like streaks consist of several randomly-oriented grains rather than single drawn-out individuals. The plagioclase forms at least fifty percent of the average leucocratic band in these migmatites. Zoned grains have a more calcic core than rim, suggesting that more sodium was introduced or otherwise made available as crystallization continued. Inclusions present are wisps of hornblende and grains of magnetite.

Orthoclase is present in all sections examined. The amount may be twenty percent of the light colored portions of the migmatite although estimation is very difficult due to its occurrence as thin streaks occupying intergranular positions paralleling the gneissose structure. Specimens stained with sodium-cobaltinitrite clearly show the minor quantity as well as the intergranular distribution of the potash feldspar. The mineral often penetrates along grain boundaries of plagioclase or quartz and completely encloses these minerals. This enclosure cannot be compared to that seen in a poikiloblastic grain since the orthoclase consists of units of varied orientation rather than an amoeba-like growth having a single orientation. The foregoing relationships suggest that the mineral formed at a late stage in the migmatization of the original amphibolite.

As indicated previously, hornblende appears in all migmatites of this group and is the major constituent of the host rock. Anhedral elongated flakes are rather uniformly distributed throughout the leucocratic areas. It is strongly pleochroic from blue-green to pale yellow. Inclusions are apatite and magnetite. Biotite after hornblende is common in many thin-sections. Epidote and some sphene may be products of the biotization process. Epidote also appears with hornblende alone and in these cases probably is derived from it.

In some outcrops biotite appears in two generations. The early, probably pre-feldspar biotite is in distinct bands without hornblende. Other bands show the mica forming from hornblende.

Epidote occurs as irregular rounded grains exhibiting pleochroism from yellow to yellowish-green. Its usual association has been mentioned above. It also occurs with chlorite as a fracture filling; this epidote is younger than that formed from hornblende.

Quartz is always present in amounts ranging from ten to as much as thirty-five percent. In some thin-sections it is concentrated into bands up to 1 mm in width and 1.5 cm in length. Commonly, however, it forms randomly distributed anhedral grains which may be elongated parallel to the foliation. A younger generation of quartz occurs with epidote in fractures which usually crosscut but may be parallel to the gneissose structure.

Sphene, apatite, zircon and magnetite are the minor accessories in all thin-sections. Sparse grains of diopside were noted in section 51.D.122. Chlorite appears as a retrograde mineral forming from hornblende and biotite wherever the latter occurs.

Summary and Genetic Interpretation

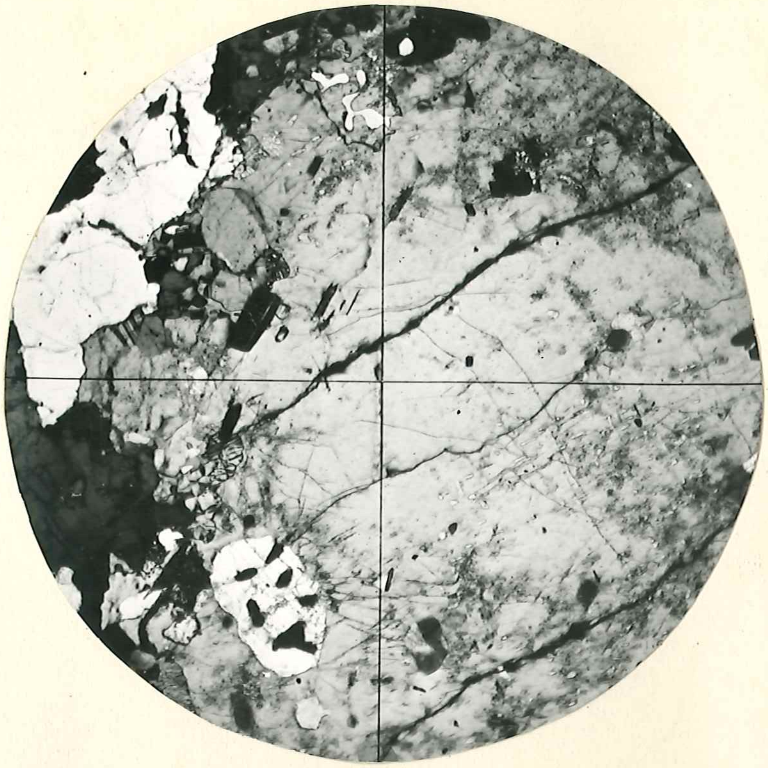
The cumulative evidence obtained from both field and microscopic examination indicates a metasomatic origin for the migmatites of the Pre-Attwood formation. Micaschists and amphibolites have been altered into texturally and chemically dissimilar rocks by the addition of sodium, potassium, and, in some instances, silica.

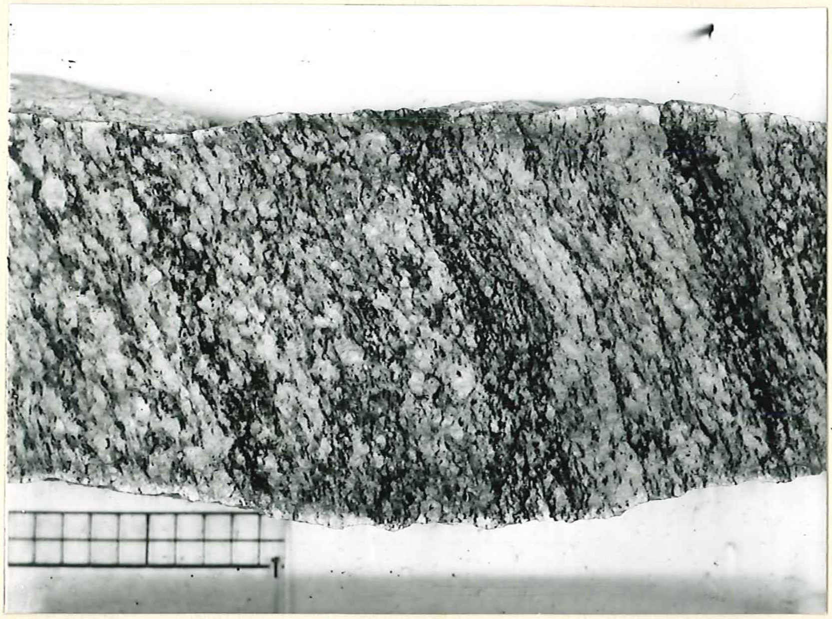
Decisive evidence in favor of a metamorphic-metasomatic origin is the occurrence of conformable intercalations of migmatites with the isochemically metamorphosed rocks. Gradations frommicaschists or biotite-paragneisses to a gneiss of granitic composition are found. Likewise, transitions occur from an amphibolite containing small amounts of sodic andesine to a gneissose rock of granodioritic composition. In all cases relict biotite or hornblende flakes are aligned parallel to the foliation of the adjacent or included isochemical rocks. Additional evidence includes textural features such as the all-over crystalloblastic nature of the rocks and the porphyroblastic and poikiloblastic habit of the plagioclase and of some potash feldspar. In the migmatized amphibolites the zoned structure of plagioclase porphyroblasts is taken to indicate a constant change in calcium-sodium ratio with continued introduction of sodium and concomitant depletion of the calcium-supplying hornblende. Other evidence includes the late, intergranular invasion by potash feldspar; the biotitization of hornblende; and the presence of relict sillimanite in the biotite-gneisses. Conversion of a quartz-poor amphibolite to a granodioritic rock with free silica would require the addition of silica also. Sufficient aluminum was probably available in both amphibolites and micaschists.

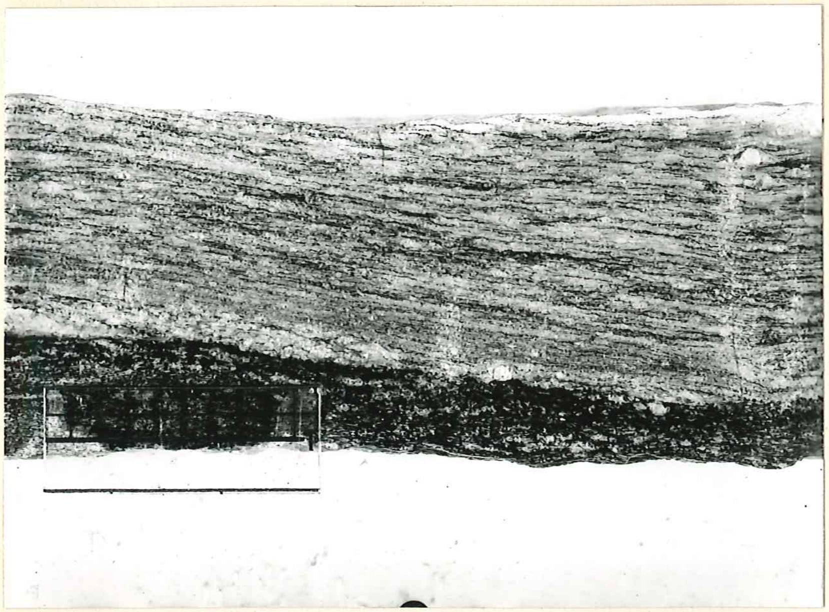
The mineral assemblages of the isochemically metamorphosed argillites and of certain carbonate rocks associated with the migmatites indicate metamorphism under high-grade conditions. In the case of the Group II amphibolites, at least medium grade temperatures were prevalent. The uncertainty is due to the absence of a diagnostic mineral assemblage.

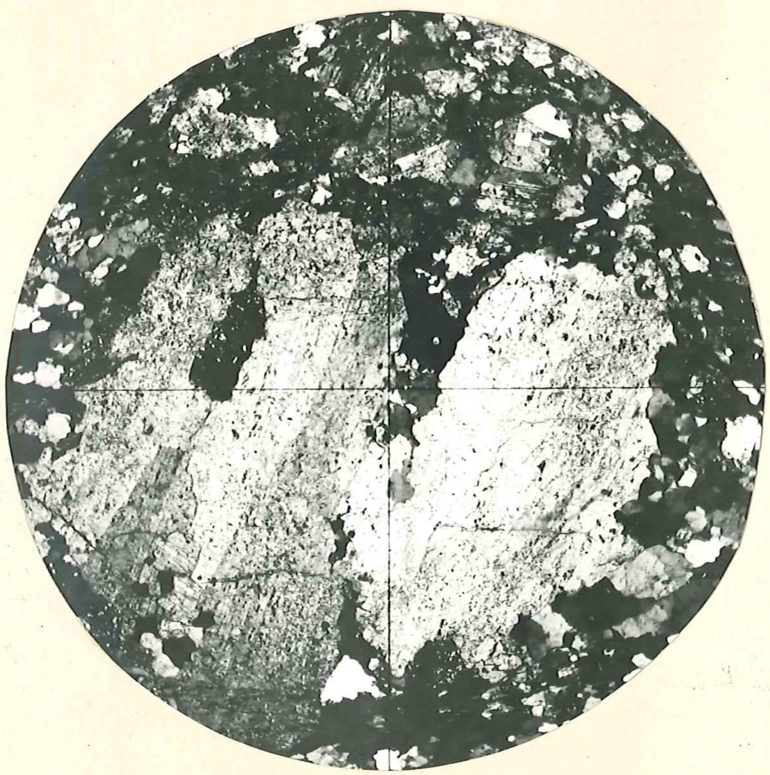
Crystallization foliation in the migmatites indicates that sodium was introduced under kinematic conditions. Potash feldspar formed later under the same conditions, and subsequently under static conditions. Recrystallization during the latter period has locally produced granulitic migmatites, especially in the Group II amphibolite areas.

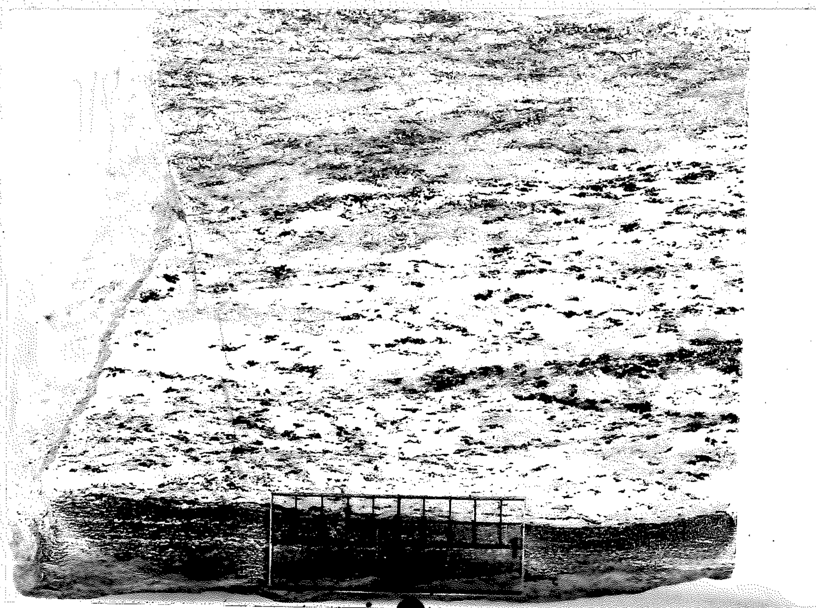
A period of still later, retrogressive metamorphism of low-grade produced chlorite in the migmatites and other units of the Pre-Attwood formation. In the section exposed in the Kettle River valley, two zones of mylonitic rocks which parallel the earlier schistosity are probably related to this low grade metamorphism.

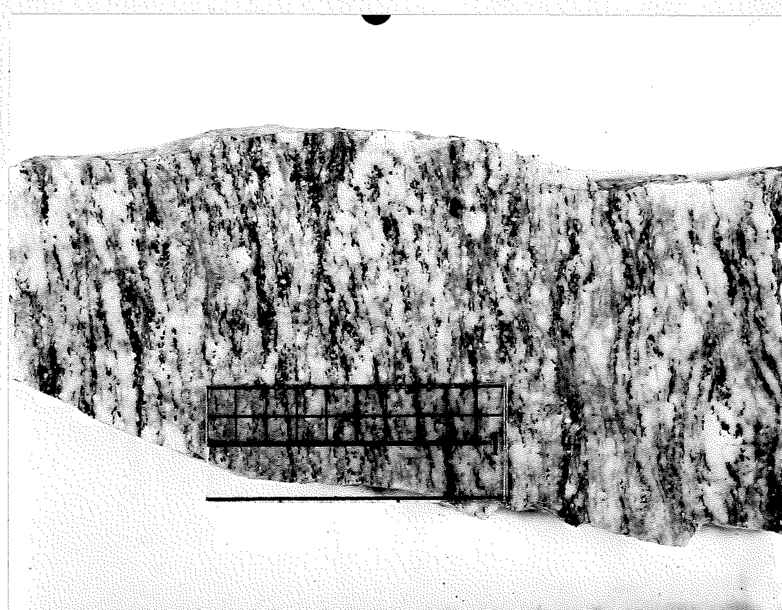












Granitic Rocks

Occurrence

The massive granitic element of the Pre-Attwood complex is best exposed along the Kettle River Canyon in the easternmost part of the map area. Extensive exposures are also found along the lower courses of Tonata and Henry creeks.

Similar granitic rocks crop out along the course of the Kettle River beyond the eastern limits of the mapped area (cf. index map, page 2). These granitic outcrops are cut-off to the east bya major, northeasterly trending fault which is clearly seen in a road-cut on the south-side road three and a half miles due west of the village of Curlew.

Relationships with Migmatites and Isochemical Metamorphics

In the section dealing with the migmatitic biotite gneisses (cf. page 90), reference was made to the gradual transition from isochemical and migmatitic rocks to those which are more or less directionless and granitic in character. Again it must be emphasized that there is no clear-cut contact between the sediment-derived Pre-Attwood rocks and the subjacent granitic rocks which will be described in the following paragraphs. With depth, an increase in light colored constituents and a decrease in biotite is noted, as well as a corresponding decrease in the degree of directional structure.

More often that not a moderately-sized hand specimen will display no gneissose structure. However, weathered high cliffs along the Kettle River always show traces of structures whose attitude parallels that of the overlying gneisses, schists, quartzites and limestones.

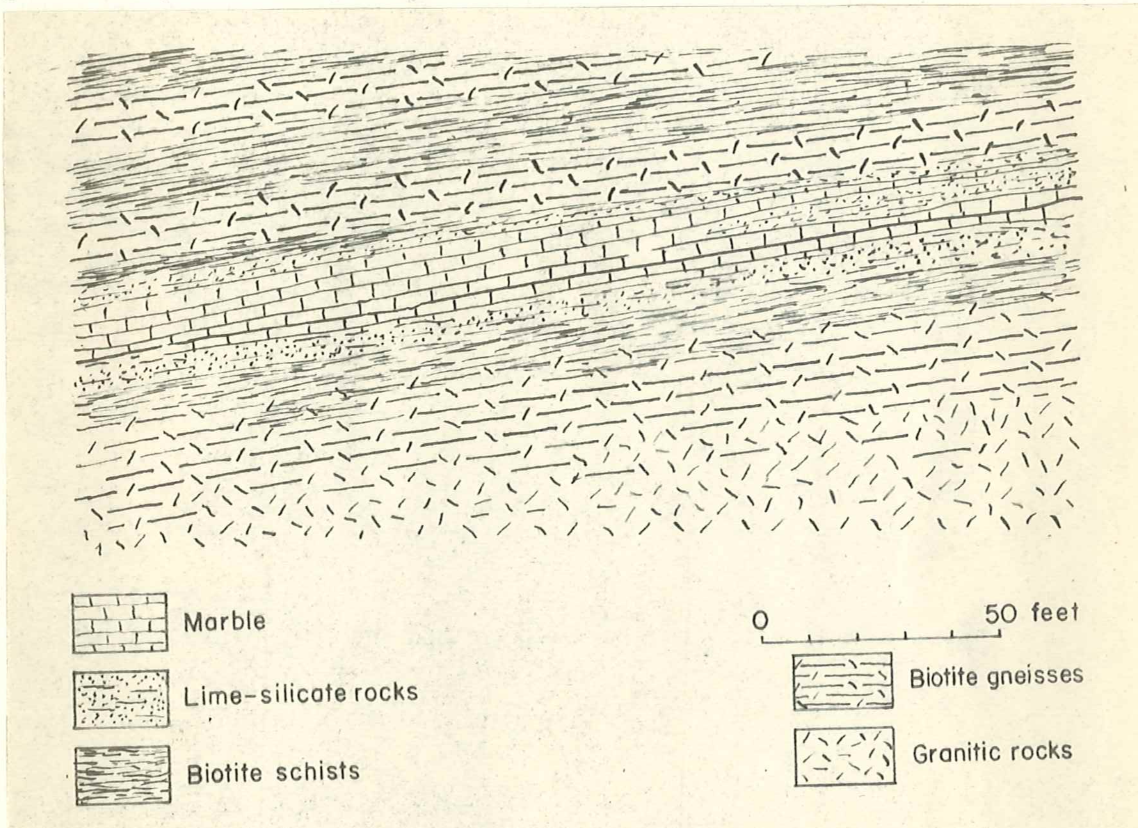


Fig. 6. Sketch illustrating the lithologic units within the border zone of the Pre-Attwood granitic rocks.

Description

A cross section of these granitic rocks is displayed in the Kettle River canyon. A prominent vertical jointing striking an average N 10 E is noted throughout the area. Locally the joints are spaced one to two feet apart, but over most of the outcrop area the spacing is quite erratic. Horizontal or other systematic jointing is absent. Massive portions weather to "exfoliation dome" forms. The slight differential weathering which accentuates the directional element is a result of the concentration of biotite and potash feldspar into bands.

Linear "skialiths" (G. E. Goodspeed, 1948) rich in biotite are occasionally noted. A gneissic zone with prominent alternating bands of biotite and feldspar was noted on the south wall of the Kettle River canyon (station 193). In this locality the biotite gneiss is overlain by a thin (3 to 4 feet) band of garnet-diopside-plagioclase gneiss. This

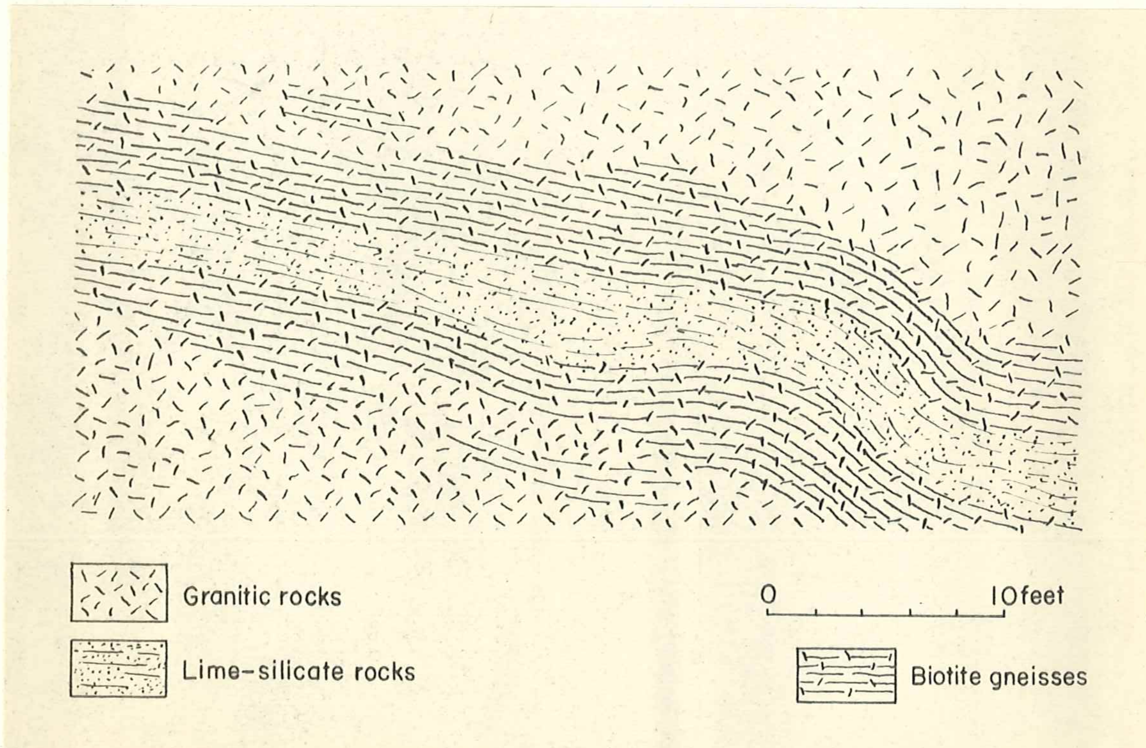


Fig. 7. Lime-silicate band and bordering biotite gneisses included in the nearly directionless portion of the Pre-Attwood granitic body.

lime-silicate rock is succeeded by a biotite-gneiss which grades upward into the nearly directionless type of granite rock.

Megascopically the usual granite specimen is medium to coarse grained and light gray. Visible constituents are feldspar, quartz, biotite, sparse grains of dark red garnet, and rare crystals of pyrite. In the transitional zone between migmatites and granitic rock the average specimen is markedly gneissose. With depth, however, most specimens show very little, if any, foliation. Staining of potash feldspar with sodium-cobaltinitrite will bring out a banded structure in what otherwise is an essentially directionless-appearing fabric. Subhedral potash feldspars up to 4 cm in length are found near the margin of the granite. Inclusions of biotite are common in these porphyroblasts, and in some localities the porphyroblasts are surrounded by an aureole of biotite. With depth the feldspars become anhedral and seldom exceed a maximum of 1 cm.

Pegmatites consisting mainly of potash feldspar and a little quartz are common in some localities. Locally these late veinlets form a complicated reticulated pattern. Their size ranges from a width of less than one inch to four inches. In most cases they do not follow the vague directional element in the granitic rock but cross it at every angle. There is no uniformity in attitude and no apparent relationship to a joint set or system within the host rock. Borders are gradational with the granite rather than sharp and well-defined. No dilation occurs where pegmatite crosses pegmatite.

In thin-section the all-over fabric of the granitic rocks is crystalloblastic. In detail the texture ranges from granoblastic to a sutured mosaic. Porphyroblasts, especially those of potash feldspar, are usually filled with inclusions of early minerals. These relict grains are often aligned in such a manner that a mimetic structure representing a pre-potash feldspar schistosity is plainly defined (see photomicrograph of section 51.D.161A, page 128). Porphyroblasts of oligoclase include grains of quartz and an occasional grain of magnetite, biotite, apatite or magnetite.

The plagioclase is calcic oligoclase. It may be untwinned or twinned after the albite, carlsbad and pericline laws. Zoning is present in a vague sort of way. Two-thirds of the core of a porphyroblast may be at extinction while the outer shell lies but a few degrees from extinction. In the majority of sections plagioclase predominates over potash feldspar by a ratio of 1.5:1 or occasionally 2:1. In some sections, however, the reverse relationship exists.

Orthoclase locally forms porphyroblasts ranging up to 4 mm in length, but its common occurrence is as an amoeba-like intergrowth occupying an intergranular position with respect to the other earlier minerals in the rock. This interstitial feldspar seldom maintains the same crystallographic orientation for any distance, as might be the case in a growing porphyroblast.

Except in the most gneissose varieties, biotite does not have a preferred orientation. In sections showing a general alignment the transverse position of some flakes of mica is common. Small amounts of chlorite after biotite were observed in all thin sections examined. The mica seldom exceeds 5% of the volume of the rock.

Quartz is present in an amount ranging from twenty to thirty percent. It occurs as inclusions in oligoclase and potash feldspar and also as xenoblastic grains intergrown with the two minerals. Undulatory extinction and irregular fractures are noted in most thin-sections.

Microscopic intergrowths of two feldspars or of quartz and feldspar are exceedingly uncommon in these rocks. Antiperthitic structures in certain portions of a mutual grain boundary between the intergranular potash feldspar and the oligoclase have been observed. No intergrowths were noted where the plagioclase is included in an orthoclase porphyroblast. Myrmekitic intergrowths are present but are also rare. Where noted, the potash feldspar appears to be replacing the quartz. This view of the time relations of the two minerals is substantiated by the common occurrence of quartz inclusions in the orthoclase.

Apatite, magnetite, pyrite, and garnet are minor accessories. A number of grains of orthite were noted in thin-section 51.D.161A. The garnet appears as anhedral rounded grains up to 4 mm in diameter. It is commonly crossed by irregular fractures. Quartz inclusions were noted.

Summary and Genetic Interpretation

From the foregoing description it appears that the principal "granitic" mass of the Pre-Attwood formation actually ranges in composition from a granite to a granodiorite. The examination of a number of thin-sections from various localities indicates that the rocks of granodioritic composition are the most abundant. True granites are confined to a border zone between overlying migmatites and subjacent plagioclase-rich types. The thin pegmatites mentioned earlier are most common in certain zones within the granodiorite and are rare in the granite areas.

Field and microscopic evidence points toward a metasomatic rather than an orthomagmatic origin of these rocks.

Field evidence consists primarily of the extremely gradational character of the zone between granitic appearing rocks and overlying migmatites. Several thousand feet of micaschists, quartzites and migmatites with depth give way to granitic gneisses which in turn grade into rocks which dispaly only vague traces of a directional element. The attitude of the latter corresponds to that of overlying Pre-Attwood quartzites, micaschists and amphibolites. Zones of biotite gneiss and lime silicate gneiss completely enclosed by granodioritic rocks also retain the loacl trend of the Pre-Attwood complex.

Microscopic evidence in support of a metasomatic origin includes the following features.

(a) Consistent presence of crystalloblastic and porphyroblastic textures.

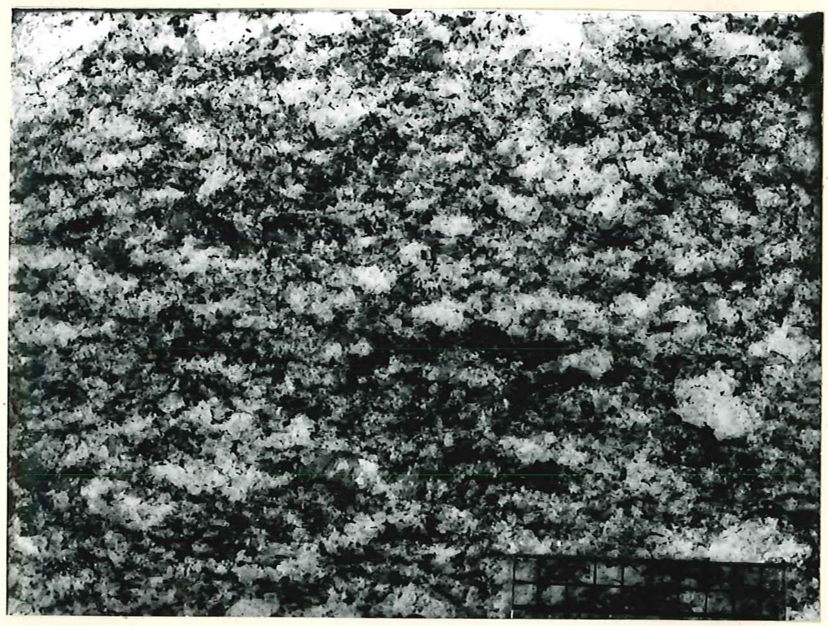
(b) Poikiloblastic calcic oligoclase containing inclusions of quartz and ragged biotite. The plagioclase also appears to be replacing larger grains of quartz.

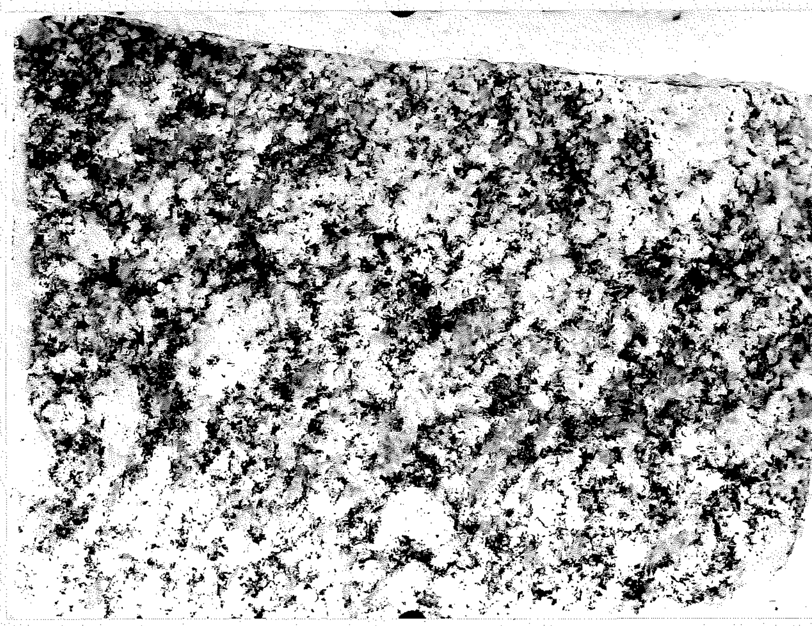
(c) Poikiloblastic orthoclase with inclusions of oligoclase, quartz and biotite. Mimetic structures occur in orthoclase porphyroblasts of rocks which on a hand-specimen scale are directionless. Cusp-like grain boundaries suggest that potash feldspar has partially replaced quartz and plagioclase.

(d) In areas where gneissose structure is prominent, the orthoclase porphyroblasts grow across the foliation planes. Aside from the porphyroblasts, potash feldspar also occupies an intergranular position which with other evidence indicates that it was the last mineral to form.

The foregoing agrees in general with the metamorphic history of the Pre-Attwood formation. An exception is in the time relation of sodium metasomatism and active deformation. Static addition of sodium followed by potash introduction destroyed much of the directional element in certain local zones. In migmatitic areas overlying the granitic rocks sodium introduction was synorogenic and potash alone was post-orogenic.

Silica apparently was not introduced. Quartz forms from 20 to 30 percent of the present granitic rock and it also appears to have been replaced by all constituents except biotite. Such evidence suggests that the original rock may have been a quartz-rich, argillaceous sediment.





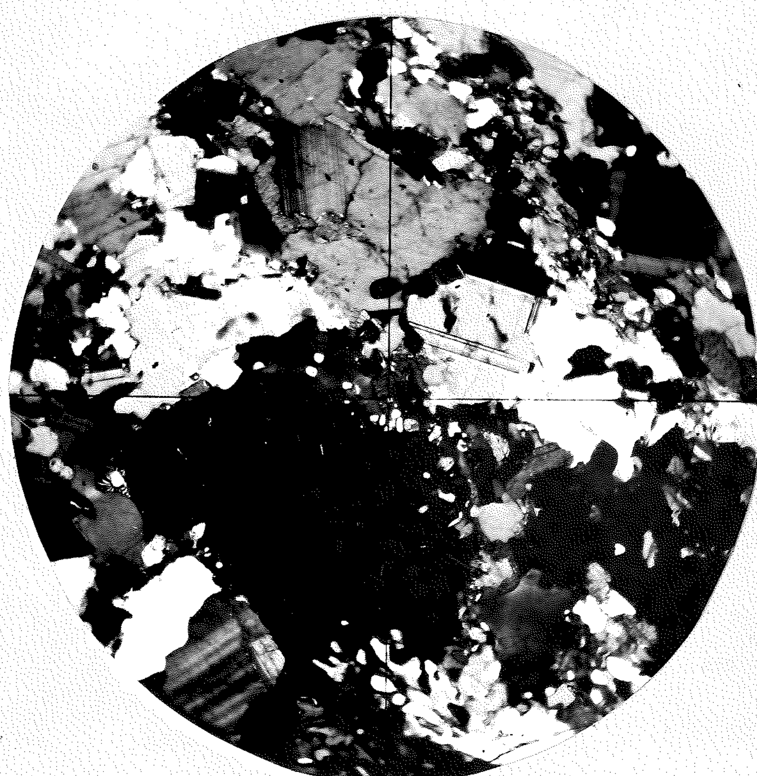


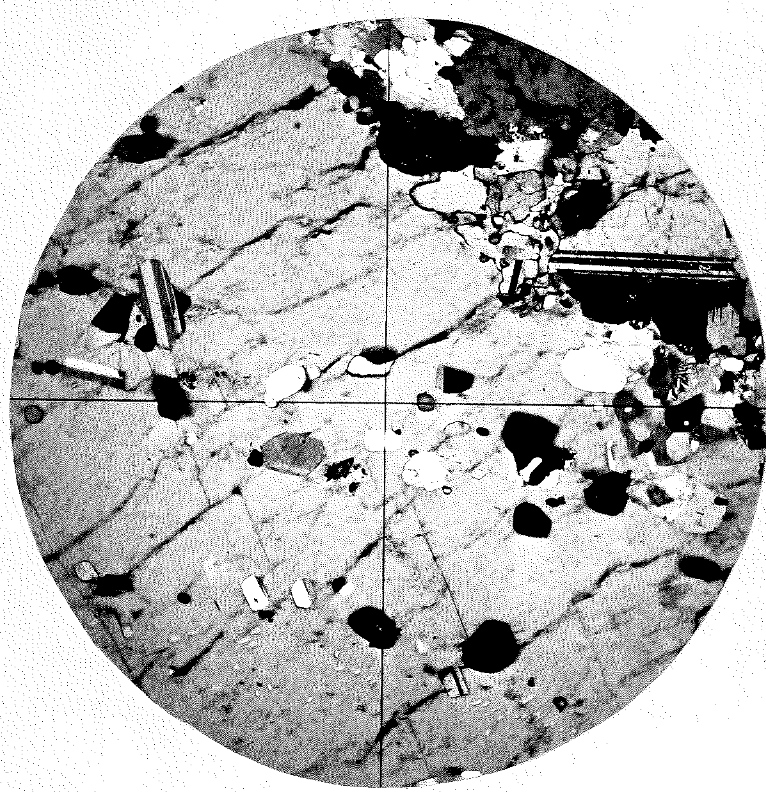
PLATE XIX

A. Polished slab of a gneissose lime-silicate skialith within the directionless portion of the Pre-Attwood granite. Dark garnets and diopside with calcic plagioclase and quartz.

Specimen 51.D.164.

B. Photomicrograph showing aligned inclusions in a section of an anhedral orthoclase porphyroblast.

Specimen 51.D.161A. Crossed nicols. X16.



Metadiorites

Occurrence

Dioritic rocks occur as tabular bodies lying within the upper (Group II) amphibolite. The contact observed are conformable with the foliation of the enclosing rocks and the diorite bodies are, at least locally, sill-like in form. Outcrops on the north side of the east fork of Catherine Creek show thicknesses ranging from 150 to 175 feet.

Description

Megascopically the rocks are dark gray in color, fine to medium-grained and not notably porphyritic. Hand specimens have a crudely tabular form though neither weathered nor fresh surfaces show marked parallel structure. Recognizable constituents include biotite and plagioclase. Etched and stained specimens clearly show the plagioclase phenocrysts and the groundmass potash feldspar.

Under the microscope, the plagioclase was determined as andesine ranging between An_{35} and An_{45}. The mineral forms euhedral to subhedral phenocrysts which may reach 3 mm in maximum dimension but commonly are less than 1 mm. In the thin-sections examined plagioclase phenocrysts constitute approximately 50% of the rock. Groundmass minerals include hornblende (20%), plagioclase (5%), biotite (5%) and orthoclase (20%). Quartz, sphene, apatite, zircon, orthite and magnetite are minor constituents. Mica and some hornblende show preferred orientation but other groundmass minerals have a mosaic texture. Hornblende grains often have cores of altered augite.

Thin sections cut normal to the foliation show elongated, subparallel flakes and aggregates of mica. Plagioclase phenocrysts are often sheathed with deformed thin flakes and stringers of the biotite. Additional evidence of deformation is seen in the fracturing, bending and slight granulation of the large feldspar crystals.

Summary and Conclusions

Two features which support an orthogmagmatic origin for the diorite are: (a) the augite cores of hornblende grains are suggestive of crystallization differentiation or deuteric alteration; (b) the euhedral form and random orientation of the plagioclase phenocrysts. In addition, the directional element in the diorite is obscure in comparison to the same feature in the enclosing amphibolite.

It is possible that these rocks were emplaced after the period of medium to high grade synorogenic metamorphism of the Pre-Attwood formation and before the period of later low-grade metamorphism which affected both the Pre-Attwood and the Attwood formations. On the other hand, emplacement during the late stages of Pre-Attwood metamorphism must not be ruled out in view of the lack of evidence for the foregoing suggestion.

Mylonites

Occurrence

Several zones of mylonitic rocks are found in the area. The most extensive occurrence is within the biotite migmatites stratigraphically overlying the tan quartzite. Excellent exposures may be seen on the north side of the Tonata Creek road approximately one and a half miles south of Toroda. Mylonites developed from migmatites within the Group II amphibolites crop out at an elevation of 2020 feet on the west side of the lower portion of the Tonata road. The close juxtaposition of these two mylonite zones in rocks which normally are separated by a considerable thickness of metamorphics is due to normal faulting.

A third zone of mylonitization occurs in migmatitic rocks found near the upper limit of the diopside-bearing (group I) amphibolites. In this portion of the sequence both biotite and hornblende are present and potash feldspar forms less than three percent of the rock. Excellent outcrops begin at an elevation of 2500 feet along the course of Tenas Mary Creek. This stream joins the Kettle River from the east approximately three miles south of the 49th parallel.

Description

Mylonites are described in the following paragraphs according to presence of biotite, hornblende or of both minerals.

Biotite mylonites: The rock is compact and massive in outcrop. Hand specimens show a slight tabularity paralleling the distinct directional element. Fresh material is light gray in contrast to the limonite-brown of weathered specimens. Feldspar augen up to a maximum size of 5 mm are present but as a whole the average grain-size is less than 1 mm. An occasional wisp of biotite may be noted with the aid of a hand lens. The gneissose appearance results more from the crude alignment of leucocratic constituents than the sparse dark materials.

The texture of these rocks is seen in thin-section to be cataclastic in spite of the compact appearance in hand specimen. Large feldspars are fractured, somewhat elongated in outline and more often than not display undulatory extinction. Although fracturing is distinct the feldspars have not been completely broken and separated into discrete particles and thus they have a porphyroblastic rather than a porphyroclastic appearance. The fractures show no evidence of rehealing but are often marked by a limonitic stain. Shearing and granulation have removed the typical crenulation from at least the two sides of the grain which parallel the shear planes. Porphyroblasts with circular rather than elliptical outlines may have been rotated. The large feldspars may be sheathed in part by mica and are surrounded by wreathes of granulated or ribbon-like bands of quartz and feldspar. The biotite is partially chloritized and displays differential extinction due to deformation.

The dominant feldspar is orthoclase. It appears as porphyroblasts and as xenoblastic grains in the granulated areas. Inclusions of oligoclase, quartz, and ragged biotite flakes indicate age relations similar to those in the non-cataclastic migmatites. Kaolinite is a common alteration product. Oligoclase (An_{20} to An_{25}) occurs as porphyroblasts as well as in the groundmass. It may be zoned and does not always display twinning. The cores of zoned grains are more calcic than the rims. Some oligoclase is completely covered with a fine aggregate of sericite whereas in others the alteration is confined to the core.

As indicated previously, quartz is abundant in these rocks. No particular distinction can be made between the quartz of the original migmatite and that which has effectively "recemented" the mylonite. The mineral is the dominant constituent in the granulated areas. Undulatory extinction is common. Some fine, ribbon-like bands lack this irregular extinction and thus might be considered introduced quartz or may represent local zones of recrystallization.

Apatite, magnetite and rare grains of sphene or epidote are minor accessories in these rocks. Chlorite, kaolinite and sericite have been mentioned above.

<u>Hornblende mylonites</u>: The rock varies in color from

light grayish-green in leucocratic, coarse-grained portions to dark green in finely granulated bands. Feldspar appears in some specimens as isolated augen-shaped individuals surrounded by hornblende and finer-grained light-colored constituents. In others, feldspar is the dominant mineral and it appears in discontinuous thin bands separated by thin wisps of hornblende. The dark green layers, which appear at irregular intervals throughout most outcrops, are extremely fine grained. In fact, many such layers have the appearance of a chert or a very fine-grained dark green quartzite.

The greatest observed thickness of this type of mylonite is around twenty feet. Leucocratic, medium-grained material is always dominant. Foliation is pronounced in the outcrop and prominent in hand specimen. Epidote-filled fractures cutting across the foliation are common.

The slight suggestion of cataclasis seen in hand specimen is immediately substantiated in thin-section. Crystallization foliation is replaced by a directional element resulting from intense mechanical crushing and granulation. Variation in degree of mylonitization may be seen in a single thin-section. Coarse grained areas show fractured and separated porphyroblasts of calcic oligoclase surrounded by layers or ellipsoidal masses of granular quartz and feldspar. Fractures within the feldspar are filled with a mortar of feldspar and quartz. Ribbons or discontinuous bands of secondary or late recrystallized quartz appear to wrap around the plagioclase, the sparse original quartz and the hornblende. Amphibole in the shear zones has been smeared out into long, thin films which are nor largely chlorite. Some hornblende is but slightly fractured, and other poikiloblastic grains appear to have been carried along and have thus escaped alteration.

A gradual transition exists from coarse grained (average maximum grain size 6 mm) areas to the dark aphanitic bands. In the latter only rare rounded grains of feldspar, chloritized amphibole or sparse quartz have survived crushing to a nearly sub-microscopic powder. Portions of this groundmass are isotropic under crossed nicols. This suggests that fusion to a glass resulted from heat developed locally during high pressure shearing. Banding on a fine scale is prominent in these zones.

The chlorite in these mylonites is often pennine. Other minerals present include sphene, apatite and magnetite. Plagioclase is altered to sericite. Potash feldspar is absent.

<u>Hornblende-biotite mylonites</u>: In outcrops these rocks have a distinctly foliated and sheared appearance. Weathered surfaces are grayish brown in color. Closely spaced joints cut across the foliation at nearly right angles. Fresh specimens are light gray in color and distinctly tabular parallel to the foliation. In a three by four inch hand-

specimen with a cut surface the foliation is much less conspicuous than in a much larger surface exhibited in outcrops.

The average grain-size of the light-colored constituents is slightly less than 1 mm. Maximum size of feldspar porphyroblasts is 6 mm. Biotite flakes are readily seen with the hand lens.

Under the microscope the principal evidences of low temperature mechanical deformation consists of fractured plagioclase, drawn out and deformed biotite, and sparse zones of granulated quartz and feldspar. Hornblende also occasionally shows irregular extinction due to deformation. On the whole, these rocks show far less evidence of post-crystalline cataclasis than either of the mylonitic rocks described above.

Quantitatively the minerals present consist of 60% plagioclase, 15% quartz, 10% biotite and 10% hornblende. Not more than 2% orthoclase was noted in the thin-sections examined. Minor constituents include the usual magnetite, sphene, apatite and rare zircon.

Zoned plagioclase is common. The indistinct shells have a composition near An_{25}, and the cores are more calcic. More than two thirds of the feldspar porphyroblasts lack twinning.

Chlorite has formed from biotite and rarely after hornblende. The feldspars are unaltered but do show a limonitic appearing staining along cleavage planes.

<u>Summary of Mylonites in Pre-Attwood Metamorphics</u>

(a) The directional element resulting from mylonitization of these rocks is parallel in every case to the dip and strike of adjacent migmatites or isochemically metamorphosed rocks. Further, it is superimposed upon the earlier schistosity.

(b) All units of the Pre-Attwood formation show evidence of retrograde metamorphism under low-grade conditions. Local shearing within brittle migmatites may have taken place during this period.

(c) Unconformably overlying the Pre-Attwood is the Attwood formation. The rocks of the Attwood consist of limestone, conglomerate, siliceous dark shale and greenstones. These rocks have been metamorphosed under low-grade conditions, and it appears logical to assume that the Pre-Attwood group was affected in a similar manner.

Age and Correlation of the Pre-Attwood Metamorphic Complex

As might be expected, no fossils were found in the highly deformed and crystallized carbonate rocks or in any of the other members of the Pre-Attwood formation. Further, these rocks are not coextensive with any similar dated lithologic units mapped in adjacent areas. The present investigation, then, confirms the existence in this region of an older series of metamorphics but offers no contribution regarding their specific age or correlation.

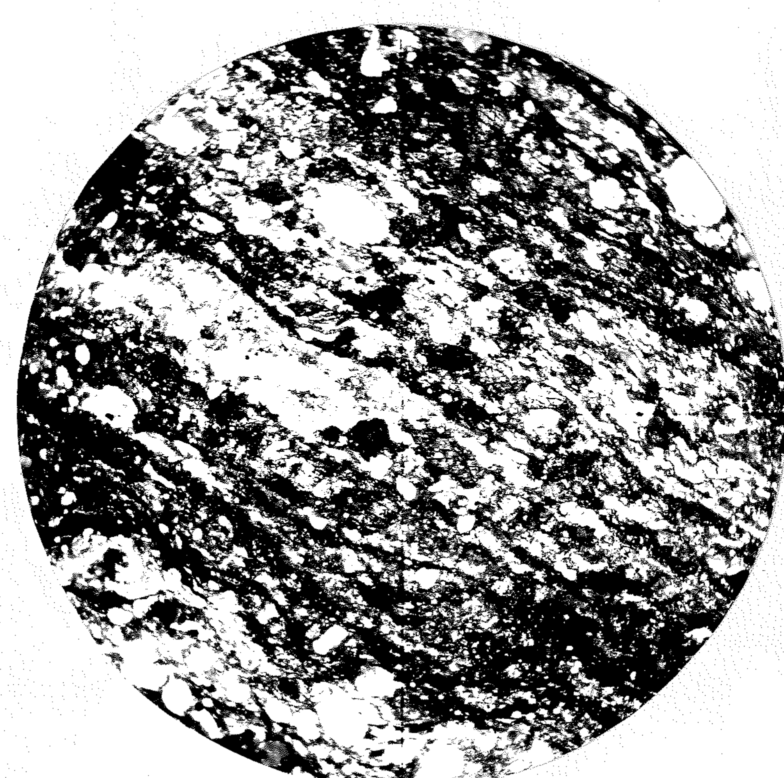
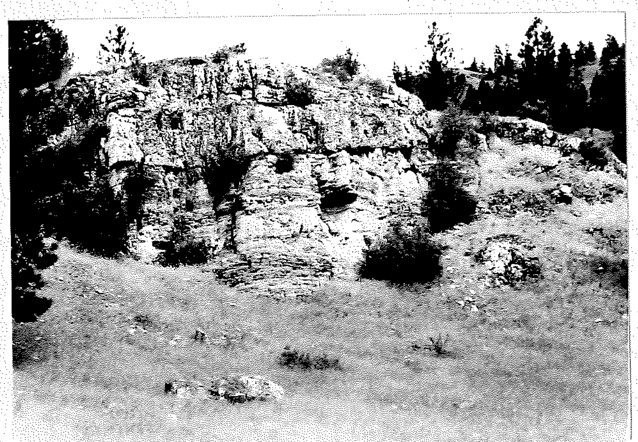


PLATE XXI

A. View of migmatite outcrop on the east side of the Kettle River near Louie Creek.

B. Outcrop of gneissose lime-silicate rocks in the Pre-Attwood rocks of the Louie Creek area.

C. Closeup of outcrop in B, above, showing scapolite-diopside bands intercalated with feldspar layers.



ATTWOOD GROUP OF LOW GRADE METAMORPHICS

Introduction

Only small, isolated patches of Attwood rocks crop out in the Kettle River-Toroda Creek district. The total areal extent of these rocks is little more than a square mile. Field relations indicate that the Attwood is in unconformable contact with the underlying rocks. An unconformity likewise exists between the unmetamorphosed lower Tertiary Kettle River formation and the Attwood.

The oldest member of the Attwood formation is a limestone. Conformably overlying rocks include a dark phyllite and a sheared quartzite-pebble conglomerate. A non-foliated greenstone appears to be the youngest exposed member of this formation.

Limestone

Occurrence

Limestones crop out in several localities on the north side of Resner canyon. In this area their thickness is approximately 50 feet. The rock is somewhat slabby; this directional element trends N 10° W and dips 45° to the south. Limestone and the overlying phyllite form the hanging wall side of a low angle reverse fault. The Attwood then, in this loaclity, is in fault contact with the younger Kettle

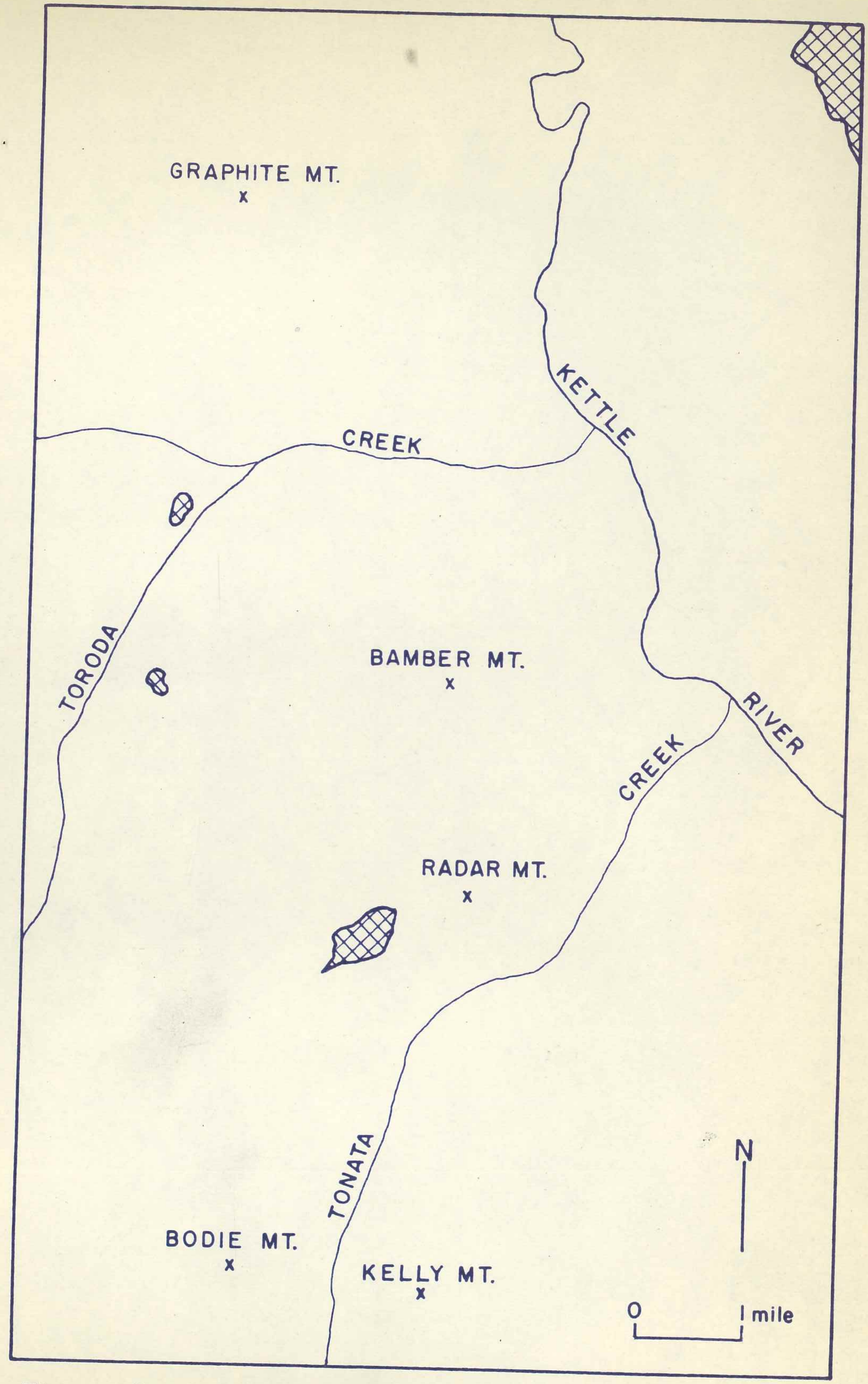


Figure 8. Distribution of the Attwood metamorphics.

River formation.

A second occurrence of Attwood limestone was mapped in a small area beginning one half mile west of the summit of Radar Mountain. An attitude taken on a cherty band gave a strike of N 55° W and a northerly dip of 20°. In this locality the rock unconformably overlies the Pre-Attwood metamorphics. Younger members of the Attwood formation are absent at this locality, and the limestone is unconformably overlain by the much younger Midway volcanics. The thickness of the limestone is roughly 1100 feet.

Description

Weathered surfaces are gray to chalky white and are fretted and pitted by solution. Occasional thin bands of gray chert are noted in the otherwise massive outcrop west of Radar Mountain. A very crude stratification is marked by zones of crystalline and non-crystalline rock. The latter weathers to a chalky white in contrast to the gray of the finely crystalline portions. Fresh specimens are gray to blue-gray in color.

Thin-sections of the fine-grained marble show a mosaic of twinned and untwinned calcite grains. In addition, rare anhedra of apatite, magnetite and muscovite may be seen. Average grain-size of the carbonate is .5 mm.

Marble from the contact zone of the Kelly Mountain granodiorite contains scattered grains of diopside, garnet, vesuvianite and phlogopite.

Phyllites

Occurrence

Phyllites crop out in three isolated patches of the Attwood formation. The occurrence of phyllite overlying the limestone in Resner Canyon has been mentioned (cf. above). Here the thickness is about 150 feet.

More estensive outcrops of the phyllite and related rocks occur in the extreme northeast corner of the map area. It is in this area that these low grade metamorphics are seen to be a southerly extension of the lithologic unit which Daly (1912) mapped in Canada as the Attwood formation. The limestone which is the lowest know member of the Attwood is absent here and the phyllite appears to be in unconformable contact with the Pre-Attwood rocks. The sheared conglomerate which overlies the phyllite at Resner Canyon is replaced by a deformed coarse sandstone or grit. Greenstones were also noted. Satisfactory attitudes were not obtained, but in general it appears that the strike is N 55° W and that dips range from 20° to 70° north.

A few hundred square feet of phyllite and underlying limestone crop out in the southeast quarter of section 36, T 40 N, R 13 E.

Description

The usual rock is dark gray or black in color. The outcrop in section 36 (cr. above) is located in the contact aureole of a small body of Kelly Mountain granodiorite and is lighter-colored and more compact. Foliation planes in the dark phyllite are closely spaced and have a faintly lustrous surface. Most outcrops are weathered and crumbling so that it is very difficult to obtain a specimen suitable for cutting thin-sections.

Under the microscope the usual minerals are quartz, sericite, biotite, chlorite, magnetite and pyrite. The opaque fine dust which is distributed throughout the rock is probably carbonaceous material and it doubtless gives the rock the dark color.

Quartz is the most abundant constituent. It occurs as discrete rounded grains ranging up to .2 mm in diameter. These grains as well as the common elongate pods and lenses of nearly sub-microscopic quartz grains are relict clastic materials. Biotite occurs as extremely small flakes but is well enough developed to show distinct pleochroism and parallel extinction. Biotite and sericite are often associated. Sericite rather than biotite is the common micaceous mineral in the sections examined. The occasional flake of muscovite may be of clastic origin rather than a product of recrystallization. Epidote, chlorite, carbonate and quartz are found as a filling in fractures which cross the foliation. These secondary minerals are found only in the area adjacent to the granodiorite.

Conglomerates

Occurrence

The conglomerate member of the Attwood formation is exposed on the north side of Reaner Canyon. In this locality the thickness could not be determined because of talus and creep from overlying greenstones and the Kettle River formation. Fragments of the rock are, however, distributed throughout the talus for a distance of several hundred feet along the slope. The actual contact between the conglomerate and overlying greenstones was not observed.

Similar clastic rocks were not found in other Attwood outcrops. Very coarse sandstones and granule conglomerates do occur with phyllites outcropping in the northeast corner of the mapped area.

Description

The Reaner Canyon conglomerate consists of light colored pebbles enclosed in a pale green matrix. Fractured and drawn-out pebbles up to one and one-half inches in length were noted although the average is about one-half inch. All of the pebbles are drawn-out into eliptical shapes which have a common orientation. The rock appears much weathered and is cut by many fractures parallel to and transecting the foliation. For these reasons a compact hand-specimen is difficult to obtain. An orange to brown stain throughout the rock is related to the many partially altered pyrite cubes in the matrix.

In the thin-sections examined all of the pebbles are seen to be a fine grained quartzite. Shear and fracture zones within these pebbles are filled with a mortar of quartz which is usually coarser grained than the quartzite. The matrix has a distinct plane parallel structure. The dominant mineral is again quartz with only minor amounts of sericite, chlorite, and cubes of pyrite which have been partially or completely altered to goethite. Occasional grains of sphene, apatite and zircon are seen. Late fractures are filled with quartz and scattered subhedral crystals of epidote.

The granule conglomerates associated with phyllites in the northeast part of the area are dark grey on a fresh surface and dark brown when weathered. In a rough hand specimen there is little suggestion of relict clastic texture and it is only in a sawn and polished specimen that the elongated granules may be noted. The average grain is about 5 mm in length. Under the microscope a majority of the grains are seen to be fine-grained quartzite. Granules of quartz are also noted. The fine grained matrix is composed of nearly equal amounts of quartz and an opaque substance. Much of the latter appears as very minute flakes which have the blue-black color of graphite in reflected light. Minor groundmass minerals include muscovite, sericite, apatite, chlorite and zircon. Fractures crossing the distinct foliation are filled with quartz and an unidentified light-yellow to dark-orange colored mineral. This unknown mineral resembles stilpnomelane although it lacks the pleochroism and cleavage described by Gruner (1946, page 14).

Greenstones

Occurrence

Non-foliated greenstones are found in several areas within the district. The first of these is the Resner Canyon location where other members of the Attwood crop out. As indicated previously, the contact between greenstone and underlying conglomerate was not observed. However, an unconformity exists between greenstone and overlying younger rocks of the Kettle River formation, and it is for this reason, as well as the similarity in degree of metamorphism, that these rocks are included in the Attwood formation.

A second outcrop area is located in the center of the north half of section 36, T 40 N, R 31 E. Here no other members of the Attwood are exposed although the unconformity with the overlying Kettle River sediments exists. Similar greenstones crop out in the floor of a canyon which trends west from the Toroda Creek road about a mile south of the section 36 outcrops. Several minor outcrops are also noted in roadcuts about one-half mile south the above canyon.

Fine-grained massive greenstones occur sparsely with the phyllites and granule conglomerates of the northeast portion of the mapped area and also, in greater abundance, on the Canadian side of the 49th parallel. Considerable additional field work would be necessary to determine the relationships in this area.

Description

Weathered outcrops are greenish-black to brown in color, and are cut by etched veinlets and by numerous fractures. A fresh specimen is dark green with disseminated pods and veinlets of white carbonate. No foliation was observed. The rock is porphyritic although this texture is very difficult to discern due to the lack of contrast between altered phenocrysts and groundmass. No features seen in outcrop or hand-specimen offer clues to an intrusive or extrusive origin.

In most thin-section, however, an amydaloidal structure is prominent and it appears that part or all of these rocks are extrusive. Chlorite, an unidentified brown mineral, and carbonate fill the vesicles. Pyrogenic minerals are augite and plagioclase. The augite occurs as partially chloritized, euhedral phenocrysts which reach a maximum length of 5 mm.

Subhedral plagioclase phenocrysts seldom exceed 1 mm and are altered to carbonate and epidote (?). The composition of the plagioclase was not determined. The groundmass is fine-grained and consists largely of chlorite with considerable magnetite and sparse epidote. Granular aggregates of quartz and albite (?) occur sporadically in the matrix. Carbonate filled fractures are common in all thin-sections.

Summary and Conclusions

Synorogenic metamorphism of low grade resulted in the production of phyllites from carbonaceous sandy shales. Excellent foliation was also developed in the dark granule conglomerates. The Resner Canyon quartzite-pebble conglomerate is crudely foliated in comparison to the finer grained rocks. No directional element is present in the greenstones and limestones. Most of the latter are finely crystalline.

The development of the sericitiform biotite in the phyllites suggest that temperatures of the warmest portion of the low grade zone were reached. On the other hand, confirmatory evidence of this temperature is not offered in the mineralogy of the greenstone since actinolite, which might be expected in a rock of this composition, is absent.

Original sedimentary bedding and schistosity are parallel. No secondary s planes were noted, and crenulation of the plane foliation in such a manner as to produce a lineation parallel to fold axes is not evident either.

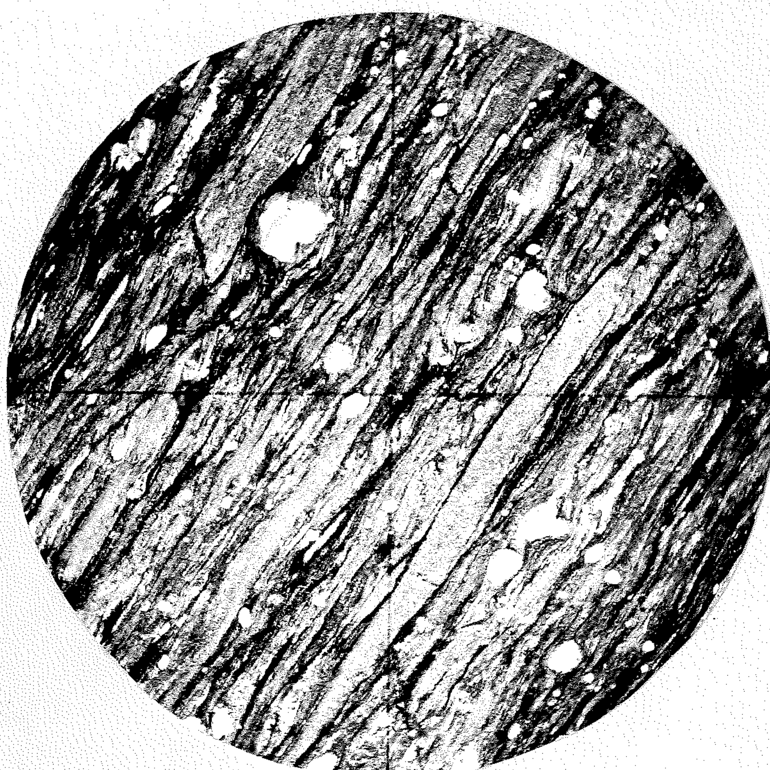
Age and Correlation of the Attwood Low Grade Metamorphics

The Attwood series of low-grade metamorphics was mapped by R. W. Brock (1901, 1902) and remapped and named by R. A. Daly (1912, Part I). These workers considered the Attwood Carboniferous in age on the basis of lithologic correlation with fossiliferous rocks which crop out in the Little Sheep Creek area between the Kettle River at Laurier, Washington, and the Columbia River to the east.

Pardee (1918), in summarizing the age relations of the Carboniferous Covada Group in the Colville Indian Reservation, correlates the Covada with the Attwood, the Slocan rocks at Kootenai Lake, British Columbia, and the lowest member of the Cache Creek series of the Kamloops district in British Columbia.

Several poorly preserved brachipods were collected in 1951 by B. Seraphim from Attwood formation in the Phoenix district a few miles north-east of the present area. V. J. Okulitch (1954) stated that these fossils were non-diagnostic and merely indicate a Paleozoic age.

The Anarchist group of rocks which crop out a short distance west of the Kettle River-Toroda Creek district is lithologically similar to the Attwood. Daly recognized this similarity, but assigned the Anarchist to the "carboniferous" on the basis of resemblances to rocks in western British Columbia. More recent investigations of the Anarchist indicate that it may comprise three or more distinct formations ranging considerably in age (P. Misch, 1949b).



KELLY MOUNTAIN GRANODIORITE

Occurrence

The distribution of this granodiorite is shown by the sketch map in figure 9, page 159. The ten to twelve square miles mapped during the present investigation represents only a small portion of the main body which lies to the east and southwest. Some parts of the area that show Tertiary sediments and volcanics on the surface are evidently underlain by the same plutonic mass.

Outcrops located in the southeast quarter of section 36, T 40 N, R 31 E clearly show that the granodiorite is intrusive into the Attwood formation. Additional information concerning the age is furnished by the fact that a basal member of the Eocene Kettle River formation consists of a talus like breccia which is composed almost exclusively of angular fragments of the rock.

Description

The usual rock is medium-grained and gray in all-over color. Light gray quartz, feldspar and biotite are readily recognized in hand specimen. Unidentified dark green mafics together with biotite form dark patches which are rather evenly distributed throughout the light-colored background. Aside from a slight range in amount of dark minerals and the altered rocks, the chief megascopic variation is a

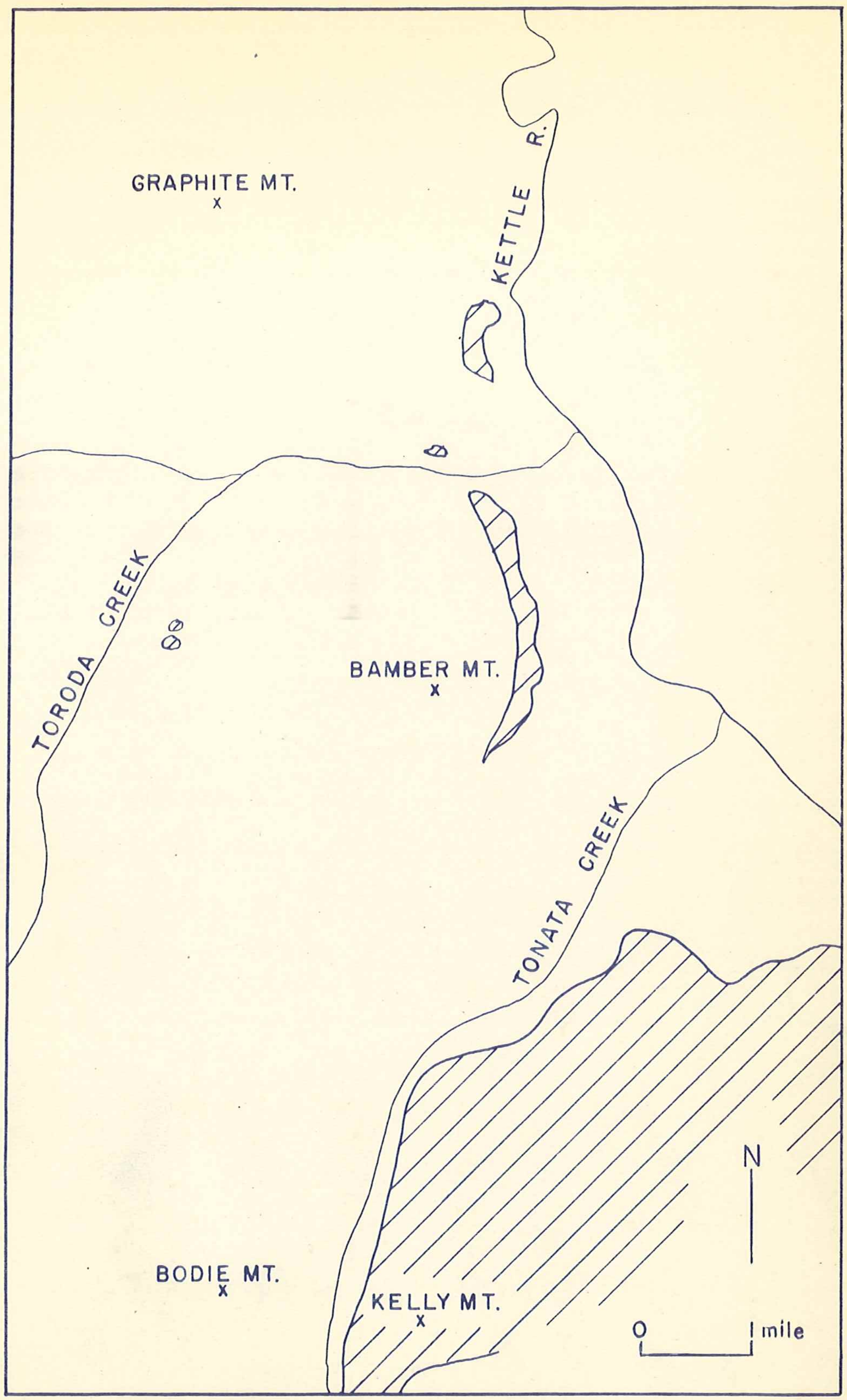


Figure 9. Distribution of the Kelly Mountain granodiorite.

porphritic rock which crops out extensively on the north side of Kelly Mountain. In this locality potash feldspar occurs as randomly oriented, subhedral phenocrysts .5 to 2 cm in length. Rocks from this area have a rather vague porphyritic texture and dark minerals appear in larger clots or aggregates than in the usual rock.

In general there is no notable diminuation of grain size in border zones. An exception was noted in the small masses which crop out in section 36, T 40 N, R 31 E. In this locality a gradation from medium to fine-grain occurs as the contact with the Attwood formation is approached.

In thin-section the average rock has a hypautomorphic-granular texture. The same texture characterizes the groundmass of the porphyritic rock mentioned above. Plagioclase, orthoclase and quartz are the essential minerals. Mafics include biotite, hornblende and augite. Minor accessories noted in all thin-sections were magnetite, apatite, zircon and sphene. Allanite was noted in one section.

The plagioclase occurs as subhedral laths showing albite, carlsbad and, rarely, pericline twinning. Zoning is invariably present with the composition of the outer shell approaching An_{25} and that of the core An_{45}. Generally the plagioclase is clear and fresh but in sections 21 and D. 8. 15.50.3 sericite is quite common in the core zones and occurs more rarely throughout entire grains. Inclusions of mafics and magnetite were noted.

Except in the relatively rare cases (specimens 51.D.54 and 51.D.54 A) in which orthoclase forms phenocrysts, this mineral occurs interstitially between the earlier minerals. It is commonly somewhat turbid in plane light, and in narrow bands paralleling fractures it is much altered to kaolinite. The poikilitic phenocrysts are subhedral and most orientations show carlsbad twinning. The margins of the grains are somewhat irregular or crenulated. Inclusions of plagioclase and the mafics are quite common.

Hornblende appears as individual subhedral crystals and as partial or complete rims surrounding altered augite. The different occurrences of the mineral suggest that two generations are present. Twinning parallel to 100 is common. Pleochroism is from yellow-green to green. Inclusions are apatite, sphene, zircon and magnetite.

Biotite is the most common dark mineral. In the average rock it is fresh, though bent laths showing wavy extinction occur frequently. In thin-sections from several localities biotite is partially altered to chlorite and magnetite; in others, it has been almost completely replaced. Apatite, zircon which is occasionally surrounded by faint haloes, augite and magnetite all occur as inclusions.

Augite is present as fresh subhedral crystals and in anhedral forms showing various degrees of alteration to hornblende, biotite and chlorite. In several sections the pyroxene associated with strongly chloritized biotite is itself completely unaltered. Aside from the minor accessories, augite crystallized earlier than the other minerals.

Quartz fills the somewhat angular interstitial spaces and apparently has been the last mineral to crystallize.

Alteration

Aside from the deuteric alteration affecting plagioclase, augite and biotite, there are two additional types of alteration which should be mentioned. The first of these consists of nearly complete change of biotite to chlorite and the development of abundant sericite in plagioclase. This kind of alteration is strictly of local occurrence. It was observed throughout a 100 foot thick zone on the hanging-wall side of a fault along the northeast border of the granodiorite body outcropping in sections 28, 33 and 34, T 40 N, R 32 E. The chloritization may have been effected by hydrothermal solutions channeled upward along this fault. A second type of alteration was observed in many outcrops throughout the granodiorite area. A heterogeneous pattern of fractures is marked by faintly pink or tan lines about 0.25 inches wide. Under the microscope these structures are seen to be fractures, filled by quartz and sparse epidote, which are bordered by thin bands in which all orthoclase has been largely altered to kaolinite.

Related Pegmatite and Oligoclase-rich Dikes

Coarse grained quartz-potash feldspar rocks associated with the granodiorite crop out in a cut on the north side of the Toroda Creek road one and a quarter miles west of the Toroda townsite. At this locality there is a transition from granodiorite to pegmatite rather than a sharp border between the two. This transition is effected through a gradual decrease in mafics and plagioclase in the granodiorite. No similar pegmatites were observed in larger adjacent masses or in the Kelly Mountain Area.

Ptygmatic dikes composed of oligoclase and rare potash feldspar crop out on the Toroda Creek road 0.9 miles west of Toroda. More extensive outcrops showing the same dikes continue northward for nearly a mile. Similar offshoots are found in cuts at an elevation of 2400 feet on the Tonata Creek road. These dikes vary from a few inches up to a foot in width. In most cases they cross rather than parallel the structure of the enclosing amphibolites. In some instances these dikes cut across each other without any dilation. In areas where dikes cross amphibolites in which diopside or distinctive bands appear there in no dilation either. Distinct sharp borders are usual. No traces of undisturbed amphibolites were noted in the dikes. Lack of dilation is accepted, however, as a valid indication of a metasomatic mode of emplacement. Direct evidence of the relationships of the dikes to the granodiorite was not found. In other words, in no case was an offshoot traced back to the parent body. The restriction of these dikes to a narrow zone paralleling the contact is the chief support of a genetic relationship with the intrusive.

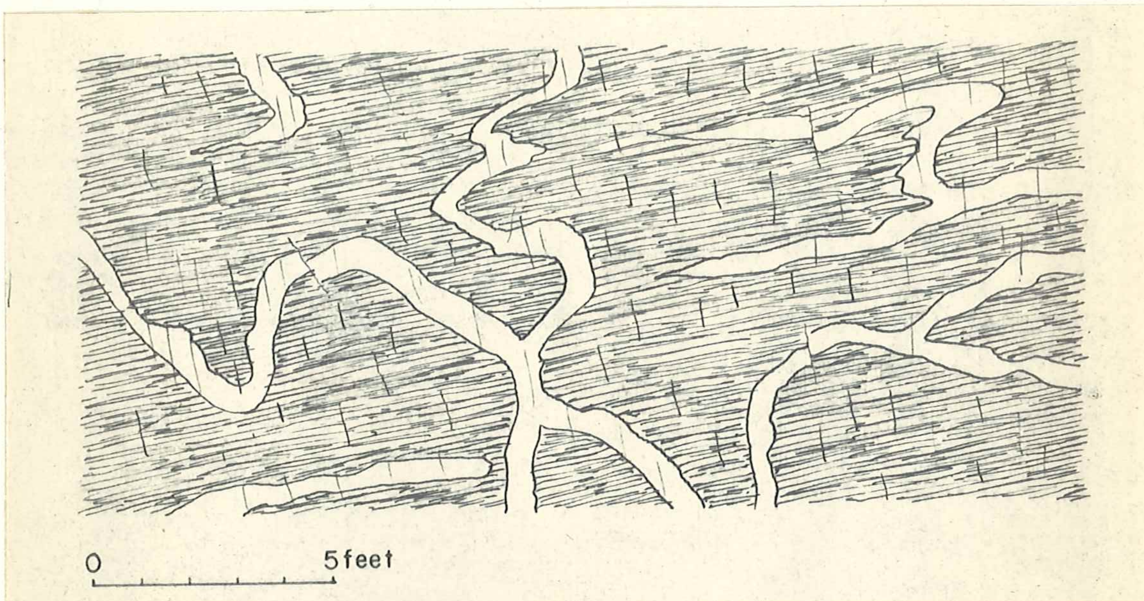


Fig. 10. Oligoclase dikes cutting diopside-bearing amphibolite exposed in a road cut .9 miles west of Toroda townsite.

Contact Effects

The contact-metamorphic zone surrounding the smaller granodiorite bodies does not appear to be more than a few hundred feet in width. Mineralogical changes in the feldspathic quartzite consist of the alteration of biotite to chlorite and rather intensive seriticization of plagioclase. In addition, a number of areas show veinlets of black tourmaline which may be related to the contact action. Amphibolites show some chlorite and considerable veining with epidote and quartz. Attwood limestone is locally crystallized to a fine grained marble containing scattered grains of diopside, garnet, and vesuvianite, and rare plates of phlogopite. The phyllite a few feet from the contact in section 36, T 39 N, R 31 E has been partially bleached to a light tan rock which in thin-section shows no more than the usual degree of crystallization.

Contact effects surrounding the main mass of the Kelly Mountain area range from slight to pronounced. Along the north and west margins no contact aureole was noted. At the Kelly Mountain tungsten property, less than a mile south of the mapped area, the granodiorite contact again crosses the strike of Pre-Attwood rocks. Limestone members of this formation have locally been converted to diopside, wollastonite, garnet, epidote and possibly hedenbergite and actinolite. In addition to the scheelite, molybdenite, chalcopyrite and bornite were noted. Ore minerals may be later than the silicates since some of the scheelite occurs within the granodiorite a short distance from the contact.

Summary and Origin

As indicated by the table (page 168) showing approximate percentages of minerals present in the various thin-sections, the rock varies from a quartz-poor granodiorite to a quartz diorite. One specimen with nearly equal amounts of orthoclase and sodic andesine is closer to a quartz monzonite.

The following field and microscopic features suggest an orthomagmatic origin for the Kelly Mountain granodiorite body.

Field observations:

I. The granodiorite mass cuts across structural trends of both the Pre-Attowwd and Attwood rocks.

II. Fracturing and minor folding of the country rocks suggest a forcible mode of emplacement.

III. Skialiths or other exotic blocks were not observed within the granodiorite.

IV. A chilled border was noted in outcrops located in the southeast quarter of section 36, T 40 N, R 31 E.

V. A contact aureole showing slight to pronounced alteration may be observed in several areas along the border zone.

Microscopic features:

I. An igneous sequence of crystallization is indicated; i.e., augite was early and quartz was the last mineral to form.

II. Crystalloblastic textures are absent. The feldspars have relatively smooth rather than crenulated borders.

III. Deuteric hornblende surrounding augite cores is commonly observed.

Age of the Kelly Mountain Granodiorite

The granodiorite is intrusive into the metamorphosed Attwood formation and was exposed to erosional agents which deposited the Kettle River formation. On this basis, the intrusion may have taken place any time between late Paleozoic and early Tertiary times. Aside from zones adjacent to faults, the granodiorite shows relatively little alteration, crushing or shearing which might indicate participation in a second regional orogeny, and thus the granodiorite might well be of late Cretaceous or early Eocene age.

TABLE 5

APPROXIMATE MODES OF THE KELLY MOUNTAIN GRANODIORITE

SPECIMEN*	55	54	54B	52	57	150	150A	21
biotite	10	10	10	10	15	10	10	1
orthoclase	15	35	40	45	25	20	20	20
plagioclase	50	35	30	25	40	40	45	40
quartz	15	10	10	10	10	15	15	15
hornblende	5	5	5	10	10	5	2	5
augite	5	2	2	2	t	5	5	5
apatite	t	t	t	t	t	t	t	t
zircon	t	t	t	t	t	t	t	t
sphene	t	t	t	t	t	t	t	--
magnetite	t	t	t	t	t	t	t	t
sericite	t	t	t	t	t	t	t	t
epidote	--	--	--	--	--	t	--	--
chlorite	t	t	t	--	--	5	1	15

*All specimen numbers are prefixed by 51.D.

KETTLE RIVER FORMATION

Introduction

As illustrated by the sketch map in figure 12, page 174, major outcrops of this formation are found along the lower course of Toroda Creek and its tributaries. Several exposures are found on the slopes of the Kettle River valley in the northern part of the district. A very small occurrence was also mapped on the Canadian border near the northeast corner of the area. Nor more than eight square miles of this formation crop out in the map area.

Daly (1912, part I) described many isolated patches of this formation on the north side of the 49th parallel. The stratigraphic sequence listed in his report consists of a coarse basal breccia, a conglomerate, and a sandstone with intercalated shale members. He also states that the sediments have been folded, faulted and intruded by various porphyritic sill and dike rocks. The thickness was estimated as 2100 feet although no single outcrop are included all members of the formation or approached the maximum thickness. These sediments unconformably overlie the phyllites, quartzites, limestones and greenstones of the Anarchist formation and are, according to Daly, conformably overlain by the Midway lavas.

The stratigraphic sequence determined in Canada by Daly is, in general, duplicated in the present area.

However, an additional member is present. It consists of a series of thin andesite flows which conformable overlie the sandstone. These flows crop out as a prominent knob in the southeast quarter of section 19, T 40 N, R 32 E. In this section the Midway volcanics are in unconformable contact with Kettle River andesites. A similar discordance between the two formations may be seen in many other localities in the district. This is in disagreement with Daly's statement that the Kettle River formation is conformably overlain by the Midway volcanics.

Sediments of Kettle River age rest unconformably on the low-grade metamorphics of the Attwood formation. Outcrops showing this relationship are found on the north side of Resner Canyon and along the west side of Toroda Creek. Locally the Kettle River formation is also underlain by the Kelly Mountain granodiorite which has intruded the Attwood formation.

The best exposed section of the Kettle River formation is found in the west half of section 2, T 39 N, R 31 E along the north slope of the Mariae Creek Valley. Here at least 1000 feet of breccia, conglomerate, sandstone and shale may be seen. A thickness of approximately 1500 feet is poorly exposed on the west side of the Kettle River in sections 9 and 16, T 40 N, R 32 E.

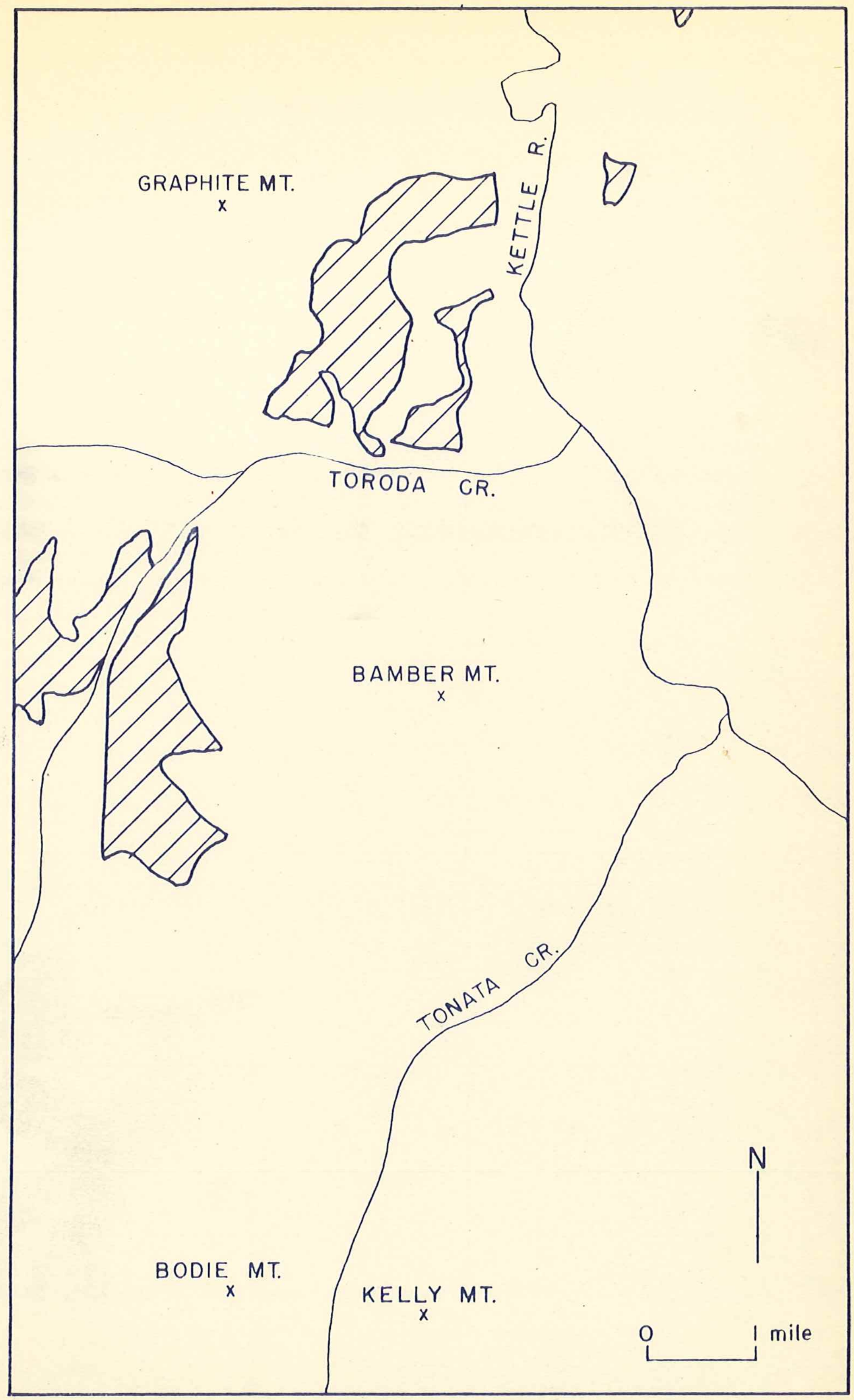


Figure 12. Distribution of the Kettle River formation.

Breccia

Occurrence

Breccias which are overlain by and occasionally interfinger with conglomerates form prominent bluffs in the Resner-O'Conner canyon area on the east side of Toroda Creek. They are also found near the valley floor in the lower course of Marias Creek. A breccia showing a crude stratification crops out on the north side of the Toroda road one and one-half miles west of the Toroda crossroads. In this area the thickness is around 400 feet. Estimation of the thicknesses in other outcrops was impossible since no traces of bedding were detected. The distribution of the breccia appears local rather than widespread. In several outcrops it resembles a talus accumulation, and in no case do the materials appear to have been transported far from the source.

Description

In the Marias Creek-O'Connors canyon area a large share of the fragments in the breccia consist of a medium-grained, light-colored rock identical in appearance with the average type of the Kelly Mountain granodiorite. Angular pieces of a dark greenstone are also found but are not common. Except in areas adjacent to the Tertiary intrusives the breccia fragments are rather loosely held in a brownish-green matrix consisting of granulated granitic material. The size of the fragments ranges from the minute grains in the matrix up to rectangular blocks measuring ten inches. Most common, however, are angular pieces ranging from 3 to 4 inches in maximum dimension. The surface of these blocks is pitted due to the weathering and removal of the dark constituents.

In thin-sections of the light-colored fragments the mafics can be identifed as biotite, hornblende and augite. Biotite is the least weathered of these minerals and unlike the pyroxenes and amphiboles shows little tendency to be removed during the thin-section grinding process. Plagioclase is the most abundant feldspar; aside from some limonitic staining along cleavage traces there is no sign of alteration which may be attributed to weathering. Orthoclase is clouded with clay minerals. Quartz constitutes about fifteen percent of the average specimen. Texturally and mineralogically these light colored breccia fragments are identical with the dominant type of the Kelly Mountain granodiorite.

Under the microscope, sections of the greenstone are seen to be composed of an aggregate of chlorite, sericite and carbonate with sparse relicts of augite. Plagioclase laths are altered to sericite. Subhedral and euhedral crystal outlines characteristic of the amphiboles now enclose a limonite stained intergrowth of chlorite and carbonate. Irregular rounded areas similar to vesicles are filled with carbonate and chalcedony. These features suggest that the original rock was an extrusive porphyry of intermediate or basic composition. There is some similarity between these fragments and the greenstone member of the Attwood formation.

In the crudely stratified compact breccia west of Toroda townsite there is a wide range in size of the fragments. Some measure two and three feet, others less than an inch. The smaller fragments show some rounding but as a whole there is little indication of lengthy, if any, transportation by water. In view of the latter, the presence of a very few well rounded pebbles in what appears to be a talus accumulation requires explanation. These deeply weathered, dark colored pebbles may have been carried over the face of an early Tertiary escarpment by intermittent streams.

Most of this breccia consists of angular blocks of a light colored crystalline rock. The origin of this material is apparent since the rock is to the eastward in contact with an offshoot of the Kelly Mountain granodiorite. The source of fragments of a green porphyry which are locally intermingled cannot be easily explained. Megascopically the porphyry appears as angular to subangular blocks an inch or less in diameter. In thin-section the rock is seen to be greatly altered but can be identified as a vesicular andesite porphyry with phenocrysts of calcic andesine and chloritized hornblende in a felty groundmass of feldspar, chlorite, carbonate and iron oxides. No glass was noted. Both generations of feldspar are much altered to sericite and carbonate. The vesicles are lined with quartz and have a light green, weakly birefringent core which is probably a chlorite. These porphyritic fragments have not undergone the metamorphism of the Attwood greenstones, nor do they resemble the andesites found locally in the Kettle River formation.

The crudely stratified breccia described above is undoubtedly a talus accumulation. Whether it is contemporaneous with similar rocks in the area is not known since the characteristic overlying conglomerate member is absent. The breccia is cut by dikes and sills and appears to be unconformably overlain by Midway volcanics.

Conglomerate

Occurrence

Conglomerates crop out in the Marias Creek area, north of Resner Canyon along the east slope of the Toroda valley, and in several localities on the west side of the Kettle River from 2 to 4 miles south of the 49th parallel. The thickness near Marias Creek is difficult to determine due to disruption of the rocks by faults and numerous dikes. However, it was estimated as 700 to 800 feet. No attempt was made to determine the thicknesses in other outcrop areas.

The lenses of the conglomerate noted in the breccia outcropping on the east side of Toroda Creek suggest that at least portions of the two units were being deposited at the same time and thus interfinger. In the lower Marias Creek valley, however, the thick conglomerate overlies the breccia. Greenstones of Attwood age are overlain by the coarse clastics in exposures noted about one and one-half miles east of the mouth of Resner Canyon.

Description

The rock is a compact aggregates of sub-rounded to rounded pebbles and boulders ranging up to a foot in diameter. These materials are enclosed in a matrix of silt and sand which is often slightly calcareous. Pebbles and boulders are composed of quartz, various greenstones, dark-colored phyllites, limestone, quartzite, granodiorite, and granite. Much of this material resembles and could have been derived from the underlying Attwood formation. A conglomerate forming a prominent outcrop in section 21, T 40 N, R 32 E consists of well rounded boulders of a rock identical with the Kelly Mountain granodiorite. Boulders of the same rock are very common in all outcrops of the conglomerate.

Arkosic Graywacke, Graywacke and Shale

Occurrence

In the Marias Creek area the upper limit of the Kettle River conglomerate is marked by a gradual transition from a pebble conglomerate to a coarse grained snadstone with subordinate intercalations of shale. Similar relations were noted in outcrops on the west side of the Kettle River valley about two miles south of the international boundary. In addition to the above areas, sandstones, shales and occasional lenses of pebble conglomerate crop out extensively in the Grephite Creek valley.

The shale occurs as one to ten foot thick beds intercalated with the sandstone. It constitutes only a very minor percentage of the Kettle River rocks mapped in this area.

Description

Arkosic graywacke and graywacke: Most of these rocks are coarse grained although, as mentioned above, gradations from sandy silt and shale to granule and pebble conglomerates do occur. The color of weathered specimens ranges from a yellowish gray to dusky yellow while that of fresher rocks shows a variation from pale olive to grayish-olive. Angular to sub-rounded grains of quartz and feldspar as well as numerous rock fragments are easily detected in coarse-grained specimens. The rock is usually sufficiently compact and well-cemented that even the weathered and slightly porous specimens do not crumble easily. Traces of bedding are generally apparent.

A fine-grained grayish-green sandstone with the appearance of a graywacke occurs locally. It is a very compact, massive rock showing very little indication of bedding and might easily be mistaken for an aphanitic igneous rock.

The microscopic description of the dominant arkosic graywacke is given below under (a) while that of the graywacke follows under (b).

(a) At least fifty percent of the rock is composed of potash and plagioclase feldspar. Quartz is present in amounts ranging from 10 to 15 percent. Other minerals include biotite, chlorite, magnetite, sparse hornblende and rounded grains of zircon and apatite. Kaolinitic and sericitic material is present but not abundant. Fragments of chert, quartzite, a dark phyllite, porphyries, trachytic textured volcanics and various altered lithic materials are present. The average size of the angular to sub-angular grains is around .5 mm and the maximum seldom exceeds 2 mm.

The cementing material and matrix may be carbonate (specimen D.7.22.50.5A) or silica (specimen D.7.20.50.5); more often they are a combination of both. The silica has a low birefringence and forms a nearly sub-microscopic aggregate of grains resembling chert or chalcedony. Carbonate occurs in random intergranular patches that may extend into and replace adjacent plagioclase grains. A dusty, orange to brown staining in the matrix is probably an iron oxide.

(b) In thin-section it appears that approximately a third of the graywacke is made up of angular to sub-angular grains which average .2 mm in greatest dimension. Of this amount quartz comprises nearly 10%, feldspar 20 and pyroxene 5 percent. The balance of the rock is composed of a fine mixture of chlorite, sericite, iron oxide, carbonate, shreds of biotite and what appears to be quartz. The latter apparently is the cement. A characteristic feature is the repacement of parts of most pyroxene and some feldspar by carbonate.

Shale: The thin-bedded, nearly papery shales which crop out at an elevation of 3250 feet on the north slope of the lower Marias Creek valley are very fine-grained and pale yellow in color. Weathered sheets of the shale are buff to nearly white colored. Imprints of leaves, grasses, seeds and other plant remains are abundant in some layers.

Shales from other localities are generally darker in color and lack the fissility of the Marias Creek rocks. Bedding is well marked, however, by alternate layers of light and dark material. Traces of fossil plants are almost always present. In one locality (D.8.30.50.3), the remains of a four inch fish were found.

Thin-sections of the main type of dark shale show very sparse grains of sufficient size to permit identification.

Quartz in angular particles .05 to .1 mm in size and smaller flakes of strongly pleochroic biotite are seen. Carbonaceous and argillaceous materials appear to constitute most of the rock. Wisps of sericite are abundant. Occasional light-colored laminae are rich in carbonate.

Andesites

Occurrence

Volcanics which conformably overlie the arkosic graywacke member of the Kettle River formation crop out as a prominent knob in the southeast quarter of section 19, T 40 N, R 32 E. This knob consists of eleven concordant thin flows which vary in strike from N 60 E to east-west and dip 70° south. A nearly flat-lying flow of the Midway Volcanic group is exposed at the base of the knob.

Similar volcanic rocks of Kettle River age were not observed elsewhere in the area.

Description

Each of the eleven flows appears megascopically similar in lithology and structure. The thickest flow measures twenty feet, with the others only a few feet less. Each flow consists of the following structural units: a bottom breccia two to three feet thick, a central columnar section up to fifteen feet in thickness, and a chilled columnar crust two to three feet thick. This chilled crust or flow top resists weathering more than other parts of the flow and thus forms a wall-like structure rising three to six feet above the general level. The blocks in the brecciated zone are three to five inches in diameter and are composed of a glassy porphyritic gray rock with sparse vesicles. The weathered outer shell of these blocks is one-half inch thick. The central zone of a flow consists of a grayish-green, dense porphyritic rock which forms crude columns about a foot in diameter. Phenocrysts are of a yellow-green color. The chilled crust consists of a brown-weathering, dark-gray, glassy rock. Its amygdaloidal character is apparent on the weathered surfaces. The amygdules are light gray in color and have the shape of elongated tubes and tabular forms paralleling the columnar joint fractures but otherwise having no relationship to them.

Thin-sections of the chilled crust show phenocrysts of calcic andesine, hypersthene and augite in a hyalopilitic groundmass composed of microlites of sodic andesine, sparse augite granules, magnetite and light brown glass. The index of the glass is slightly less than that of the Lakeside 70 cement (n about 1.53). Plagioclase is subhedral, zoned, filled with inclusions of glass, and reaches a maximum length of 2.5 mm. Augite appears in euhedral to subhedral crystals seldom more than .7 mm in length. Many augite phenocrysts are surrounded by a thin rim of a mineral having the birefringence, parallel extinction and pleochroism of hypersthene. Hypersthene also occurs as subhedral to euhedral crystals containing inclusions of glass and magnetite. Cross-sections are nearly square in outline due to the development of 100 and 010 faces rather than the unit prism (110, etc.). The material filling the vesicles is similar to the rock of the chilled crust except that the interstitial glass contains more sub-microscopic crystalline material. Under crossed nicols, then, the amygdaloidal material has less groundmass isotropism than the enclosing rock. In plain light the two are distinguished by differences in amount of disseminated iron oxide and by a darkening of the wall of the vesicles.

The columnar central portion of the flow has a texture similar to that of the chilled crust except that it is much obscured by alteration products. Late-stage volatiles, unable to escape rapidly through the chilled crust evidently reacted with the crystalline portions of the rock to produce abundant chlorite and carbonate and small amounts of quartz and secondary magnetite. The matrix of glass appears little affected. Glass-enclosed microlites are unchanged. Alteration products replace the phenocrysts to the extent that none of the original material remains.

No thin-sections of material from the brecciated zone were examined. Except for the absence of the elongated vesicles, the megascopic appearance of the blocks is similar to that of the chilled crust.

Age and Correlation of the Kettle River Formation

The Kettle River formation is similar to other Early Tertiary rocks which were deposited in broad open stream valleys and lake basins in many sections of the northwestern United States and southwestern Canada. The flora which Brock and Daly collected in the Midway section of the Canadian boundary, was examined by Penhallow (see Daly, 1912. Part II) and considered by him to be Lower Oligocene in age. Penhallow's age designation was based upon the distinct similarity of flora from the "Lower Oligocene" Green River lake beds of Wyoming and Colorado with the flora of the Kettle River formation. However, Green River rocks have, since Penhallow's time, been designated as Middle Eocene. This age is compatible with the present writer's conclusion that the Kettle River rocks were folded, faulted and considerably eroded before the first of the Midway volcanics were erupted.

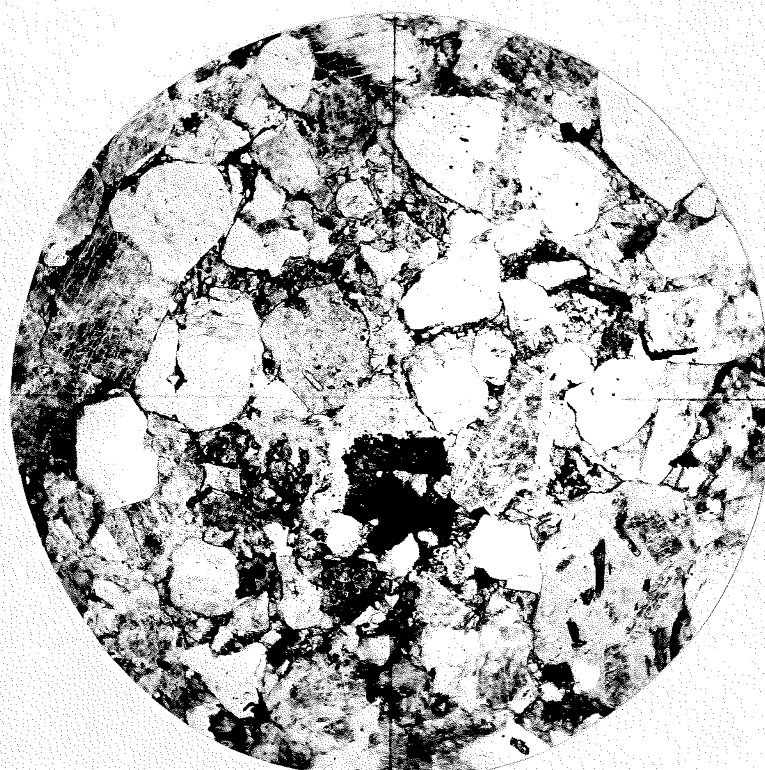


PLATE XXV

A. Photograph of massive bluff of the Kettle River breccia. Outcrop on the north side of the Toroda Creek road between the Kettle River and Graphite Creek.

B. View of a portion of the Kettle River breccia outcrop are in O'Connor Canyon.

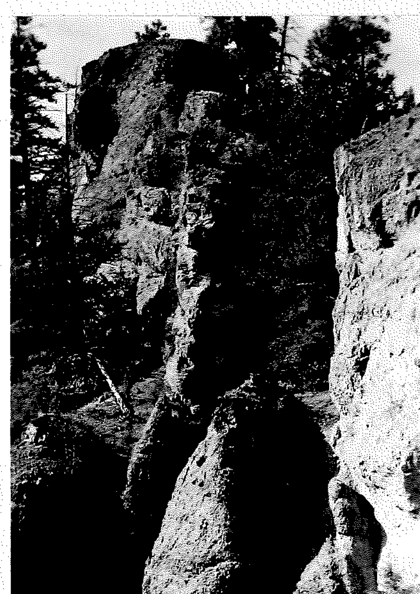
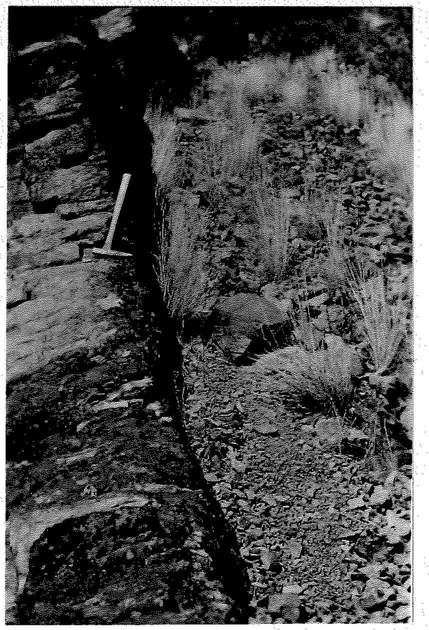


PLATE XXVI

A. Photograph of the hypersthene andesite flows which crop out west of Graphite Creek. The chilled crust and columnar section of individual flows show clearly in this view.

B. Chilled crust of one flow of the series shown in A, above. Although not shown in this photograph, pipe-shaped amygdules cross this tabular crust at right angles.



INTRUSIVE ROCKS CUTTING THE KETTLE RIVER SEDIMENTS

General Statement

Intrusive rocks cutting the Kettle River formation were noted in many localities in the district. Only a few of these bodies, however, are shown on the geologic map accompanying this report.

By far the most abundant of the intrusives are the dikes and irregular bodies of andesite which presumably are related to the flows of the Midway volcanic group. These rocks commonly contain hornblende and biotite as their mafics and are described below.

Less common, but locally prominent are dikes of hypersthene basalt, prophyritic rhyolite, and a microporphyry. Several small bodies of diorite are also intrusive into the Kettle River sediments.

Diroites

Occurrence

Two small diorite bodies crop out in the Graphite Creek valley. The larger of these is found near the floor of the valley in the northwest quarter of section 20, T 40 N, R 32 E. The intrusion is surrounded on three sides by Kettle River sandstones and is overlain on the west margin by an andesite flow of the Midway Volcanic series. The rock is characterized by prominent needles of hornblende and it is therefore described below as a hornblende diorite.

The second intrusive is located on the east side of the Graphite Creek valley in the southeast quarter of section 17, T 40 N, R 32 E. The outcrop trends nearly north-south and is roughly 500 by 100 feet in size. Heterogeneous, closely spaced jointing is present and obviously greatly facilitates erosion since the downhill side of the outcrops is strewn with angular blocks. A contact with the shales, snadstone and thin beds of pebble conglomerates of the Kettle River formation was observed on the east margin of the intrusive. The sediments in the contact zone are slightly more compact than usual.

Biotite is readily recognized in this rock and it is described below as a biotite diorite.

Description

Hornblende diorite: Outcrops of this rock are light-brown colored and are weathered to a depth of several inches. Irregular jointing is accentuated by spalling and rounding of the individual blocks. Fresh appearing specimens are grayish-green in color.

Randomly oriented amphibole laths up to 2 cm in length are the most characteristic feature of the rock. Thin laths of plagioclase, .5 to 1 cm in length, may be recognized with the hand lens. Aside from these larger crystals the rock is very fine grained.

The texture of the groundmass of the holocrystalline rock is hypidiomorphic granular. The average grain size of the groundmass feldspars is around .5 mm. Phenocrysts of plagioclase and chloritized amphibole form about 10 percent of the rock. Sparse orthoclase and rare quartz occur interstitially.

The plagioclase is zoned and has a composition ranging from An_{35} to An_{45}.

Plagioclase, hornblende and orthoclase all show evidence of late magmatic alteration. Plagioclase is partially converted to sericite and replaced by carbonate; hornblende is pseudomorphosed by chlorite, carbonate and magnetite. Orthoclase is altered to kaolinite and sericite.

Biotite diorite: The rock is fresh appearing and fine-grained. Biotite and hornblende comprise a third to one half of the specimen and feldsapr the remainder. The color resulting from this combination is difficult to describe but in general it is a gray with a faint tinge of tan.

The diorite is very uniform in texture throughout. No diminuation in grain-size was noted near the contacts.

The texture in thin-sections is hypidiomorphic and the euhedral to anhedral plagioclase, biotite and hornblende grains seldom exceed 1 mm in length. The zoned plagioclase is sodic andesine which usually is somewhat altered to sericite and kaolinite. It forms an estimated 55% of the rock.

Biotite and hornblende are present in nearly equal amounts and together make up around 35% of the typical specimen. Biotite is pleochroic from bright yellow to a brownish black. It may be partially chloritized along the grain margins and contains inclusions of apatite and magnetite. Hornblende always shows some degree of alteration to chlorite, magnetite and sparse epidote or carbonate. Inclusions of early magnetite and of apatite are common.

Turbid, anhedral orthoclase lies between the plagioclase laths. The mineral may form 5% of the rock. Quartz amounts to less than 3% and also occurs interstitially.

Rare, subhedral crystals of partially chloritized augite were noted. Minor accessories are apatite and a few scattered grains of sphene and zircon.

Andesites

Occurrence

Almost all of these intrusives are dikes which strike in a northerly direction and are either vertical or dip steeply. Outcrops are very common in the channels of east-west trending tributaries of Toroda Creek as well as on the crests of paralleling ridges. Similar dikes crop out in the Tonata Creek drainage area. One of the largest of these tabular bodies was noted at the mouth of the Marias Creek canyon. In this locality a vertical dike is 45 feet wide.

A dike which crops out in the east half of section 3, T 39 N, R 32 E can be traced for more than a mile. Within this distance the width varies from around a hundred feet to more than 600 feet. The foregoing examples are unusual since the average dike is only 10 to 15 feet in width.

A number of andesite sills in the Kettle River conglomerate crop out in the channel of Graphite Creek a thousand feet north of its confluence with Toroda Creek. The thickness of these discontinuous tabular bodies varies from one to four feet and their occurrence is not limited to a single horizon in the sediments. No sills were noted in other sections of the Kettle River formation.

Description

Weathered outcrops vary in color from pale yellowish brown to a dusky brown. Fresh specimens are yellowish gray, light olive gray, or pale greenish gray. All of the rocks are porphyritic. The phenocrysts generally comprise much less than fifty percent of the rock. Laths of feldspar and hornblende as well as small plates of biotite are surrounded by an aphanitic matrix.

Columnar jointing and thin selvages are common features. Some dikes are slightly vesicular. Contact effects on the Kettle River sediments are minor. Fine-grained sandstones and shales show slight induration. Conglomerates and the breccia appear unaffected. In areas where the dikes are abundant the sediments have been considerably fractured, tilted and shoved aside by the intrusives.

Thin-sections from many dikes were examined and aside from variations in amount and type of dark minerals and in the amount of glass, they are much the same. Phenocrysts of plagioclase and hornblende seldom exceed 2 mm in length. Microlites are embedded in a light to dark brown hypohyaline groundmass which is dusted with magnetite. The subhedral plagioclase phenocrysts are notably zoned. Outer shells are calcic andesine and the interior is more calcic. Glass and chloritized inclusions are common. Some plagioclase laths are clear and unaltered, others are partially replaced by carbonate or clouded with clay minerals and sericite. Dark minerals constitute less than 10 percent and perhaps average 5 percent of these dike rocks. Biotite and hornblende are the most common mafics. In some thin-sections augite and hyperethene are associated with hornblende. Others, like specimen D.7.28.50.4, contain biotite in addition to the foregoing. The dark minerals occur as euhedral to anhedral phenocrysts and may be partially altered. In the thin-section mentioned above, biotite and hornblende are often altered and surrounded by rims of magnetite, chlorite and some carbonate, whereas the hyperethene and augite, which presumably crystallized earlier, are unaltered. No explanation is offered for this situation.

Quartz is always present as a very minor constituent of the groundmass. It also occurs with carbonate in small veinlets (specimen D.7.20.50.1A) and as a filling of vesicles (specimen D.8.5.50.2). An early generation of magnetite forms subhedral crystals many times larger than the grains disseminated throughout the groundmass. Apatite is uncommon but has been noted as an inclusion in plagioclase and as rounded grains in the groundmass.

Rhyolite

Occurrence

Two rhyolite dikes are exposed in that part of Sawmill Gulch located within the southeast quarter of section 35, T 40 N, R 31 E. The dikes are eight to ten feet wide and in this locality cut through the dark shales, sandstones and granule conglomerates of the Kettle River formation. The two dikes are about a hundred feet apart and have a common north-south strike. The dip of the western dike is 65^{o} to the east. The second dike is vertical. Both show a crude columnar jointing and a thin chilled border.

No other rhyolite dikes cutting the Kettle River formation were noted in the district. Rhyolite dikes which intrude the Pre-Attwood formation in the Tonata Creek basin (section 10, T 39 N, R 32 E) may, however, be of the same age as the Sawmill Gulch intrusives.

Description

The two dikes from Sawmill Gulch are similar in hand-specimen and in thin-section so the following description applies to both.

Megascopically most of the rock is light tan colored on a fresh surface and slightly darker in a weathered outcrop. Sparse phenocrysts of biotite and feldspar and rare grains of quartz are distributed throughout a very dense groundmass. Vesicles are present but not common. The chilled border zone consists of a nearly white, cherty appearing band two to three inches wide. The fracture varies from irregular in most of the rock to sub-conchoidal along the margins.

A thin-section from the central portion of the dike shows sparse euhedral phenocrysts of sodic oligoclase and biotite together with anhedral quartz in a holocrystalline groundmass consisting of quartz, orthoclase, biotite, magnetite and sanidine. Zircon is found as inclusions in biotite, as grains in contact with magnetite and as isolated grains in the groundmass.

A thin-section of the chilled border shows phenocrysts of sodic plagioclase, orthoclase and biotite in a groundmass consisting of brown glass, small laths of biotite, and orthoclase. Groundmass biotite laths are crudely aligned. Quartz fills irregular fractures. Subhedral zircon is common and prisms of apatite occur.

Microporphyry

Distribution

Micro-porphyritic dike-rocks of rhyolitic composition intrude the Kettle River formation in at least three localities in the district. A ten foot dike is exposed 200 feet west of the center of section 2, T 39 N, R 31 E at an elevation of 2850 feet. The dike is vertical and strikes N 45° W. Two thin dikes of limited lateral extent crop out in the area on the west end of the ridge separating Resner and O'Connor Canyons. Shearing and minor faulting make the thickness uncertain but it does not exceed ten feet in either dike. Both strike N 15° E.

A third occurrence was noted at an elevation of around 2750 feet in the southeast quarter of the southwest quarter of section 21, T 40 N, R 32 E. The dike is 15 to 20 feet wide, has a vertical dip and strikes N 40° W. It does not cut the nearby Midway Volcanics.

Description

In outcrop the rock is light-colored and not notably jointed. It weathers at approximately the same rate as the enclosing Kettle River conglomerates. Some exposures are cut by shear zones and minor cross-faults.

The hand-specimen is a light gray, very fine-grained rock with few dark minerals. The porphyritic texture is vaguely discernible in a cut slab and can be accentuated by staining with sodium-cobaltinitrite. Quartz and feldspar can be recognized with a hand lens.

On the basis of thin-section examination it appears that quartz constitutes 10%, plagioclase 15 to 20%, mafics less than 10% and orthoclase 60 to 70% of this holocrystalline rock.

The plagioclase is a calcic oligoclase which forms subhedral phenocrysts with a maximum length of 1.5 mm. Zoning is present but not pronounced. The plagioclase is usually somewhat turbid and partially altered to sericite and carbonate. Orthoclase occurs in subhedral phenocrysts less than a millimeter in length and as spherulitic aggregates. These radiating structures are about .2 mm in diameter. Inclusions of biotite and sparse laths of plagioclase are present. At least 95% of the groundmass is composed of orthoclase. It is usually clouded with kaolinite.

Quartz is a minor constituent of the groundmass. It is also found as euhedral hexagonal crystals .5 to 1 mm in diameter and as corroded rounded grains of about the same size.

The common mafic is biotite. In most cases it is partially or completely altered to pennine and magnetite, and replaced by sparse epidote. Subhedral amphibole phenocrysts have been pseudomorphed by chlorite and carbonate. Sphene and magnetite are found as inclusions in the chlorite or in close proximity to it.

Irregular fractures in section D.7.26.50.7 are filled with epidote, chlorite and carbonate. These minerals also appear as a deuteric alteration of hornblende and it is possible that the filled fractures are products of the same phase in the cooling history of the dike.

Hyperathene Basalt

Occurrence

A hyperathene-basalt dike cuts the Kettle River conglomerate exposed on the west side of Toroda Creek in section 36, T 40 N, R 31 E. The dike is approximately three-quarters of a mile in length and on the northern few hundred feet it is intrusive into an andesite flow which locally is the oldest member of the Midway volcanic series. Its strike is N 10° E and its dip varies from 45° N at the south end to 70° N at the north end. The width ranges from 40 to 70 feet. Faults transecting the dike in several localities have displaced it 5 to 10 feet. Columnar jointing and a glassy chilled border are present.

Contact effects on the andesite flow of the Midway volcanics series are not noticeable. The silty matrix of the Kettle River conglomerate, however, is darkened and indurated throughout a four to five foot zone paralleling the dike.

No other basaltic intrusives were noted in the district.

Description

In hand-specimen the rock is grayish-black to olive black in color. Phenocrysts of plagioclase and mafics are sparsely distributed in a dense to glassy matrix. The fracture of the rock is irregular, sub-conchoidal or conchoidal, depending upon proximity to the chilled border zone.

In thin-section the phenocrysts are identified as plagioclase, hypersthene and augite. These minerals are embedded in a groundmass of feldspar microlites, magnetite, and dark brown glass.

The larger plagioclase crystals are euhedral or subhedral and enclose erregular patches of glass and subhedral grains of hypersthene. Average maximum length of the laths is .9 mm. They are invariably zoned and twinned. The composition varies from a core near An_{65} to An_{50} for the outer shell. In some zoned crystals there is no gradation from a calcic core to a more sodic rim. Instead there is a repetition of the core composition in successive alternate shells. Internal shells have the same composition as the outermost rim.

The microlites are lath shaped and have a composition of An_{50}. In the section examined there is only a slight tendency toward alignment of the laths.

Hypersthene occurs as euhedral prisms. The average maximum dimension is .5 mm. Pleochroism is distinct from a pale bluish green (z) to a faint pink color (x). The mineral usually forms a part of clusters of grains which also include plagioclase and augite. It also is found as isolated phenocrysts.

Augite forms euhedral to subhedral crystals which are usually about .3 mm in diameter. In plane light the color is a pale, yellowish brown. Simple twinning parallel to the c and a pinacoids is common. The crystals are bordered by a thin reaction rim of an unidentified fibrous mineral. Inclusions of magnetite were noted.

Hypersthene evidently was the first of the intratelluric minerals to form since it is found as inclusions in the plagioclase. The augite appears to have crystallized at about the same time as the plagioclase.

Summary and Discussion of Age

The two diorite bodies described above are clearly younger than the Late Eocene Kettle River formation. Field relations indicate that they are also older than the Late Oligocene - Early Miocene Midway eruptives. There appears to be little in common between these diorites and the "porphyrites" which Daly (1912, Part II, pp. 416-417) mapped a short distance north of the international boundary.

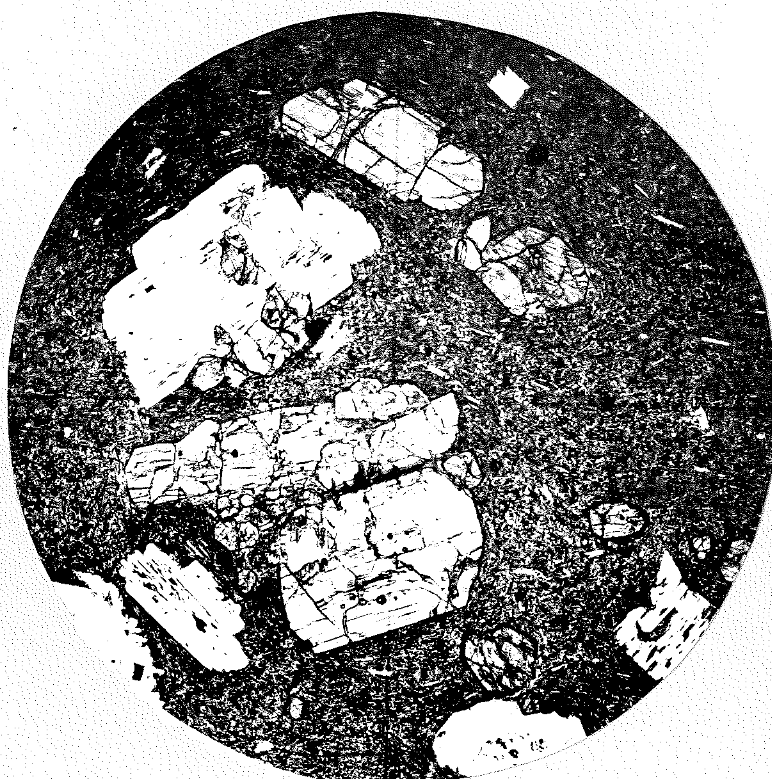
The andesite dikes are considered to be related to the Midway volcanic series since flows of comparable composition occur in this formation. Andesite dikes are by far the most abundant among those observed in the map area. This is in agreement with the bulk composition of the Midway lavas. If these dikes are to be regarded as feeders for the overlying flows it appears obvious that they are likewise of varying ages.

One or more rhyolite flows occur in the lower part of the Midway lava sequence. The rhyolite and microporphyry dikes may be related to this period of vulcanism.

The hypersthene basalt dike described on page 203 is clearly younger than the flows near the base of the Midway Volcanics since it cuts these rocks as well as the Kettle River formation. Flows of comparable composition were found in the middle portion of the Midway sequence. Since the hypersthene basalt dike cuts the lower Midway rocks it may be younger than the other dikes described in foregoing paragraphs of this paper.

PLATE XXVIII

Photomicrograph of a thin-section from a hypersthene basalt dike which cuts the Kettle River formation exposed on the west side of Toroda Creek. Subhedral grains of hypersthene and plagioclase together with anhedral augite are embedded in a felty groundmass.



MIDWAY VOLCANICS

General Statement

The Midway Volcanics in this district are a part of a discontinuous blanket of dominantly andesitic rocks which are widespread in the western part of the Okanogan Highlands and adjacent sections of the Midway Mountains in southern British Columbia.

In Canada, R. W. Brock (1902), R. A. Daly (1912), and O. E. Leroy (1913) have given descriptions of the Midway Volcanics occurring in the boundary district north of the present map area. Daly's descriptions are the most complete of the three. He subdivides the Midway into an "oldest", a "middle", and a "youngest" group. Except for an olivine basalt the first two groups are dominantly andesitic and are probably equivalent to the rocks in the present area. However, the trachyte, rhomb porphyry and analcitic lava of the "youngest" group have not been recognized in this district.

C. W. Drysdale (1915) describes trachytic lavas as representing the Midway Volcanics in the Franklin Mining District forty miles northeast of the international boundary at Midway, British Columbia. These might be the equivalent of part of Daly's "younger" group.

Andesites of possible Midway age have been described by Umpleby (1910), Lindgren and Bancroft (1914) and Pardee (1918) in the Sanpoil, Republic and Curlew areas.

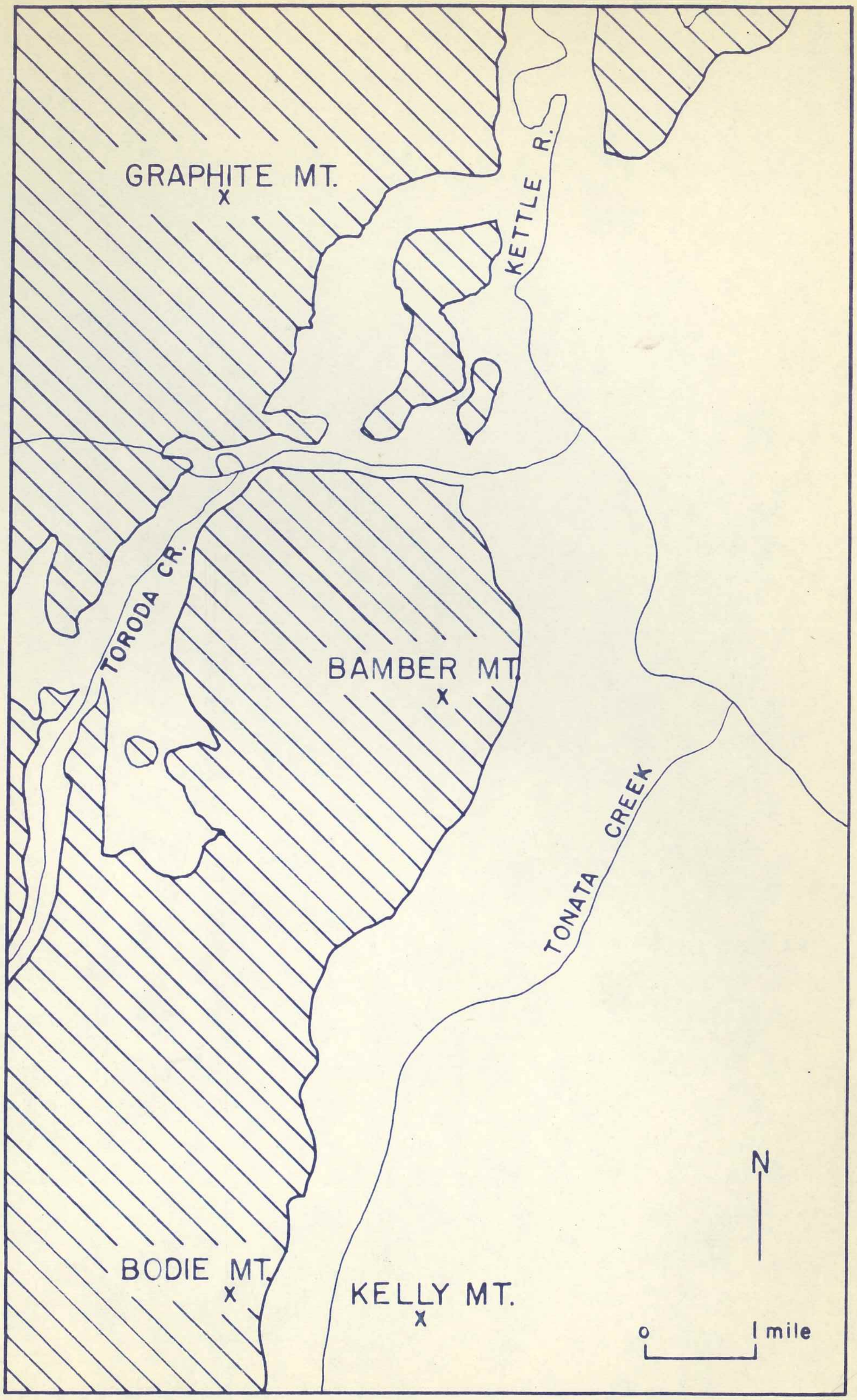


Figure 13. Distribution of the Midway volcanics.

Reconnaissance by the writer indicates that Midway lavas extend southward from the map area for a distance of at least twenty miles.

Within the Kettle River - Toroda Creek District the Midway Volcanics are, with the exception of Quaternary deposits, the youngest rocks represented. These lavas crop out over an area of forty-five square miles and unconformably overlie the Kettle River formation, the Attwood rocks and the Pre-Attwood rocks.

The thickness may reach as much as 3000 feet in the area from Bodie Mountain northwest to Toroda Creek. A similar thickness is indicated between the floor of Toroda Creek and the north end of the Bamber Mountain - Bodie Mountain ridge. Between the crest of this ridge and the Midway-Kettle River contact at the head of O'Conner's Canyon the lavas are at least 2500 feet thick. The succession of lavas is at best rather vague; however, from what is known of the sequence it appears that the Pre-Midway terrain was quite rugged. Early flows were limited in areal extent and as the topography was buried the younger flows covered greater areas.

The various lavas in the Midway series are described in the following paragraphs. This succession of rock types is based largely upon field work in the area lying between Toroda Creek and Tonata Creek. The subdivisions offered are tentative. In some cases the field relations were obscure and mineralogic variations were used as a basis for distinguishing the flows.

Trachytic Andesite

This rock overlies the conglomerate of the Kettle River formation in the Resner-O'Conner Canyon area. It is also found in contact with the Kettle River breccia on the north slope of the Marias Creek valley.

The usual specimen is porphyritic and light gray in color. Phenocrysts of feldspar up to 3 mm in length and smaller laths of a mafic mineral are randomly distributed throughout a dense groundmass. In some varieties altered mafics are more abundant than feldspar. Flow structures are absent in all except the vesicular specimens. In these, the flattened vesicles show a distinct alignment. Isolated crystals of analcite .5 mm in maximum diameter are occasionally noted in the vesicles.

In thin-section all specimens show distinct or indistinct microlites of feldspar which are crudely aligned to form a trachytic fabric. These microlites have a maximum extinction angle of near five degrees and an index distinctly greater than 1.537 and thus appear to have a composition close to An_{35}. Larger plagioclase laths and aggregates are more basic, being in the range from An_{60} to An_{65}. Inclusions of chlorite and a yellow-brown glass are common in these phenocrysts. The principal dark mineral is augite. It is almost always altered along crystal boundaries to a yellowish-green chlorite mineral. The same chlorite is abundant in the slightly glassy groundmass and perhaps is also an alteration product of augite. Euhedral brown hornblende, heavily rimmed with iron oxide, is a minor constituent of these rocks. In addition to these two mafics, several laths of hypersthene were noted in section D.7.24.50.3.

Hornblende-Augite-Andesite Porphyry

This distinctive lava crops out in the southwest quarter of section 25, T 40 N, R 31 E, and in nearby areas. In this locality it overlies the trachytic andesite described above. Thickness and relations with overlying flows were not observed. Also, the flow does not appear to be widespread and was not recognized in other parts of the district.

In hand-specimen, several features characterize this flow. First, it is a porphyry whereas other flows in the older Midway Volcanics are merely porphyritic. In addition there is an extreme regularity in the size (average 1 mm) and distribution of the feldspar phenocrysts. Hornblende forms distinct prisms with a maximum length of 2 mm. The rock weathers to a dark brown color but is yellowish-gray in a freshly broken specimen.

Under the microscope the plagioclase phenocrysts are twinned, usually zoned, and euhedral to subhedral in outline. The composition ranges from An_{35} to An_{45} which is in agreement with the negative and positive signs obtained from various phenocrysts. Alteration to sericite and a dusty opaque material are usual. The inclusions are magnetite and rounded grains of augite. Approximately forty percent of the rock is composed of the feldspar. The dark minerals are augite and hornblende with the latter by far the most abundant. It occurs in fresh, euhedral crystals which are pleochroic from pale yellow to a dark yellow-green. The maximum extinction angle observed was 18 degrees. Hornblende constitutes perhaps ten percent of the average specimen.

Augite makes up less than five percent of the rock. It is found in euhedral to subhedral crystals which are colorless to faint green in plane light. Like in the hornblende, magnetite is the only inclusion.

The constituents of the groundmass are magnetite, plagioclase microlites, small amounts of brown glass, rare apatite and irregular aggregates of a mineral resembling antigorite. The latter is possibly an alteration product of hypersthene although no evidence supports this suggestion.

Rhyolite

Acidic flows crop out in several areas in the district; however, due to the patchy nature of the exposures it is not known whether these lithologically similar rocks constitute a single or several flows.

In the northeast quarter of section 1, T 39 N, R 31 E the rhyolites are in uncomformable contact with the Kettle River conglomerate. A similar relationship with Kettle River sandstone and shale was observed on the west side of the ridge between the Kettle River and Graphite Creek (station D.9.1.50.5, southeast quarter of section 17, T 40 N, R 32 E). In the faulted area south of the lower part of O'Conner's Canyon and again on the north slope of the Marias Creek valley, the rhyolite overlies the trachytic andesite.

Megascopically the specimens from the various localities are very much alike. The chief differences consist of a range in color from a grayish-white to a pale tan, and a variation in the size and quantity of phenocrysts. No flow structures nor any other directional elements are seen in hand-specimen or outcrop. All specimens are slightly vesicular.

In the thin-sections the phenocrysts are identified as plagioclase, biotite and sparse sanidine. The plagioclase is sodic oligoclase. It occurs as subhedral to anhedral crystals which are commonly .8 to 1 mm in length. The mineral shows albite and carlsbad twinning and is seldom zoned. Sparse inclusions of magnetite, apatite and ragged biotite were noted. Biotite laths and plates up to 2 mm in maximum dimension were noted although .5 mm is a more common size. It is pleochroic from yellow to brown and shows no alteration. Clear, subhedral crystals of sanidine are very rare. In one section (D.7.21.50.1) it occurs in the holocrystalline groundmass.

At least ninety percent of an average specimen consists of a very fine-grained aggregate of orthoclase microlites, sparse biotite, quartz and magnetite. A dusty, limonite stained appearance in plane light is usual. Zircon and apatite were noted in several thin-sections.

Hypersthene Basalts

The best exposures of these rocks are found on the east side of Toroda Creek. In this area there are at least three recognizable flows which together have a thickness of approximately 900 feet. A large share of this thickness consists of blocky but compact lava. Columnar structures and flow-banding were noted locally. These rocks overlie the hornblende-augite andesite porphyry described on page 215, and are overlain by a porphyritic biotite andesite. In some areas on the east side of the ridge between Toroda and Tonata Creeks the basalts overlap onto the Pre-Attwood metamorphics.

Similar lavas crop out in the triangular-shaped area lying south of Nicholson Creek and west of Toroda Creek. Basalts also occur in other sections of the north part of the map area.

Megascopically these rocks vary in color from a dark gray to a gray black. The darkest varieties are glassy, porphyritic rocks with sub-conchoidal fracture. Several specimens show flow-banding. Phenocrysts of plagioclase up to 5 mm in length occur singly or in clusters associated with the mafics.

All thin-sections show phenocrysts of plagioclase, augite and hyperesthene. The texture of the groundmass may be microlitic or hyalopilitic. Alignment of the plagioclase microlites is pronounced in sections D.8.7.50.3 and D.7.24.50.5. In section D.7.24.50.4 the phenocrysts as well as the microlites are distinctly aligned although the hand-specimen shows no traces of flow structure.

The plagioclase phenocrysts are invariably clear and unaltered though they do contain inclusions of magnetite, mafics and glass. Several phenocrysts in section D.8.1.50.4 show a noteworthy alignment of glass inclusion with the 001 and 010 cleavages. The composition of the feldspar is An_{60} to An_{70}. The microlites, however, are in the An_{45} to An_{50} range.

Hyperesthene occurs in euhedral to subhedral prisms. It is often associated with augite and feldspar phenocrysts. In one section (51.D.12) it does not form phenocrysts but is found with groundmass microlites as laths .1 mm or less in length. The augite forms subhedral stubby prisms. Twinning parallel to 001 is common. The two pyroxenes are commonly present in about equal porportions. Several thin-sections contain sparse grains of dark brown hornblende. Aside from its color and distinct pleochroism, this amphibole is characterized by a thick shell of an opaque mineral which in reflected light appears to be magnetite.

Minor constituents are magnetite and rare apatite. Glass is always present. In sections 51.D.12.35 and D.8.7. 50.3 it is especially abundant. It is light to dark brown in color and in all specimens has an index slightly less than the 1.537 of the thin-section cement.

Biotite Andesite

Andesites containing scattered small flakes of mica are found in various parts of the district. The rocks are treated separately because of their mica and the absence of other dark minerals. In the ridge area between Toroda and Tonata Creeks these rocks overlie the hyperesthene basalt and are overlain by a hornblende andesite. Outcrops in the north half of section 30, T 40 N, R 32 E show the biotite andesite overlain by a biotite-augite andesite.

In hand specimens the rock is dark gray to brownish gray in color. Phenocrysts of plagioclase up to 3.0 mm in length and plates of biotite less than 1.0 mm in diameter are sparsely distributed throughout a dense groundmass. Vesicular specimens were not collected but do occur.

Plagioclase phenocrysts are altered to an aggregate of carbonate, albite and microscopic grains of a clear unaltered mineral which may be quartz. The abundant carbonate suggests that the original feldspar was relatively calcic. This is confirmed by the An_{40} composition of the less altered groundmass microlites. Inclusions in the plagioclase are magnetite, apatite, glass and chlorite. The latter apparently is as alteration product of a mafic mineral. Biotite laths and plates always have an external shell of iron oxide. The core of many biotite laths has been partially altered to muscovite and partially replaced by chalcedonic quartz. Groundmass constituents include chlorite, magnetite, feldspar microlites and glass. The all-over turbidity of the matrix appears due to the glass and disseminated iron oxide.

Hornblende Andesites

Hornblende andesites are the most common lavas in the district. These volcanics cap the upper portions of Graphite, Bamber and Bodie Mountains as well as many of the higher ridges. The number of individual flows is not known. In the Bodie Mountain area the thickness appears to be around a thousand feet. A greater thickness may occur in the area west of Graphite Mountain since most of the rocks from Nicholson Creek northward are of this type. Similar rocks occur in the Midway volcanics exposed in the northeast part of the map area.

Megascopically all of these andesites are alike in that they are porphyritic. Feldspar phenocrysts up to 1 cm were noted in some specimens. The average size, however, is around 2 to 3 mm. Needles and laths of amphibole average a few millimeters in length and may reach a maximum of 6 mm. Flow structure in several specimens is marked by the alignment of hornblende needles. In others a color banding accentuates this structure. The color range of the porphyries is from pinkish-brown through brown to gray or purple-gray. Feldspar phenocrysts are white in some rocks and not prominent in others.

Microscopic examination indicates that the fresh plagioclase ranges from An_{35} to An_{45} in composition. In specimen D.9.9.50.2 the mineral is so altered to carbonate that its composition could not be determined. The feldspar in most sections is twinned, zoned and subhedral or euhedral in outline. Inclusions are magnetite and sparse glass. Microlites are common in the groundmass of specimens D.8.14.50.1 and D.9.9.50.3, but sparse in other sections. The groundmass is light tan to dark brown in plane light and appears to be composed of minor glass, iron oxides, some chlorite, rare quartz and turbid, nearly sub-microscopic microlites of plagioclase (?). Euhedral crystals of apatite are easily identified.

Hornblende is or was the common mafic. In most thin-sections the euhedral amphibole crystals have been altered to and replaced by magnetite and hematite. These oxides form a thick shell around the crystals. Core areas may have a few fibers of chlorite or partially chloritized hornblende but in most cases these minerals were lost during the thin-section grinding operation. In sections D.9.9.50.3 and D.7.31.50.2 the iron-oxide rim is less prominent and amphibole cores are preserved. In these, the pleochroism is from yellow to orange-red. The extinction angle is small and the variety is probably lamprobolite.

Augite and biotite are sparse accessories in some thin-sections. Magnetite appears as subhedral, pyrogenic grains and as minute groundmass granules. The magnetite surrounding the amphibole may be deuteric.

Biotite-Augite Andesites

Volcanics characterized by the combination of biotite and augite occur in several localities in the northern portion of the map area. The occurrences are in different horizons within the Midway series and will therefore be discussed separately in the following paragraphs.

Toroda Creek Occurrence

The biotite-augite andesite crops out at an elevation of around 2400 feet in the north half of sections 29 and 30, T 40 N, R 32 E. In this locality the thickness is approximately one hundred feet and the lateral extent more than a mile. The flow overlies the biotite andesite described on page 220 and is overlain by a hornblende andesite similar to those described above. The sequence biotite andesite, biotite-augite andesite, hornblende andesite also occurs near the crest of the ridge located in the center of section 2, T 40 N, R 32 E, but was not observed elsewhere in the map area.

The rock is a porphyry with abundant light colored plagioclase and scattered biotite and pyroxene phenocrysts enclosed in a pale brown, dense groundmass. It weathers to a dark brown color and is not notably vesicular.

Under the microscope the plagioclase is seen to be sodic andesine. The subhedral laths seldom exceed 5 mm in length. A slight turbidity, resulting in a light gray color, is always present. Albite and carlsbad twinning are general, but zoning is rare. An occasional phenocryst of orthoclase occurs. Feldspar phenocrysts constitute approximately 45% of the average specimen. Of the mafics, biotite is most abundant. It is found as laths and plates which are always partially altered to chlorite and magnetite. The anhedral grains of augite are also partially altered to a greenish-yellow mineral which appears to be a chlorite. Mafics do not exceed 15% of the volume of the rock.

The groundmass apparently is holocrystalline. Recognizable constituents include minute laths of biotite, sparse feldspar microlites, sericite, magnetite and, rarely, quartz.

Disseminated iron oxide rather than glass accounts for the light brown color of the groundmass.

Minor accessories are euhedral crystals of apatite and an occasional zircon.

Graphite Mountain Occurrence

An andesite flow crops out at an elevation of approximately 4000 feet on the northeast slope of Graphite Mountain. Older and younger flows in this area consist of hornblende andesites similar to those described on page 221.

Evenly distributed biotite flakes, up to 2 mm in diameter, are a characteristic megascopic feature of this porphyritic flow. An occasional lath of feldspar or pyroxene may also be detected in the dark gray, aphanitic groundmass.

In thin-section, the major minerals are seen to be plagioclase as both phenocrysts and microlite, biotite, and pyroxene. Feldspar phenocrysts are euhedral or subhedral, slightly turbid and seldom exceed .8 mm in length. Zoning is common and the composition of the outer shell is An_{45}. Microlites have average indices equal to or slightly greater than quartz. The composition is evidently in the sodic andesine range. Biotite laths and plates average 1 mm in maximum dimension. The mineral is rimmed and spotted with granular secondary magnetite. Larger, early grains of magnetite as well as euhedral apatite are common inclusions in the mica. Pyroxene grains and subhedral crystals are clear and unaltered. A small 2 V indicates that pidgeonite occurs in addition to augite. Biotite and pyroxene phenocrysts together constitute no more than ten percent of the rock.

Constituents in the felty, holocrystalline groundmass include small laths of biotite, sparse quartz, magnetite and apatite as well as the dominant andesine microlites. In section D.9.9.50.6 late fractures are filled with very finely granular quartz.

Age and Correlation of the Midway Volcanics

Daly concluded that the lower Midway lavas were conformable with the Kettle River formation and that they were probably of Oligocene age. The upper Midway lavas (not known in the Kettle River-Toroda Creek area) were considered early Miocene.

Pardee (1918, page 40), considers the dominantly andesitic volcanics of the Okanogan Highlands as of probable Lower Miocene age. He offers as evidence the fact that the andesites are overlain by the Middle Miocene Columbia River basalts on both sides of the Columbia River in the Nespelem Valley area (southeastern Okanogan County), and again at Whitestone Creek in southern Ferry County. Pardee also points out that lake beds in the Sanpoil-Curlew trough at Republic, include fossil fish which are Oligocene or Lower Miocene in age. These lake beds are intercalated with andesitic lavas which extend up the Sanpoil-Curlew trough into Canada. The same lavas can probably be traced northwest of Republic to the head of Toroda Creek and into the Kettle River-Toroda Creek district.

On the basis of Pardee's work in the Colville Indian Reservation and on the assumption that the andesites of this limited region are of the same age, the Midway volcanics appear to be no older than Late Oligocene and no younger than Early Miocene. That they are not conformable with the Kettle River formation as Daly has stated, but are, on the contrary, separated from this formation by an angular unconformity, has already been mentioned.

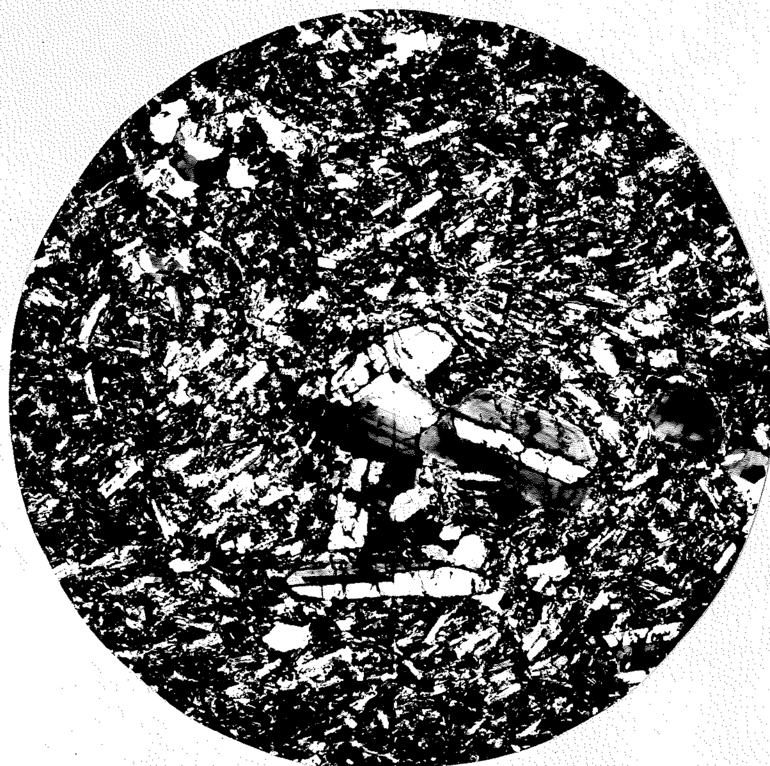


PLATE XXX

A. Photomicrograph of hornblende andesite. Hematite and magnetite form pseudomorphs after euhedral hornblende. Carbonate (high relief) is abundant in the groundmass. Specimen D.9.9.50.2. Plane polarized light. X50.

B. Photomicrograph of biotite-augite-andesite. Radial grouping of subhedral augite in the center of the field. Dark plates are magnetite-clouded biotites. Microlites are sodic andesine.

Specimen D.9.9.50.6. Plane polarized light. X50.

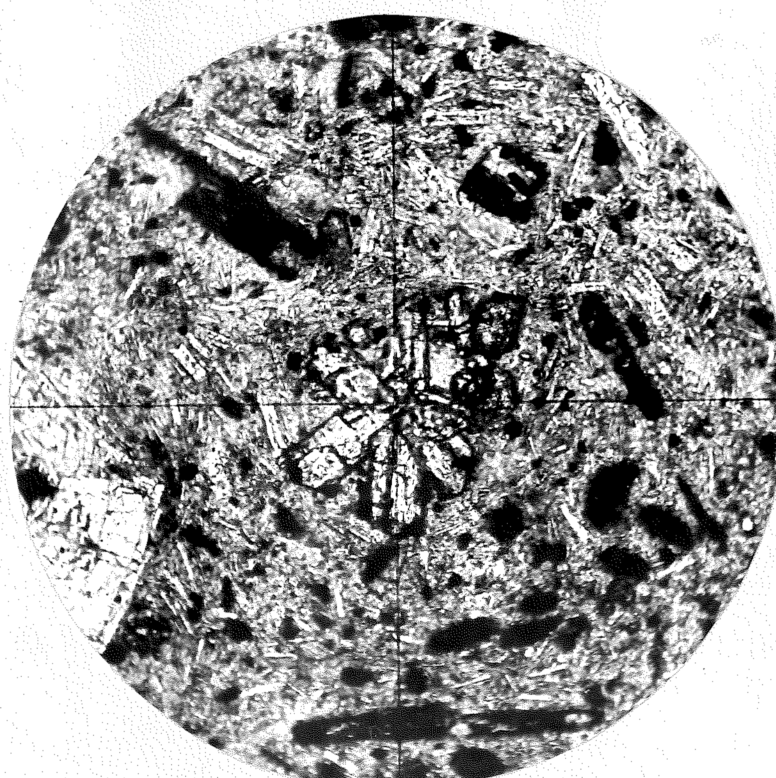


PLATE XXXI

A. Andesite outcrop on west side of Bodie Mt.-Bamber Mt. ridge. Basal breccia has been partially eroded to form shallow cavern shown in lower right corner of the picture.

B. Columnar jointing in an andesite flow near the summit of Bamber Mountain. This escarpment faces east.

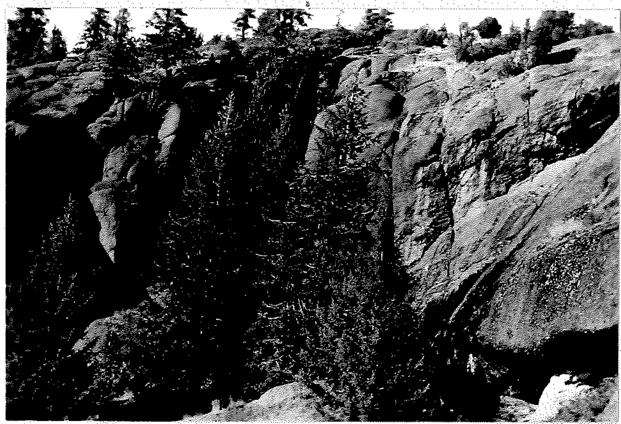
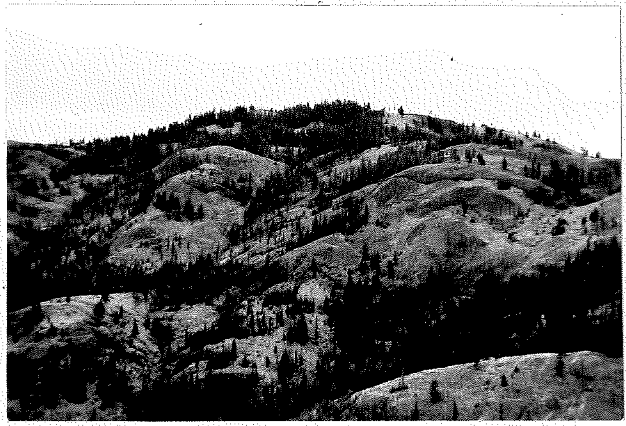
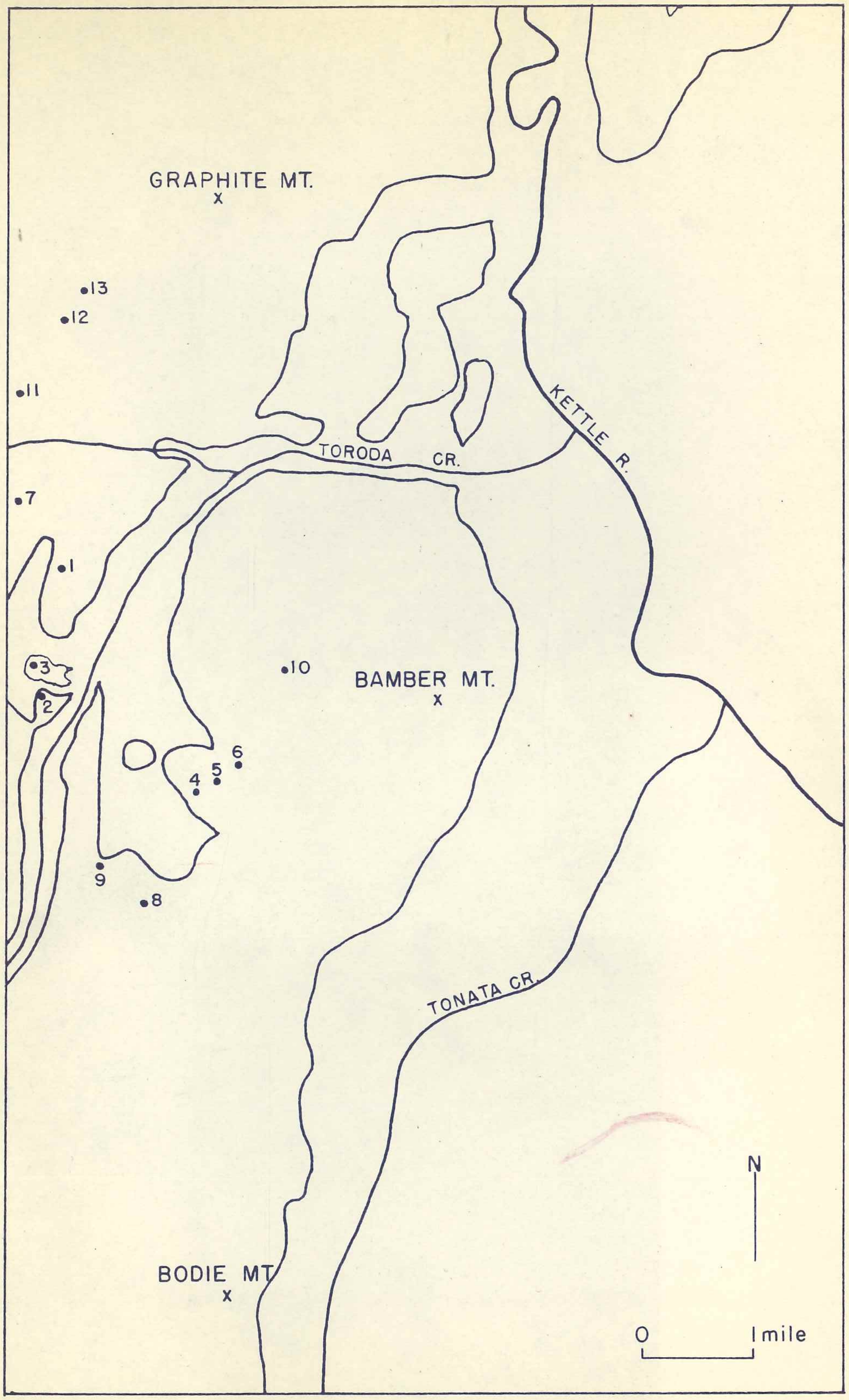


PLATE XXXII

A. View of thick andesite flows on the west side of Bamber Mountain.

B. Photographs of portion of two hypersthene basalt flows on the east side of Toroda Creek.





SPECIMEN

D.7.18.50.9
D.7.20.50.6
D.7.21.50.1
D.7.24.50.3
D.7.24.50.4
D.7.24.50.5
D.7.31.50.2
D.8.1.50.4
D.8.7.50.3
D.8.14.50.1
D.9.9.50.2
D.9.9.50.3
D.9.9.50.6

Figure 14 Sketch map showing the locations of the Midway volcanic rock specimens referred to in the text.

PLATE XXXIV

A. View of the east side of the Kettle River canyon showing the northwest dip of the rocks in the Pre-Attwood monocline.

B. Photograph of the Pre-Attwood monocline on the east side of the Kettle River. Louie Creek on the left. Migmatite zone in the center of the picture. Geissose granite and other granitic rocks outcrop on the lower right.

C. Photograph of the Pre-Attwood graphitic schists and granulites which crop out in the complexly folded section on upper Tonata Creek.

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C. Photograph of the Pre-Attwood graphitic schists and granulites which crop out in the complexly folded section on upper Tonata Creek.

PLATE XXXV

A. Outcrop of Pre-Attwood granite in the Kettle River canyon. The traces of the directional element are accentuated by weathering.

B. Fresh outcrop of Pre-Attwood granite on Toroda-Curlew road. The faint gneissose structure is marked by linear concentrations of biotite and potash feldspar. Note the reticulated system of pegmatite veinlets. Hammer near the center of the photograph gives scale.

C. Closeup of the outcrop shown in photograph B, above.

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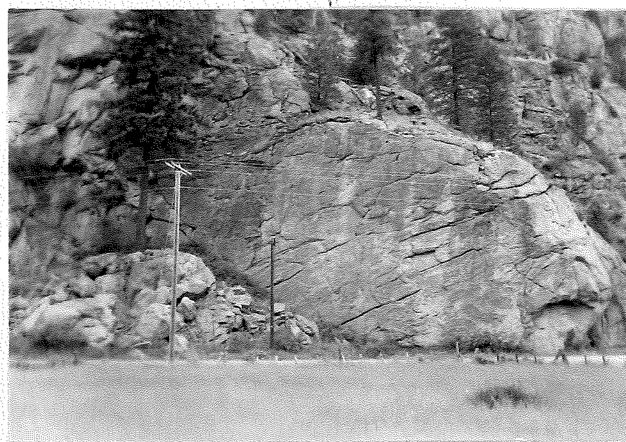

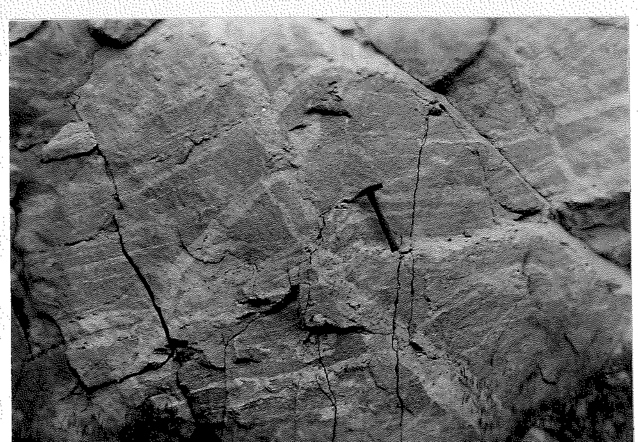

P H Y S I O G R A P H Y

GENERAL FEATURES

The area is a part of the northeastern Washington physiographic province which is most commonly known as the Okanogan Highlands. This province lies north of the east-west belt marked by the Columbia and Spokane rivers and extends from the Idaho border to the Cascade foothills west of the Okanogan River. Elevations throughout most of the northerly trending ranges average 4000 feet and occasionally attain 7000 feet. The major stream valleys paralleling the ranges include the Okanogan, Sanpoil, and the north-south section of the Columbia.

Daly considered the Okanogan Highlands an extension of an area in southern British Columbia which he named the Columbia Mountain System. This "system" was in turn broken down into various subdivisions. The Kettle River-Toroda Creek district lies within part of two units which Daly called the Midway Mountains and the Sanpoil Mountains. The former extends from the Kettle River at Toroda north for a distance of 40 or 50 miles. The Sanpoil Mountains include the region bounded on the south by the Columbia and lying between the Okanogan, Sanpoil and Kettle Rivers.

The northerly trends of the ranges and valleys in the western part of the province are considered by Pardee (1918) and others to be related to similar trends of folding and faulting within the older basement rocks. This conclusion is clearly substantiated in the present area by the parallelism of Toroda and Tonata Creeks, the ridge lying between the two streams, and the major faults with the trend of the Pre-Attwood monocline.

GLACIAL FEATURES

Relatively few scratched and grooved surfaces indicating the direction of movement of the continental ice sheet are preserved or exposed in this district. At an elevation of 4000 feet on the northeast side of Graphite Mountain a smooth, striated surface cut on an andesite flow indicates a north-south movement. Striated granitic rocks which crop out at an elevation of 2550 feet on the east bank of the Kettle River (northwest quarter of section 1, T 39 N, R 32 E) indicate a local deflection of ice to a S 40 E direction. Although this type of evidence of glaciation is meager, there is, in almost all areas except the upper slopes of Bodie Mountain (elev. 5738), a scattering of foreign boulders and pebbles which were evidently glacially transported. The absence of this material in the upper 200 to 300 feet of Bodie does not necessarily indicate that the ice did not cover the mountain. Striations trending S 20 W occur on the east slope of Buckhorn Mountain at an elevation of nearly 5500 feet. This occurrence is located five miles west of the border of the map area. In conclusion it may be stated that the ice covered the entire district with the possible exception of Bodie Mountain. A minimum ice thickness, based on the Buckhorn evidence, would be 3700 feet.

Glacial scouring of bedrock carved small depressions now occupied by lakes in several sections of the district. Lakes of this type are found in the area between Marias Creek and Nicholson Creek, on the ridge between the two forks of Catherine Creek, and on the north flank of Kelly Mountain.

During deglaciation ice occupied the Kettle River and Toroda Creek valleys. Tributary valleys were occupied by lakes and filled with glacial and local materials. These same valleys were evidently occupied by more than one lake since terrace fragments are found at various elevations. Ice-marginal streams have cut across projecting ridges and terraced the upper slopes of the Kettle River valley. Perched channels of this type were noted in sections 14 and 23, T 40 N, R 32 E and in the northeast quarter of section 1, T 39 N, R 32 E.

With continued northward retreat of the continental ice sheet, the Kettle River valley was filled with a 300 to 400 foot thickness of outwash sands and gravels. This rapidly accumulating alluvium dammed the mouth of Toroda Creek and a temporary lake was formed. Very fine silts and varved clays are overlain by coarse alluvium and the general impression is that the "Toroda Lake" was filled in by glacial materials delivered by its tributary streams. Probably the largest of these tributaries was Beaver Creek. This stream occupies a valley which cuts across the range lying between Toroda Creek and the Upper Myers Creek valley to the west. Evidently it carried large quantities of outwash materials from the Myers Creek section of the Okanogan Valley lobe of ice.

Terraced remnants of the fluvioglacial material are preserved in many sections of the Kettle River-Toroda Creek valleys. Two major terraces, differing in elevation by a hundred feet, closely parallel the Kettle River valley floor in a number of localities but are not prominent along Toroda Creek. Depressions in the upper terrace one-half mile south of Toroda are probably kettles. The upper terrace immediately north of the mouth of Catherine Creek canyon (southeast quarter of section 10, T 40 N, R 32 E) is cut in Pre-Attwood rocks and veneered with gravels and the usual cover of flood-plain silts and minor slopewash material. Matching terraces on the south side of Catherine Creek are cut in both rock and outwash alluvium.

Evidence of local stream diversion which is at least partially related to glaciation, was noted in the case of the north fork of Tenas Mary Creek (section 23, T 40 N, R 32 E). Prior to diversion, the present north fork was an independent stream which flowed westward across the Tenas Mary fault to the Kettle River. During deglaciation, the fault zone was occupied by an ice-marginal stream which lowered the gap between the ancestral "north fork" and a parallel stream to the south to the extent that a permanent diversion was established.

SUMMARY OF THE GEOLOGIC HISTORY

The evidence for reconstructing the geologic history of the Kettle River - Toroda Creek district begins with the marine deposition of the conformable sequence of shales, limestones, argillaceous limestones, calcareous shales, feldspathic sandstones which form the Pre-Attwood formation. The relative abundance of pure quartz sandstones in these sediments suggests the uniform conditions of sedimentation considered characteristic of shelf conditions. During a period of regional metamorphism of medium to high grade, these Pre-Attwood sediments were converted to schists, gneisses, migmatites and granitic-appearing rocks.

Erosion of these metamorphics was followed by submergence and burial beneath a second accumulation of marine sediments which R. A. Daly named the Attwood formation. The Attwood limestones, shales, conglomerates and volcanics probably accumulated during the Paleozoic, perhaps as early as the Devonian period but more probably in late Paleozoic time. A second orogeny followed, accompanied by regional metamorphism under low grade conditions which converted these rocks to marble, phyllite, sheared conglomerates and greenstones. Zones of mylonites and the development of retrogressive minerals in the Pre-Attwood metamorphics are considered related to this port-Attwood orogeny and low grade metamorphism.

Intrusion of the Kelly Mountain granodiorite evidently occurred after or in a late phase of the post-Attwood orogeny. It appears likely, then, that its emplacement was an event of the later Mesozoic or the early Tertiary.

By early Eocene times the region had been uplifted and the surface maturely eroded. Some faulting along north-south trends evidently preceded the deposition of the Middle Eocene Kettle River formation. The coarse, breccia-like conglomerates at the base of this formation are composed largely of fragments of the Kelly Mountain granodiorite and the various rocks of the Attwood metamorphic complex. Much of this material appears to have been shed from escarpments and highlands adjacent to broad, open valleys and to have spread outward in coalescing alluvial fans. Later deposits of Kettle River age graywackes and finer-textured lake beds. These sediments were intruded by dikes and sills and capped by flows of andesitic composition. Following this period of igneous activity, the Kettle River formation was tilted, moderately folded and eroded.

The first of the Midway Volcanics evidently were erupted during late Oligocene or early Miocene times. Early flows were confined to valleys and successive lavas gradually leveled out the terrane. A maximum thickness of about 3000 feet was accumulated and apparently the flows covered all except the higher peaks and ridges in this section of the

Okanogan Highlands. The source of these volcanics is not known but they may have come from the Midway mountain region of southern British Columbia since the greatest thickness is found in this locality. There is a general decrease in thickness southward to the Columbia River. Following the accumulation of the Midway volcanics, a period of faulting, tilting and erosion destroyed all traces of the former lava surface.

In the present area the record of Middle Miocene to early Pleistocene geologic history is absent. Evidently this section of the Okanogan Highlands was mountainous and was undergoing erosion within this time interval.

At least once during the Pleistocene, the Cordilleran ice sheet covered all except perhaps the higher peaks of the northerly trending ridges. Evidence in the Kettle River - Toroda Creek district indicates that the minimum thickness of the ice was 3700 feet.

Since the retreat of the continental ice, much of the fluvioglacial material has been eroded from the valleys of the Kettle River and its tributaries. Prominent terraces cut in outwash, or rarely in rock, indicate several pauses in the post-glacial interval of downcutting.

In pursuing the geologic history to the present, it is of interest to note that a thin veneer of volcanic ash, probably from sources in the Cascade Mountains, is found on the upper terrace but not on lower terraces or the current valley-floor of the Kettle River.

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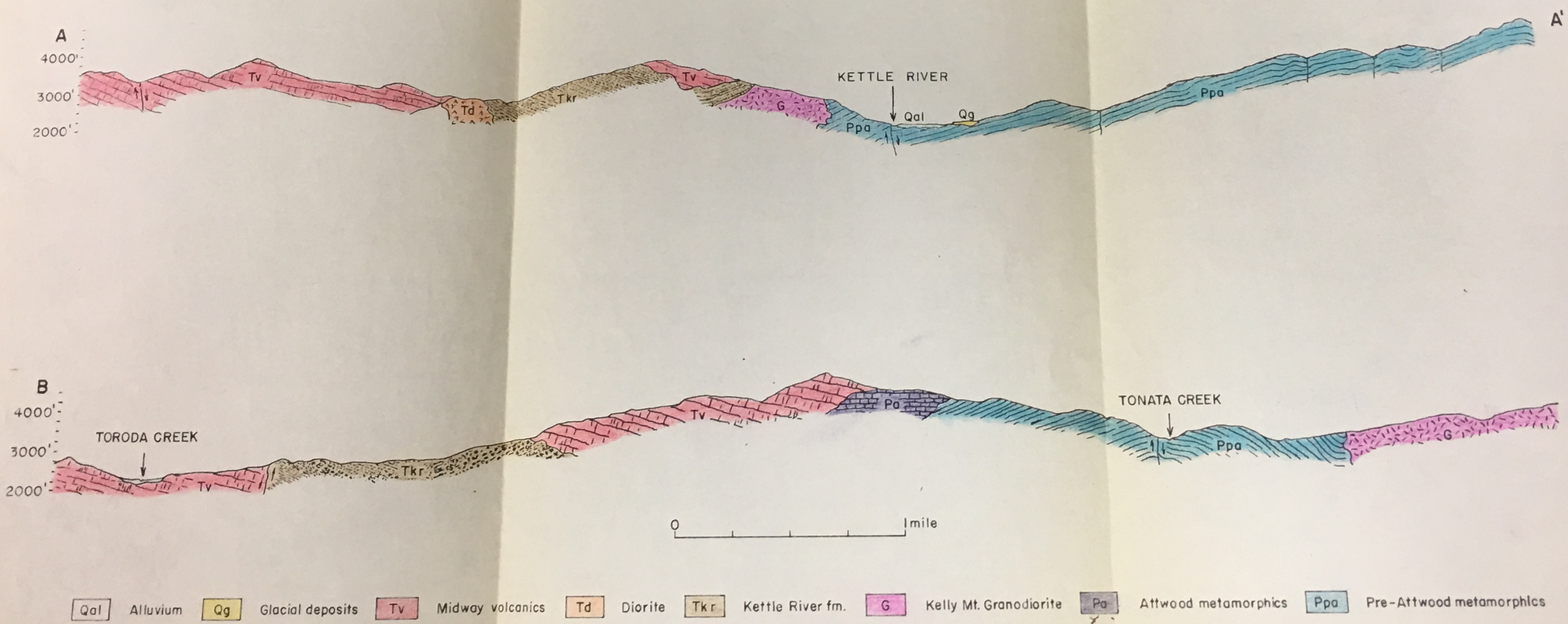
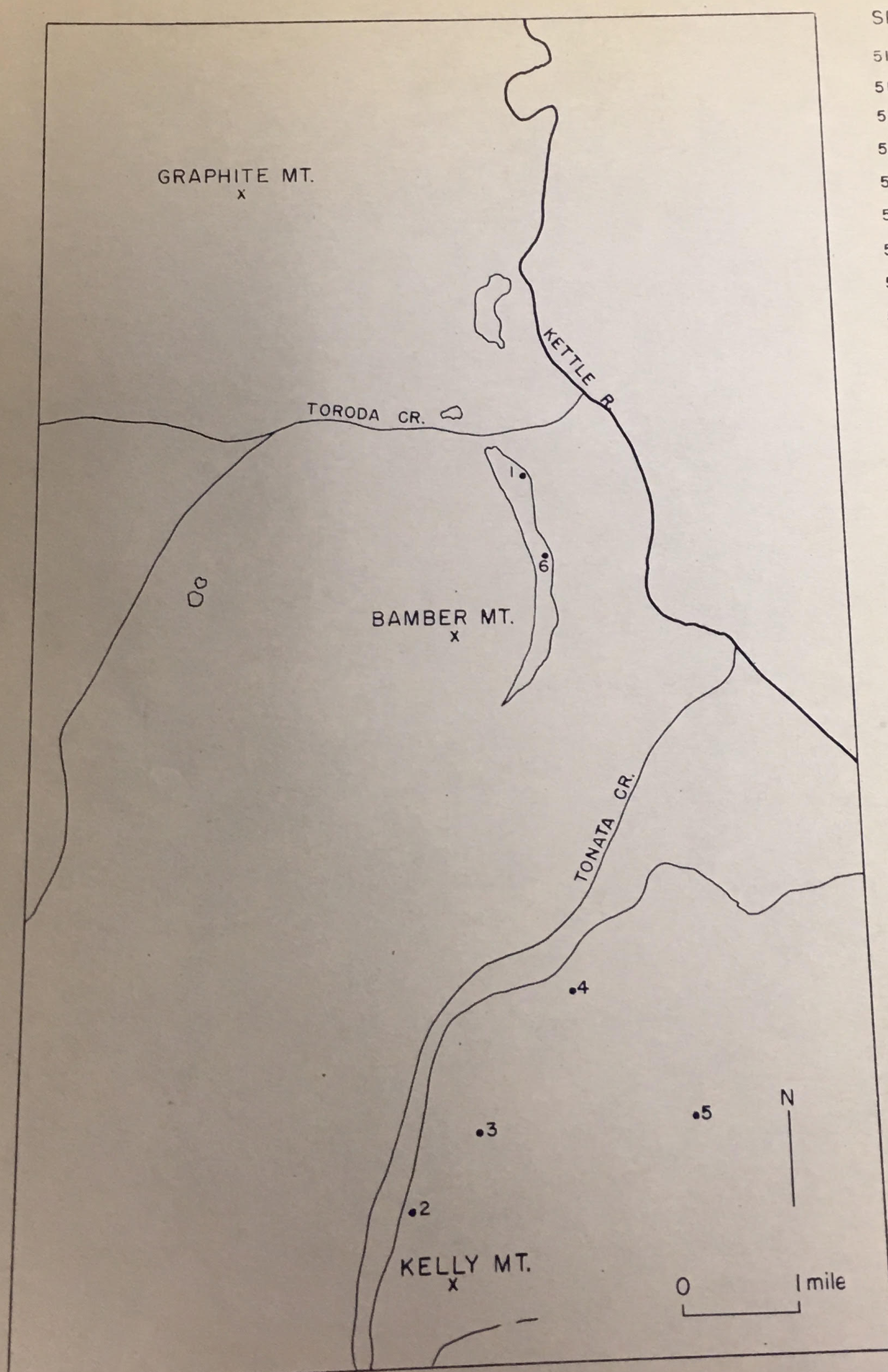
GEOLOGIC MAP OF THE KETTLE RIVER-TORODA CREEK DISTRICT OF NORTHEASTERN WA
EXPLANATION
QUATERNARY
RECENT
PLEISTOCENE
TERTIARY
L.MIOCENE
?
U.EOCENE ?
CARBONIF ?
?
Qal
Alluvium
Gravel, sand and silt
Qg
Glacial deposits
Poorly sorted gravel, sand and silt
Tv
Midway volcanics
Dominantly andesites. Includes rhyolite and hypersthene basalt
Tkr
Kettle River formation
Coarse breccia, conglomerate, sandstone, shale and local andesite flows
Pa
Attwood metamorphics
Limestone, phyllite, conglomerate and greenstone
Ppa
Pre-Attwood metamorphics
Micaschists, quartzites, granulites, marble, amphibolites, migmatites, granite and mylonites
Contact
Fault
U
D
Strike and dip
Tertiary dikes
Td
Diorites
Light to dark gray rocks with hornblende and biotite or hornblende alone
G
Kelly Mountain granodiorite
KETTLE RIVER
A
A'
B
B'

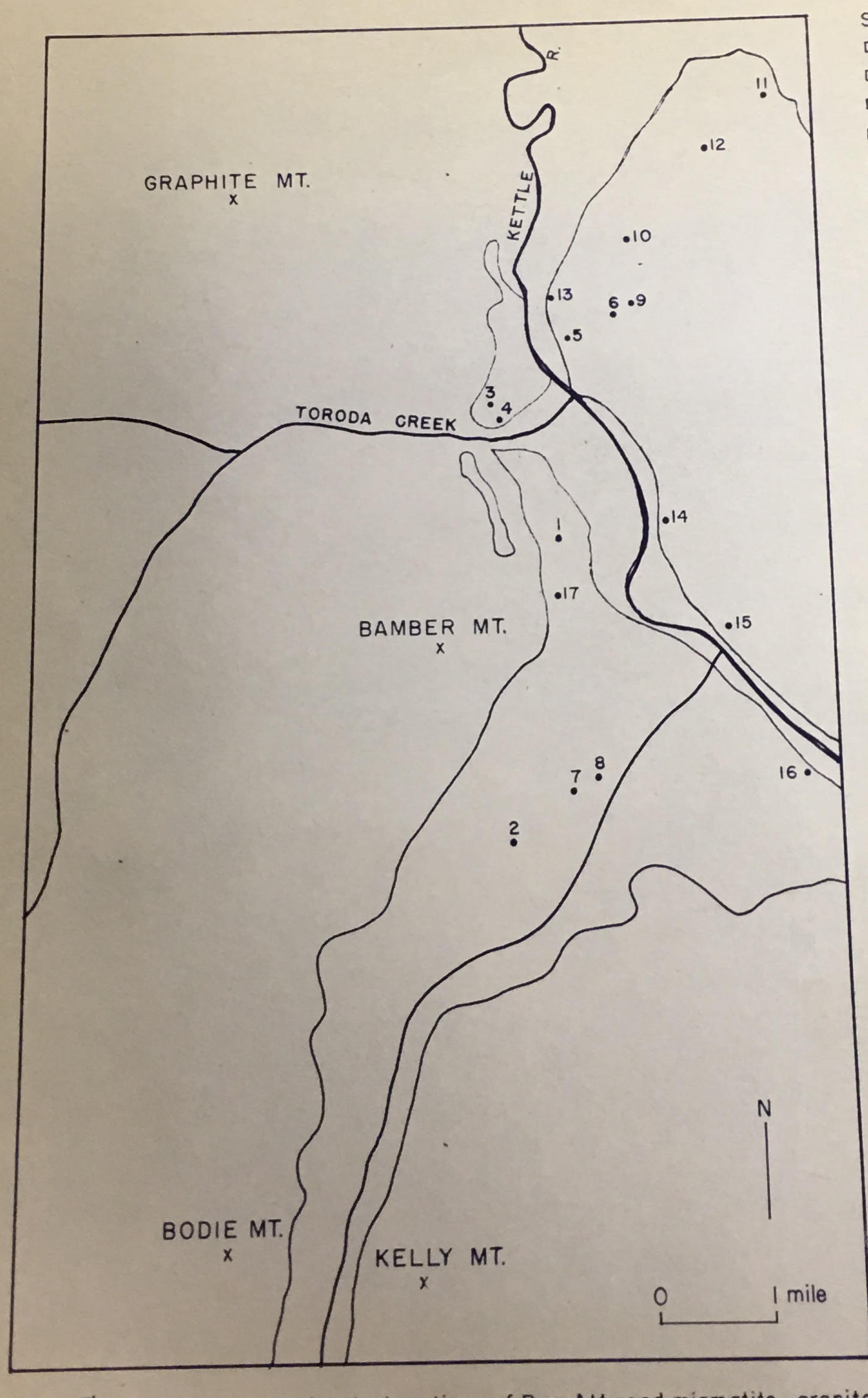
GEOLOGIC CROSS SECTIONS OF THE KETTLE RIVER-TORODA CREEK DISTRICT





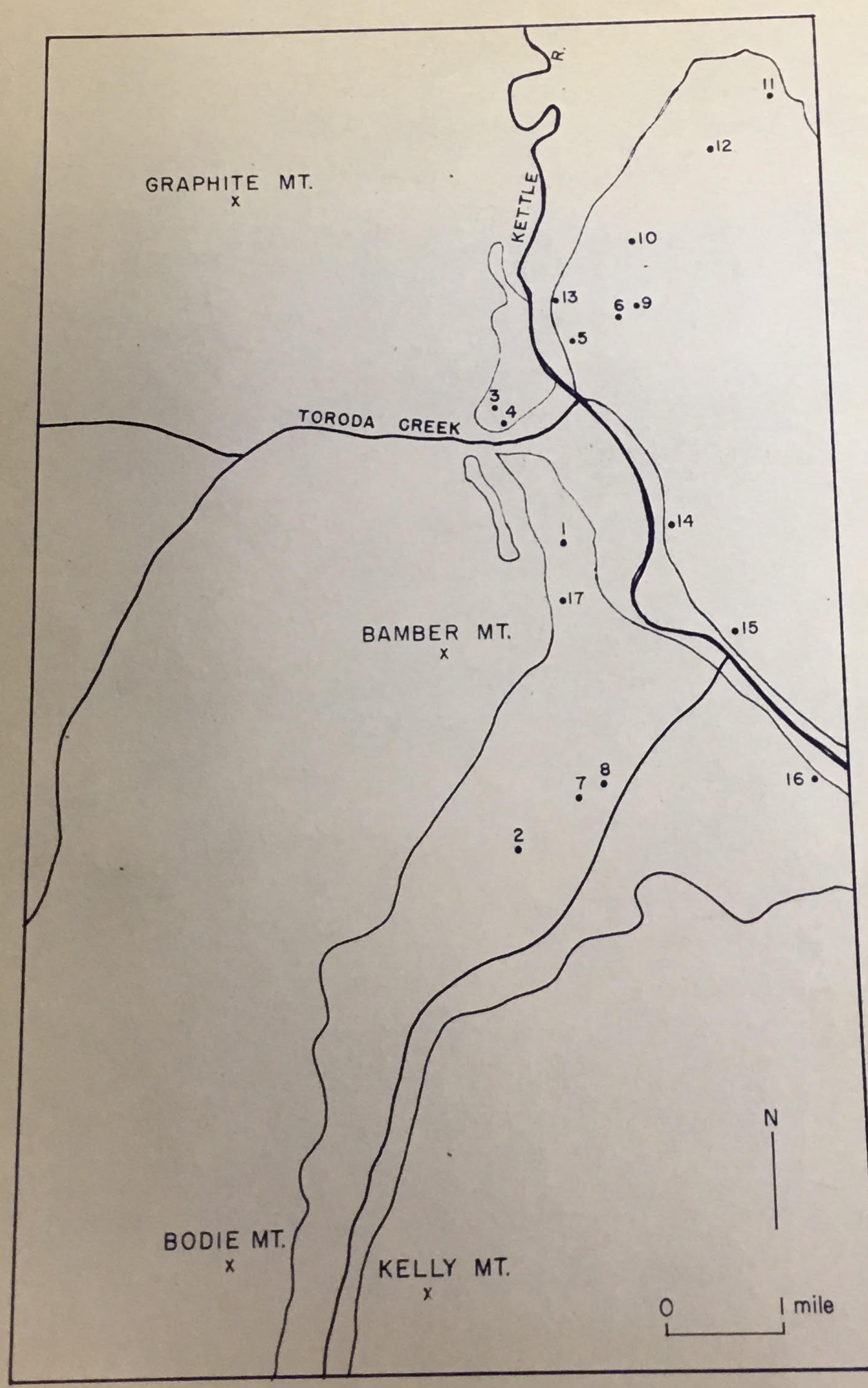
SPECIMEN	LOCALITY
51.D.21	1
51.D.52	2
51.D.54	3
51.D.54A	3
51.D.54B	3
51.D.55	4
51.D.57	5
51.D.150	6
51 D 150A	6

Figure 11 Sketch map showing the locations of the Kelly Mountain granodiorite specimens referred to in the text.



SPECIMEN	LOCALITY
D.2.9.49.1	1
D.8.4.50.5	2
D.9.4.50.6	3
D.9.8.50.1	4
D.9.17.50.2	5
D.9.17.50.5	6
51.D.25	7
51.D.27	8
51.D.28	8
51.D.103	9
51.D.112	10
51.D.125	11
51.D.136	12
51.D.153	13
51.D.155D	14
51.D.161	15
51.D.164	16
51.D.186	17

Figure 5 Sketch map showing the locations of Pre-Attwood migmatite, granite and mylonite specimens referred to in the text.



SPECIMEN	LOCALITY
D.2.9.49.1	1
D.8.4.50.5	2
D.9.4.50.6	3
D.9.8.50.1	4
D.9.17.50.2	5
D.9.17.50.5	6
51.D.25	7
51.D.27	8
51.D.28	8
51.D.103	9
51.D.112	10
51.D.125	11
51.D.136	12
51.D.153	13
51.D.155D	14
51.D.161	15
51.D.164	16
51.D.186	17

Figure 5 Sketch map showing the locations of Pre-Attwood migmatite, granite and mylonite specimens referred to in the text.

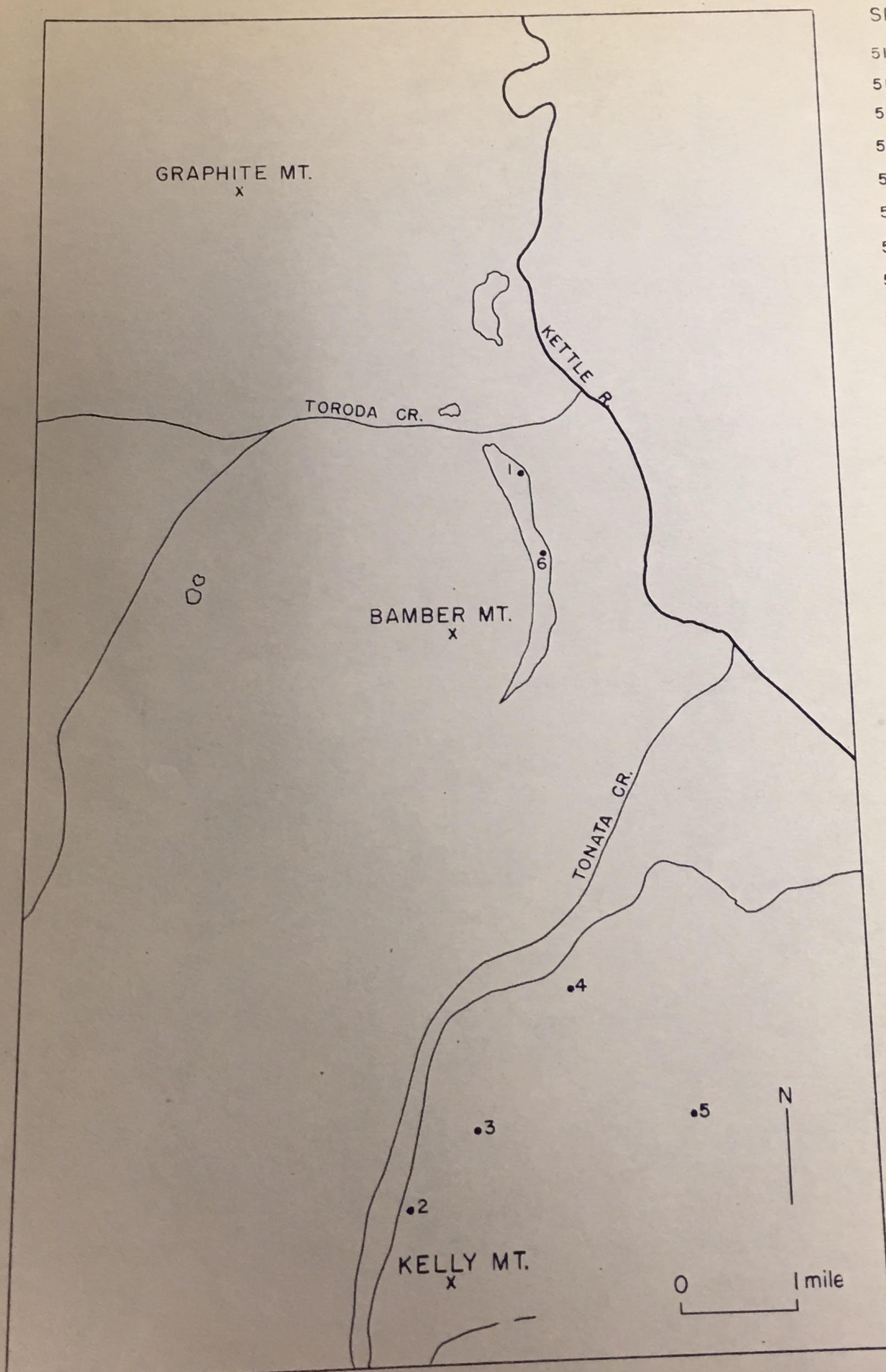


Figure 11 Sketch map showing the locations of the Kelly Mountain granodiorite specimens referred to in the text.

SPECIMEN	LOCALITY
51.D.21	1
51.D.52	2
51.D.54	3
51.D.54A	3
51.D.54B	3
51.D.55	4
51.D.57	5
51.D.150	6
51 D 150A	6