GEOLOGY OF THE PINEY RIVER-ROSELAND TITANIUM AREA, NELSON AND AMHERST COUNTIES, VIRGINIA

by

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TABLE OF CONTENTS

	Page
Introduction	7
Location	7
Purpose of Investigation	7
Topography and Drainage	8
Accessibility	9
Culture	10
Method of Investigation	10
Acknowledgments	11
Previous Work	12
Regional Geologic Setting	14
Rock Units	15
Nomenclature	15
Augen Gneiss	18
Granitic Gneiss	24
Biotite Aplitic Gneiss	26
Biotite Pencil Gneiss	27
Massive Hypersthene Granodiorite	29
Layered Hypersthene Granodiorite	34
Altered Hypersthene Granodiorite	36
Border Gneiss	44
Pegmatitic Anorthosite	50
Nelsonite	66

	Page
Dolerite	72
Late Quartz Veins	73
Pegmatite	73
Age Relationships of the Rock Types and Units	75
Petrogenesis	82
Structure	86
Foliation	87
Folds	88
Faults and Shear Zones	90
Economic Geology	93
Feldspar Deposits	93
Titanium Deposits	94
Ilmenite Deposits	95
Ilmenite Nelsonite	95
Piney River Deposit	98
Johnson Deposit	99
Bryant Deposits	101
Blue Rock Deposit	101
Hite Farm Deposit	102
Other Deposits	102
Disseminated Ilmenite	103
Tom Wood Deposit	105
Reserves	107
Rutile Deposits	109

Page

Disseminated Rutile Deposits 109

American Rutile deposit 111

Other deposits 114

Rutile Nelsonite 115

Rutile-quartz deposits 115

Reserves 116

Origin 117

Suggestions for Prospecting 124

References Cited 126

Vita 129

ILLUSTRATIONS

Plate

1. Geologic map of the Piney River-Roseland area, Nelson and Amherst Counties, Virginia in pocket

2. Photomicrographs of massive hypersthene granodiorite 32

3. Hypersthene diorite from layered hypersthene granodiorite 37

4. Photomicrographs of altered hypersthene granodiorite 38

5. Altered hypersthene granodiorite 39

6. Photomicrographs of tremolite pseudomorphs after hypersthene 40

Plate		Page
7	Photomicrographs of altered hypersthene granodiorite	41
8.	Altered layered hypersthene granodiorite from old American Rutile pit	42
9.	Photomicrograph of garnet-rich rock from border gneiss unit	51
10.	Photograph of large broken oligoclase crystal from pegmatitic anorthosite	55
11.	Photomicrograph of antiperthite from pegmatitic anorthosite	56
12.	Photomicrographs of altered pegmatitic anorthosite	57
13.	Photomicrographs of reaction rims across aggregates of ferromagnesian minerals	62
14.	Rutile in saussuritized plagioclase	63
15.	Photomicrographs of nelsonite	69
16.	Photomicrograph of rutile-bearing altered hypersthene granodiorite from American Rutile pit	112
17.	Photomicrographs of ilmenite-rich altered hypersthene granodiorite	113

Figure		Page
1.	Index Map	7_a
2.	Diagramatic sketch of typical reaction rims around mafic aggregates	61a
3.	Contact between augen gneiss and massive feldspathic lens of the border gneiss unit	87a

TABLES

1.	Lithologic units and correlation with nomenclature used by earlier investigators	17
2.	Range in mineral content of augen gneiss	19
3.	Mode of massive hypersthene granodiorite	30
4.	Modes of ilmenite, nelsonite and adjacent amphibolite	70
5.	Crosscutting relationships between major rock types	80
6.	General age relationships of the rock units	81

INTRODUCTION

Location

The Piney River-Roseland titanium deposits are situated in Nelson and Amherst counties, Virginia, about midway between the cities of Lynchburg and Charlottesville (Fig. 1). Amherst is 5 miles south of the area and Lovingston is 3 miles to the east.

The deposits are scattered over several tens of square miles. Approximately 70 square miles were mapped to include most of the deposits. The mapped area (Fig. 1) is along the western edge of the Piedmont in the foothills of the Blue Ridge.

Purpose of Investigation

The mapped area (Pl. 1) is centered about a large pegmatitic feldspar body, called the Roseland anorthosite by Ross (1941). Spatially associated with this body are rich titanium and feldspar deposits. Although several aspects of these deposits had been studied previously, no thorough geologic and structural study had been made. Therefore, a relatively detailed field investigation of these economically important deposits and the surrounding rocks was conducted by the writer to determine the distribution, relationships, structure and origin of the

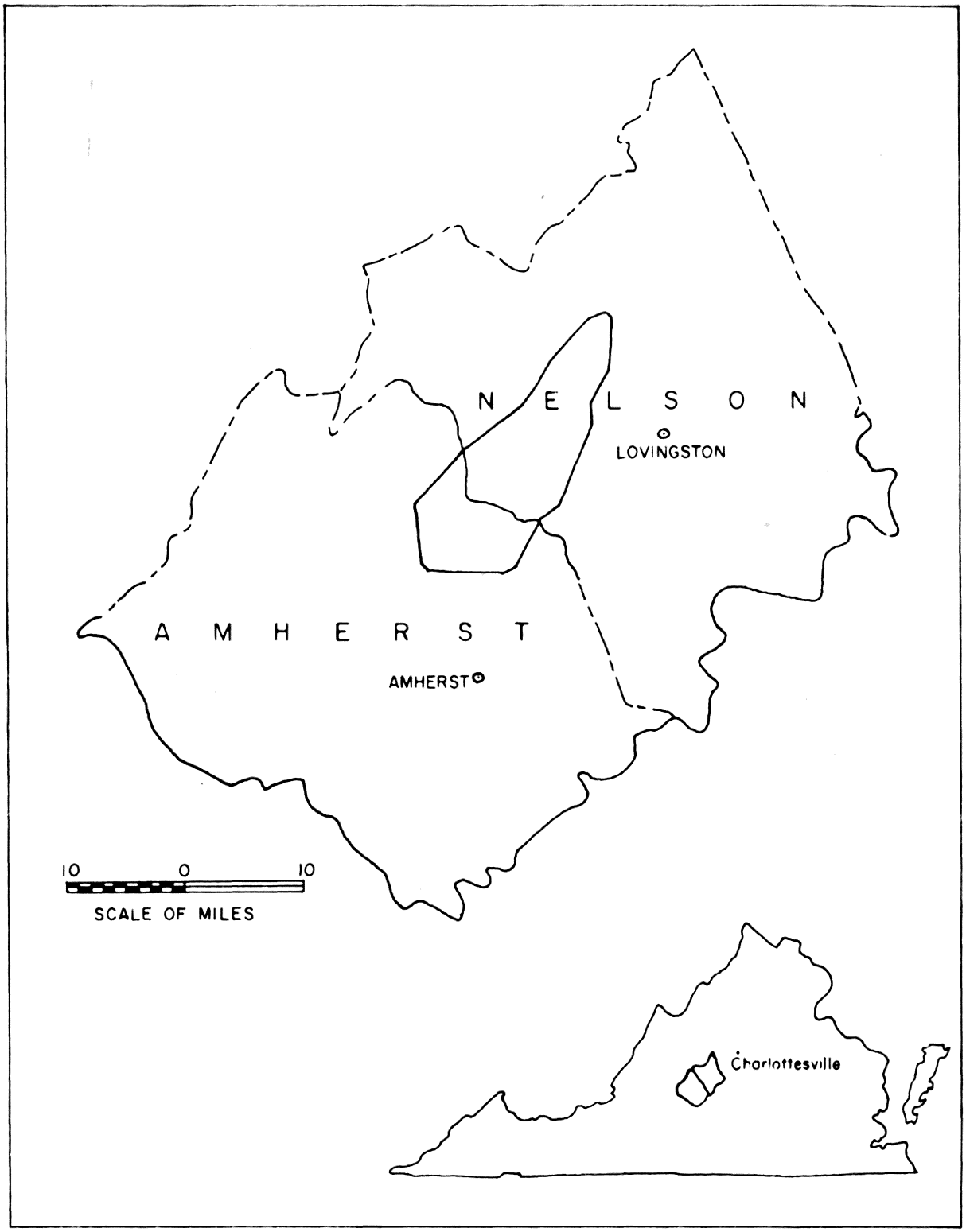

Figure 1. - Index map, Piney River-Roseland area, Nelson and Amherst Counties, Virginia

various rock types with emphasis on the titanium mineralization.

Topography and Drainage

Two major streams, the Tye River and the Piney River, which flow in generally southeasterly directions into the James River, divide the mapped area into three approximately equal parts (Pl. 1). The Tye River separates the northeastern, relatively mountainous section from an area of low rounded hills to the southwest. Elevations north of Tye River range from 800 to 2200 feet. To the south they range from 700 to 1200 feet.

The northern part of the map area is bounded by Horseshoe Mountain, the major peaks of which are Cat Rock Mountain on the west, Brent's Mountain on the northeast, and Pat's Knob on the east. Mars Knob, with a relief of 700 feet, is in the approximate center of the valley between the limbs of Horseshoe Mountain. Hat Creek, a tributary of the Tye, flows southwestward through the center of the valley west of Mars Knob. Several small, steep obsequent streams occupy narrow, short valleys, and a few small canyons, in the mountains to the southeast. On the northwest, resequent streams occupy wider valleys with gentler gradients.

A large, relatively flat, low area, surrounded by small hills, lies south of the Tye River. The small tributaries of the Tye, Piney, and Buffalo rivers form a somewhat dendritic pattern within this low area.

This flat low area is underlain almost wholly by anorthositic rock, whereas most of the prominent ridges are held up by quartz-mica-feldspar gneiss or granitic rocks. Most of the smaller rounded hills are underlain by intercalated gneiss and anorthositic rocks or by hypersthene granodiorite.

Accessibility

With the exception of the mountainous northern section, the area is easily assessible from a network of state and county primary and secondary highways and private roads (Pl. 1). State Highway 151 crosses almost the entire length of the area and connects with U.S. Route 29 eight miles south of Piney River and three miles northeast of Amherst. State Highway 56 crosses the area along the valley of Tye River and State Highway 158 crosses about one mile north of the settlement of Piney River. The Virginia and Blue Ridge Railroad connects Piney River to the Southern Railroad at Tye River Depot.

Culture

A large part of the area is under cultivation or is used for grazing. The major crops are corn, tobacco, peaches, and apples. This area supports a large rural population, centered about the small communities of Piney River and Roseland on the southeast, and Lowesville and Massies Mill on the west. Although the steep slopes are generally uncultivated they provide a minor amount of the grazing land. Small scale logging operations are conducted on several of the mountains. A considerable part of the flat low area is covered with scrub pine growth.

The major industrial operations within the area are the mining and processing of feldspar and titanium minerals. Feldspar is mined at three quarries in the vicinity of Piney River. Titanium minerals are mined at Piney River and at the Tom Wood property near Lowesville.

Method of Investigation

Parts of the U.S. Geological Survey's topographic maps of the 15-minute Vesuvius, Lovingston, and Amherst quadrangles were enlarged to a scale of two inches to the mile and were used as a base for field mapping. Aerial photographs were used for a base map in the area around Roseland where no adequate topographic map coverage was available. Photographs were also used in other parts of the area to aid in geologic mapping.

Long traverses were made along roads approximately parallel to the regional strike. Short cross traverses were made at intervals of about 300 yards on the north side of Tye River where the bedrock is relatively well exposed in the mountainous terrain. The interval between cross traverses was much greater in the flat southern portions where outcrops are rare.

The writer logged and sampled diamond drill core furnished by the U.S. Bureau of Mines and by C.E. Craven and Associates. Laboratory studies included detailed petrographic study of thin sections of all rock types and study of polished sections of rocks consisting largely of opaque minerals. All specimen localities are shown on the map in the appendix.

Acknowledgments

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Previous Work

The most comprehensive report dealing with the titanium deposits of this area was published by Watson and Taber (1913). An annotated bibliography of all of the known literature concerning the area and published before 1913 is included in that report. Most of the earlier reports were written by Watson and co-workers (eg., 1907a, 1907b, 1909, 1910, 1911) although the earliest recorded report is that by Merrill (1902), which dealt only with the Roseland rutile deposits. Watson also published several later articles dealing with specific aspects of the deposits (eg., 1915, 1918a, 1918b, 1922a). C.S. Ross also wrote many articles refering to the deposits (eg., 1934a, 1934b, 1936, 1941, 1944, 1947). His most complete treatment of the subject was published in 1941 as U.S. Geological Survey Professional Paper 198. C.H. Moore Jr. (1940) mapped many nelsonite bodies in Amherst County. Davidson, Grout, and Schwartz (1946) discussed the origin of the Piney River ilmenite deposit based on data obtained during exploration of the deposit. Ryan (1933) described the occurrence of "disseminated ilmenite deposits" in the Piney River area. Hess and Gillson (1937) presented data on the geology and mining operations at Piney River.

Although many other publications mention these titanium deposits, those mentioned above include essentially all of the original data and diverse interpretations.

So far as the general geology is concerned, the anorthosite body, herein called pegmatitic anorthosite, and the surrounding rocks were mapped by Watson and Taber (1913). Smaller scale maps including the Piney River-Roseland area were published by Stose (1928) and by Bloomer and Werner (1955). Relatively detailed descriptions of the rocks were given by Watson and Taber (1913, etc.), Thornton (1911), and Ross (1941, etc.).

REGIONAL GEOLOGIC SETTING

The rocks of the Piney River-Roseland area occur within a long belt of granitoid rocks, gneisses, and schists that constitute the core of the Blue Ridge-Catoctin Mountain anticlinorium (Jonas, 1927). The crystalline rocks exposed in the core of the anticlinorium in central Virginia have been called the "Injection Complex" by Jonas and Stose (1939), the "Basement Complex" by Bloomer and Werner (1955), and the "Virginia Blue Ridge Complex" by Brown (1958). The relationship of the rocks of the "complex" to other rocks in the anticlinorium, especially to the metasedimentary Lynchburg gneiss, is controversial. Dietrich (1959) gives a summary discussion of the literature dealing with this subject. The above mentioned workers assign the rocks to the Precambrian.

ROCK UNITS

Nomenclature

The nomenclature of rock units is a real problem in the Piney River-Roseland area. The first relatively thorough investigations of the rocks in and adjacent to the Piney River-Roseland area were made by T.L. Watson and co-workers in the early part of this century. Watson (1907a) first described the titanium- and apatite-rich rocks and named them nelsonite after Nelson County. In 1913 Watson and Taber published a generalized map showing the distribution of units which they called "biotite-quartz monzonite-gneiss", herein called augen gneiss, syenite, herein called pegmatitic anorthosite, and nelsonite. In an earlier report (1909) Watson called the syenite "pegmatite" but in the 1913 (p.68) report Watson and Taber noted that anorthosite might be a better name for this rock. Watson and Cline (1916) described "quartz-bearing hypersthene-andesine syenite", herein called hypersthene granodiorite, of the adjacent part of the Blue Ridge.

Jonas (1927), in describing the geology of the Piedmont of Virginia and of the hypersthene granodiorite in Virginia (1935), divided these same rocks into the Lovingston granite gneiss (chiefly Watson's biotite-quartz monzonite-gneiss), hypersthene granodiorite (Watson's quartz-bearing hypersthene-

andesine syenite), anorthosite (Watson's syenite), Marshall granite, and older metamorphosed sediments. In 1941 Ross proposed that the feldspar-rich body be called the Roseland anorthosite. Bloomer and Werner (1955) used the following nomenclature for rocks exposed in the area mapped by the writer: (1) basement complex gneiss (2) Lovingston formation, consisting of granite-gneiss and granite (3) Marshall formation of granite (4) Pedlar formation (formerly largely hypersthene granodiorite) (5) Roseland-anorthosite (after Ross, 1941). Brown (1958) in his report on the Lynchburg Quadrangle adjacent to the Piney River area, used a nomenclature similar to that of Bloomer and Werner, for these rocks.

Detailed mapping enabled the writer to distinguish 12 rock units (Table 1). Table 1 also presents a correlation of the rock units used by the writer and nomenclature used by earlier investigators.

The first 5 units listed in Table 1 are somewhat gradational and some may represent cataclastically altered phases of other rock types. The same relationship may hold for the diverse hypersthene-bearing rocks.

Table 1. - Lithologic Units and Correlation With Nomenclature Used by Earlier Investigators

Hillhouse (1960)	Watson and Taber (1913)	Jonas (1939)	Bloomer and Werner (1955)
Augen gneiss			
Granitic gneiss			
Biotite aplitic-gneiss	Biotite-quartz monzonite-gneiss	Lovingston fm.	Lovingston in part
Biotite pencil-gneiss			Marshall in part
Feldspathic gneiss			
Hypersthene granodiorite	Mapped with syenite in Piney River-Roseland area	Hypersthene granodiorite	Pedlar fm. (not mapped in Piney River-Roseland area)
Layered hypersthene granodiorite			
Altered hypersthene granodiorite			
Border gneiss	Mapped with syenite	not mapped	not mapped
Pegmatitic anorthosite	Syenite	Anorthosite	Roseland anorthosite
Nelsonite	Nelsonite	Nelsonite	Nelsonite
Dolerite dikes	Not mapped	Not mapped	Not mapped

Augen Gneiss

The augen gneiss unit consists chiefly of medium to dark gray augen gneiss characterized by coarse feldspar augen in a matrix of mica and quartz. It underlies the northern, eastern, and southern parts of the map-area as shown on Plate 1. The unit also includes minor amounts of fine-grained gneiss, biotite schist, and quartz-rich lenses. Fresh outcrops of the augen gneiss are most abundant on the steep flanks of the mountains in the northern part of the area. Thin bands of augen gneiss are also found in topographically low areas, intercalated with other rock types. Most intercalated layers of augen gneiss could not be mapped separately. Some zones of the augen gneiss have undergone extreme cataclasis, resulting in a fine-grained schistose, mylonitic rock which was mapped separately where possible. This deformed rock is generally deeply weathered to a soft, fissile, brown schist.

Although most outcrops are relatively uniform in texture and composition, a few outcrops of the augen gneiss are somewhat layered as indicated by textural changes in the feldspar augen between adjacent layers. Most of the layers are essentially parallel to the dominant gneissosity.

The augen gneiss is cut locally by white to green, epidote-rich bands as much as one foot thick. These bands are clearly secondary because they locally cut sharply across the gneissosity.

The augen gneiss is medium- to coarse-grained and consists of lenticular feldspar grains surrounded by subparallel bands of biotite, muscovite, blue quartz and clear quartz. The augen range from a few millimeters to eight centimeters in length in different layers but are uniform in size within each layer. Quartz and biotite inclusions occur in the augen. The major accessory minerals are ilmenite, magnetite, apatite, and epidote.

The mineralogic character of the augen gneiss, as seen in thin section, is remarkably consistent in spite of apparent differences in texture. The minerals listed in Table 2 are commonly present and generally occur within the ranges indicated.

Table 2. - Range in Mineral Content of Augen Gneiss*

Mineral	Range (in per cent)
Microcline and perthite	15-55
Plagioclase (albite-sodic oligoclase)	15-30
Quartz	22-27
Muscovite	2-22
Biotite	3-15
Epidote	1-6

*Computed from point count analyses of 20 thin sections

Apatite, ilmenite, sphene, and zircon are constant accessories and small amounts of chlorite and amphibole are present in a few specimens. Most of the specimens contain approximately 35 per cent of microcline and perthite, 22 per cent of plagioclase, 24 per cent of quartz, 8 per cent of muscovite, and 6 per cent of biotite. The rock is a quartz monzonite as originally stated by Watson and Taber (1913), but its composition is near that of a granite.

In most specimens, the augen are polymineralic, consisting of potassic feldspar, plagioclase, quartz and apatite. Perthitic microcline is the most abundant mineral and may constitute as much as 80 per cent of each augen. The augen are separated by sinuous bands consisting chiefly of fine-grained quartz, muscovite, biotite, albite, and epidote. Some of the bands cut through large microcline, perthite, quartz, and albite grains. The differences in texture and composition between different bands within the gneiss reflect the relative proportions of augen and inter-augen areas. Because the augen present a distinctly granitoid texture in thin section, whereas the inter-augen areas are more schistose, the overall appearance of the rock can range from a schistose rock where the inter-augen areas dominate to a granitic textured rock where the bands of finer grained minerals are subordinate.

Microcline and microperthite occur in grains up to 2 cm.

in diameter in the augen and as smaller fractured grains in the sheared areas. Round quartz grains and rounded, altered remnants of plagioclase occur as inclusions in the potassic feldspar. The plagioclase of the perthite is largely replaced by sericite and epidote.

Plagioclase occurs both in the augen and inter-augen areas, and consists of two types or generations. The first type occurs mainly in the augen and has been extremely altered (saussuritized) so that the original composition is difficult to determine. The second type is relatively fresh albite to sodic oligoclase which occurs chiefly in the inter-augen areas where it is fractured and twin lamellae are bent. In general, neither type of plagioclase exhibits zoning, although examples of slight normal zoning can be found. Twinning is well developed in the majority of grains and is commonly simple albite twinning although many examples of complex twinning (combination albite-pericline-carlsbad) occur. Myrmekite is abundant along contacts between plagioclase and microcline.

The composition of the unaltered plagioclase in the gneiss, based on measurments of extinction angles, is albite-sodic oligoclase with a range of An_2 to An_{14}. The altered plagioclase in the augen is probably albite, as concluded by Watson and Taber (1913). However, judging from the large amount of clinozoisite developed from it, it must have been considerably more calcic before alteration.

Most of the quartz occurs as a fine-grained mosaic in the matrix of the inter-augen areas. It also occurs interstitially within the augen, and as rounded anhedral grains within the feldspar. Large quartz grains in the sheared zones show strong undulatory extinction and are cut by fractures filled with fine-grained quartz, mica, and epidote. Quartz also occurs as myrmekitic inter-growths with plagioclase. Although the quartz shows a bluish purple tint in hand specimen, the networks of fine rutile needles, so common in the blue quartz of the pegmatitic anorthosite are not seen in the gneiss except directly adjacent to the anorthosite. The color may be caused by submicroscopic rutile.

Fresh-appearing grains, 1 to 2 mm. long, of muscovite form sinuous, sub-parallel stringers in the inter-augen areas. Muscovite also forms narrow envelopes around the well-defined augen. Fine-grained sericite is abundant as an alteration product of feldspar.

Two types of biotite are common in the gneiss. The more abundant variety occurs in clusters and stringers of stubby, prismatic crystals with very dark to light brown pleochroism. These biotite stringers are parallel to the muscovite stringers in the inter-augen areas. The other type, which exhibits green pleochroism, is scattered throughout the rock and forms more poorly defined crystals. The green and brown biotite occur together in the inter-augen areas.

Most of the titanium-bearing minerals occur in the finer grained inter-augen areas of the augen gneiss in close association with the brown biotite stringers, apatite, and epidote. The ilmenite grains are irregularly shaped and range from 0.2 to 1 mm. in length. The outer rim of all ilmenite grains has been altered to fine-grained sphene and/or leucoxene. Fractures in the ilmenite and sphene are filled with fine-grained quartz and mica.

There appear to be two generations of apatite. The older apatite occurs as fresh euhedral crystals in the feldspar of the augen. Apatite in the inter-augen areas is anhedral. The anhedral apatite commonly contains inclusions which appear to have preferred orientations. Several grains with cores of zircon were observed. The anhedral apatite grains are commonly surrounded by a rim of epidote.

Minerals of the epidote family occur as fine-grained aggregates forming small stringers in the inter-augen areas, as rims about apatite, and as an alteration product in feldspars. Both epidote and clinozoisite were identified.

Zircon is widespread but not abundant. It typically occurs as extremely small, elongate, subrounded grains in both the augen and in the inter-augen areas. A few larger (up to 0.1 mm.) euhedral crystals occur in the inter-augen areas.

The textural relationships observed in thin sections indicate that the augen gneiss has undergone considerable

deformation. The augen appear to have acted as resistant "islands" and most of the shearing was around the augen. The large size of the microcline grains containing rounded inclusions of quartz and altered plagioclase within the augen suggest that some of the augen are porphyroblasts which replaced the fabric of an earlier rock before shearing occurred. However, the exact nature of the earlier rock cannot be determined. Apparently it consisted of feldspars, quartz and micas, with minor apatite and ilmenite or magnetite. These minerals have undergone considerable alteration as indicated by the saussuritization.

Granitic Gneiss

The granitic gneiss unit, although gradational with other rock types, is sufficiently distinctive to be mapped separately. The rock is uniform in most outcrops but its structure ranges from that of a well-defined granitic gneiss to a cataclastic granitic rock. The granitic gneiss forms a series of more or less semicircular bodies in the southeastern corner of the map area. In other parts of the area, it forms bodies that appear to be arranged zonally about hypersthene granodiorite bodies. It is also found locally as lenses intercalated with the augen gneiss, but these are too small to map separately at the scale used.

The granitic gneiss is a medium-grained rock, similar

in composition to the augen gneiss. Contacts between the two rock types are commonly sharp and locally cut across the prevailing gneissosity. It is extremely difficult in the field to distinguish between the granitic gneiss and some of the altered phases of the hypersthene granodiorite. This suggests that the granitic gneiss is a somewhat gradational unit between the augen gneiss and the hypersthene granodiorite or that it may represent a reaction zone between the two.

In hand specimen, the granitic gneiss is characterized by aggregates of biotite in "bundles" or "patches" scattered through a matrix of equidimensional feldspar and quartz. Biotitic stringers or seams are locally abundant. The color of the rock ranges from light to dark gray depending on the biotite content.

Thin sections of rocks included in the granitic gneiss unit show the following ranges in composition between individual sections: potassic feldspar, including microperthite and microcline, 7 to 42 per cent; plagioclase (albite to calcic oligoclase), 6 to 43 per cent; quartz, 22 to 33 per cent; biotite and muscovite, which occur in approximately equal proportions, 11 to 18 per cent. Minor mineral constituents are epidote, apatite, ilmenite, sphene, chlorite, zircon, and sulfides. The composition of the granitic gneiss is therefore similar to the augen gneiss, that is, it ranges from quartz monzonite to granite.

The potassic feldspar includes microperthite and "patch perthite" grains up to 3 mm. in length and microcline grains up to 1 mm. in length. The plagioclase grains, which range up to 3 mm. in length, are complexly twinned. Quartz is chiefly interstitial but also occurs as inclusions in the feldspars, as myrmekitic intergrowths with plagioclase, and as fine-grained veinlets. In some sections, the micas are extremely fine-grained and occur as aggregates apparently formed by the alteration of a pre-existing mineral, possibly amphibole. In other sections the micas form clusters and stringers of grains up to 0.5 mm. long. Most of the feldspar and quartz and some of the biotite and apatite, exhibit subhedral textural relationships. Most of the biotite, muscovite, fine-grained quartz, epidote, apatite, and titanium minerals occur in stringers or seams which are essentially identical to the inter-augen areas of the augen gneiss.

Biotite Aplitic Gneiss

A fine to medium granular or aplitic texture biotite-quartz-feldspar gneiss underlies Thompson Mountain and other prominent hills on the northwestern border of the map area. This is shown as biotite aplitic gneiss on Plate 1, and is distinct from other gneisses in the area because of its fine-grained, aplitic texture, mica-rich composition, and lack of augen structure. The rock is light to medium gray and forms outcrops at moderate elevations.

The character of the biotite aplitic gneiss is dominated by a strongly cataclastic texture marked by equigranular feldspar and quartz which are cut by micaceous seams. Fine-grained quartz, which is abundant in the augen-gneiss, is rare in these micaceous seams.

The minerals in this rock are essentially the same as those in the augen-gneiss, but their proportions are strikingly different. A typical specimen contains 26 per cent of plagioclase (An_8-An_{12}), 30 per cent quartz, 5 per cent microcline, 17 per cent biotite, 14 per cent muscovite, 5 per cent epidote, and accessory sphene, zircon, chlorite, and apatite. Potassium feldspar is relatively less abundant, and mica more abundant in this rock than in the augen gneiss. Albite grains exhibiting twinned and untwinned portions grading into each other within one individual are common. No difference in index of refraction between the twinned and untwinned parts can be detected.

Biotite Pencil Gneiss

A dark green-gray, mylonitic, schistose, biotite-quartz-feldspar gneiss underlying the low hills in the southwestern corner of the area is mapped as biotite pencil gneiss (Pl. 1). Specimens of this gneiss are characterized by closely spaced gneissosity planes, along which the feldspar, quartz, and mafic minerals are streaked into wavy subparallel aggregates.

A distinctive feature is a pronounced lineation of the feldspars and mafic minerals. Rectangular aggregates of an abundant dark mineral resemble hornblende megascopically, but in thin-section are seen to consist of fine-grained biotite with minor amounts of hornblende.

Only one thin-section of a typical sample of this rock was examined. It contained 5 per cent microcline, 16 per cent perthite, 8 per cent intermediate oligoclase, 27 per cent quartz, 30 per cent biotite, 2 per cent sericite, 9 per cent epidote, and traces of ilmenite, hornblende, chlorite, apatite, and zircon.

The most noticeable differences in composition between this and previously described rocks are the high biotite to muscovite ratio and the relatively calcic-rich nature of the plagioclase. Complexly twinned plagioclase, fine microperthite, and myrmekite are common. Biotite occurs as scattered small green grains, as large and small brown grains (probably largely after hornblende), and as red-brown grains in altered areas.

The texture is dominantly cataclastic, but only a few grains have been reduced to the small size characteristic of mylonites. Larger quartz grains show extremely wavy extinction and, like the feldspars, are highly fractured and cut by fine-grained biotite and epidote. Fine-grained quartz veinlets, so characteristic of the augen gneiss, are essentially lacking.

Massive Hypersthene Granodiorite

Dark gray, medium- to coarse-grained, massive granodiorite occurs as several small, roughly equidimensional bodies, a few hundred yards long, in the northeastern part of the area (Pl. 1). These rocks are poorly exposed on low rounded hills near the edges of the steeper slopes underlain by augen gneiss.

Specimens of the massive hypersthene-bearing rock are unaltered and have an equigranular igneous texture. They consist chiefly of coarsely crystalline, dark gray feldspar with scattered pyroxene and abundant black opaque minerals. The central parts of the massive bodies of hypersthene granodiorite exhibit no lineation or layering. However, the outer parts of some of the bodies consist of somewhat gneissic and cataclastically altered varieties. The texture of the somewhat altered varieties is similar to that of the massive rock; the color is lighter because the feldspars are white.

Thin sections of the coarse, massive hypersthene granodiorite consist of almost equal amounts of plagioclase, potassium feldspar, and quartz and about 10 percent of hypersthene. In most specimens a clinopyroxene is also present. A mode of the rock is given in Table 3.

The plagioclase is complexly twinned and generally antiperthitic. The largest grains are slightly antiperthitic and exhibit an unusual type of twinning which consists of

Table 3. - Mode of massive hypersthene granodiorite*

Mineral	Amount (in per cent)
Plagioclase (An_{35})	27
Potassic feldspar	23
Quartz	25
Hypersthene	9
Augite	3
Hornblende	4
Chlorite	2
Biotite	1
Epidote	2
Apatite	2
Magnetite	2
Sulfide	Trace
Zircon	Trace

*Computed from point count analyses of three thin sections

normal albite twin laths and wider, parallel laths with closely spaced very fine perpendicular lamellae, probably pericline twins. Peculiar, coarse "myrmekite" intergrowths of quartz are common between the smaller plagioclase grains and microcline.

Large grains of potassic feldspar are perthitic, but small grains are pure microcline. The latter tend to fill the interstices in the rock. The perthite contains small

(0.1 mm.), lenticular blebs of plagioclase which are oriented parallel to both of the twin planes of the microcline. Modal measurements made on large perthite grains reveal that they contain up to 40 per cent plagioclase.

The iron-bearing minerals are generally clustered together in aggregates consisting of hypersthene, augite, and ilmenite. Some of the hypersthene occurs as skeletal crystals as much as 2 cm. long (Pl. 2, Fig. 1). These crystals enclose plagioclase and other minerals in the rock. Augite occurs as associated subhedral grains. Ilmenite occurs as anhedral grains, some of which are enclosed in hypersthene (Pl. 2, Fig. 1).

In the freshest available specimens there is no evidence of alteration or deuteric reaction. All of the above minerals and also apatite and zircon are in direct contact with each other without reaction rims. However, in most specimens, the pyroxene is surrounded by a thin reaction rim of very pale tremolite-actinolite, and, as the alteration increases in intensity, the entire pyroxene grains are replaced by a fibrous aggregate of amphibole. Rarely, there are small amounts of chlorite in the outer part of a former pyroxene grain. Also, an outer reaction rim of a colorless, fibrous mineral which is apparently anthophyllite as described by Ross (1941), is evident in more intensely altered specimens. The hypersthene is preferentially altered over the

Plate 2. - Photomicrographs of massive hypersthene granodiorite

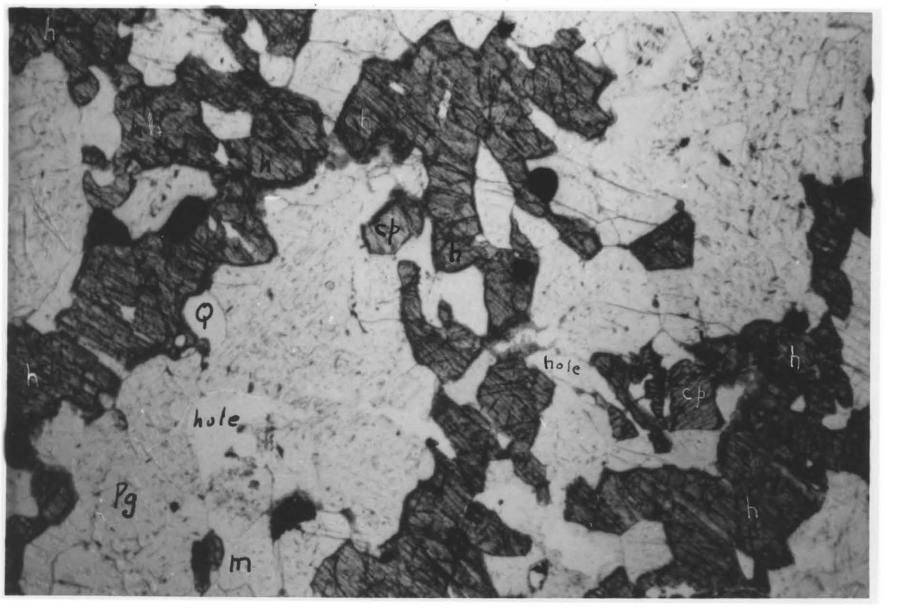


Figure 1. - Skeletal hypersthene from fresh hypersthene granodiorite. All of the hypersthene (h) is in optical continuity. Smaller clinopyroxene (cp) occurs as inclusions within the skeletal hypersthene. Opaque blebs are ilmenite. Matrix is fresh plagioclase (pg) and microcline (m). Plane light, X 24.

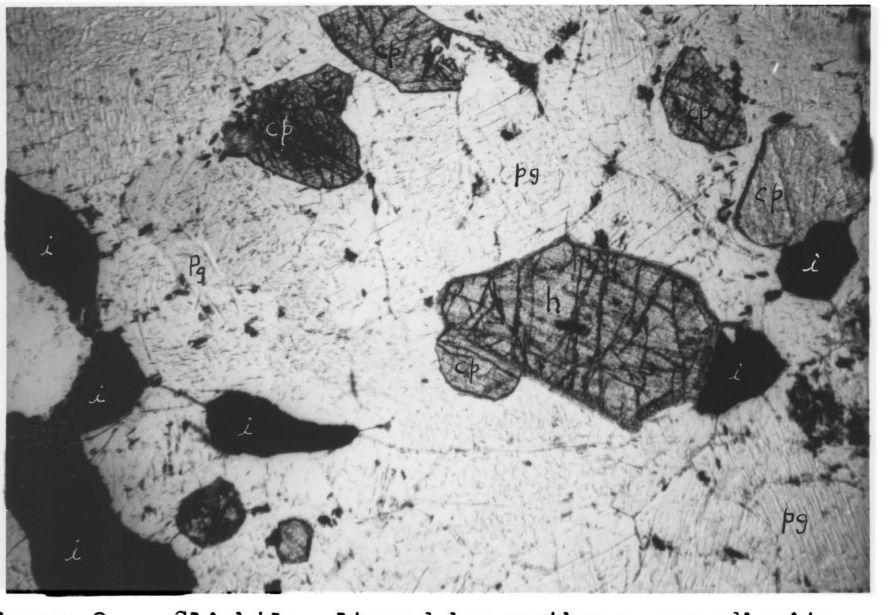


Figure 2. - Slightly altered hypersthene granodiorite. Clinopyroxene grains (cp) are fresh and others such as large hypersthene grain (h) near the middle of the photograph have a fibrous amphibole reaction rim. The reaction rim separates the pyroxene from the ilmenite (i) grains but ilmenite and clinopyroxene have no reaction rims in grains at the top of the photograph. Matrix is slightly saussuritized antiperthitic oligoclase. Plane light, X 24.

clinopyroxene (apparently augite) Pl. 2, Fig. 2). Near ilmenite grains there is a noticeable reaction rim of biotite flakes. Adjacent altered pyroxene grains are bordered by an outermost rim of biotite which decreases in thickness away from the opaque grains. A reaction rim of sphene is directly in contact with the ilmenite grains. Most contacts between pyroxene and ilmenite show no reaction rim.

As alteration of the ferromagnesian minerals becomes more evident in specimens from the outer parts of some of the massive bodies, the pyroxenes are all altered and the feldspars become increasingly saussuritized and filled with epidote and sericite until the latter minerals form about 30 per cent of each feldspar grain. Small amounts of pyrite and graphite occur locally in the altered rocks.

A somewhat different type of alteration occurs in the gneissic and argillitized rocks which occur as broad halos around the bodies of massive hypersthene granodiorite. A typical specimen of this rock contains 12 per cent plagioclase (andesine and albite), 22 per cent microcline and microcline perthite, 23 per cent quartz, 11 per cent biotite, 8 per cent sericite, 3 per cent hornblende, 2 per cent kaolinite, 12 per cent fine-grained allophane, 3 per cent ilmenite, and accessory epidote and apatite. The approximate chemical composition of this rock is essentially the same as that of the fresh hypersthene granodiorite but water has been added.

The textures, except for clay alteration and the presence of "patch" perthites, are similar to those of the fresh rock. The presence of clay minerals possibly suggests that this alteration is due to weathering. However, in the field, this type of clay alteration occurs only in weathered outcrops in gneissic zones around the fresh massive granodiorite. Therefore, it appears that position with regard to the boundary of the massive granodiorite body is the important control of this alteration. This suggests that the alteration might be, in part at least, due to hydrothermal effects.

Layered Hypersthene Granodiorite

Fine- to medium-grained, layered hypersthene-bearing rock, largely of granodiorite composition is much more extensive in areal distribution than the massive type. The best and most widespread development of this rock is in several bodies in the northeast corner of the map area east of Hat Creek and Mars Knob (Pl. 1). It also crops out in a narrow body along the Tye River 700 yards west of Highway 151.

The layered hypersthene granodiorite consists of layers, ranging in width from three inches to several feet, of dioritic rock intercalated with highly feldspathic layers rich in blue quartz. The boundaries between the layers are sharp and parallel. The dioritic layers have granular,

almost aplitic textures. The megascopically visible minerals are feldspar, quartz, hypersthene, ilmenite, graphite, and pyrite.

In thin sections the diverse layers are commonly fresh and unaltered. The texture is hypidiomorphic and nearly equigranular, although antiperthite grains are commonly larger than grains of the other minerals. Textures are more or less identical with those of the massive hypersthene granodiorite. The approximate mineral composition of a specimen from one of the lighter-colored layers is 35 per cent calcic oligoclase, 30 per cent microcline, 20 per cent quartz, 5 per cent hypersthene and minor apatite, ilmenite, magnetite, epidote and zircon. However, this is probably somewhat more granitic than most of the hypersthene granodiorite of the area. The plagioclase of the granodiorite is chiefly antiperthitic and commonly contains inclusions of microcline ("patch antiperthites") and rounded, oriented blebs of quartz.

Specimens from some of the darker layers have compositions corresponding to diorite rather than to granodiorite. Both clinohypersthene and augite (?) are present as shown in Plate 3. The most basic section studied contained 65 per cent of plagioclase (An_{40-45}), 3 per cent microcline, 25 per cent hypersthene, 2 per cent augite (?), 2 per cent quartz, and minor amounts of epidote, sericite, apatite,

and zircon.

Specimens of the dioritic layers are generally fresher in appearance than the lighter, more granitic layers. The plagioclase is antiperthitic as in the hypersthene granodiorite, but contains much less microcline.

Some specimens of the layered rock are altered in the same way as the massive rock. All gradations exist between fresh rock and one in which the pyroxenes are altered to amphibole and micaceous minerals, and the feldspars to saussuritic aggregates.

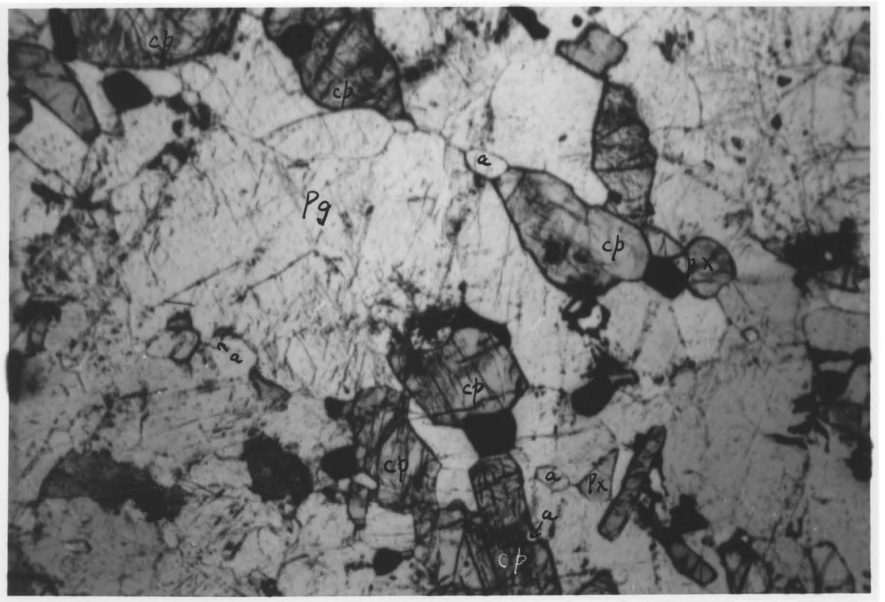
Altered Hypersthene Granodiorite

Several small bodies of rock mapped as altered hypersthene granodiorite occur in close association with the pegmatitic anorthosite and the ore deposits in the central part of the area (Pl. 1). The rock is mostly medium grained and gray-green and characteristically it has a gneissic or layered structure.

The altered hypersthene granodiorite is exposed best for 1½ miles along Tye River south of Roseland. It is also exposed where Highway 151 crosses Tye River and locally adjacent to areas of the pegmatitic anorthosite in the southern half of the mapped area.

All degrees of alteration are demonstrated in thin sections of the rock. In some sections, the rock is essentially the same as the fresh layered hypersthene granodiorite

Plate 3. - Hypersthene diorite from layered hypersthene granodiorite



Both augite (px) and clinohypersthene (cp) are present in a matrix of antiperthitic plagioclase (pg), apatite (a) and ilmenite. Plane light, X 24.

Plate 4. - Photomicrographs of altered hypersthene granodiorite

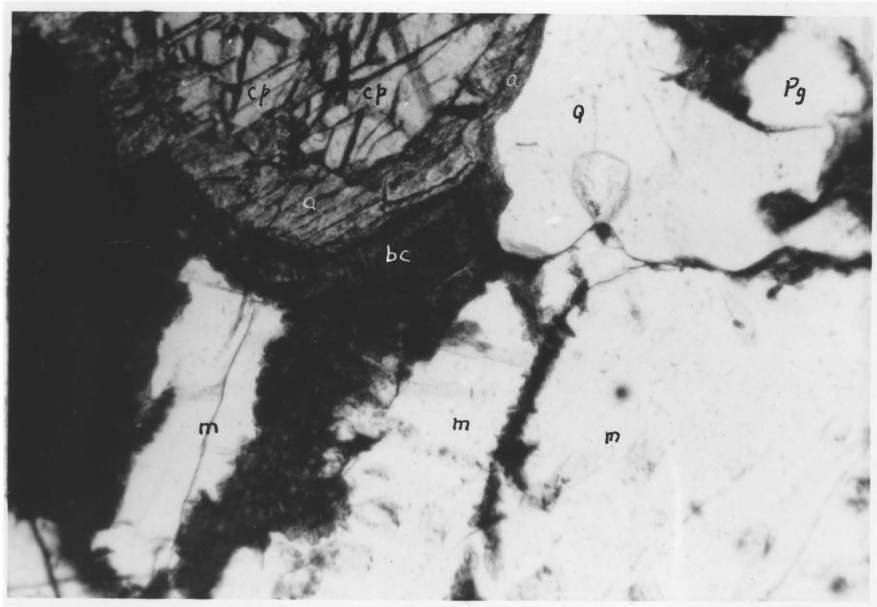


Figure 1 - Double reaction rim of actinolite and biotite-chlorite around pyroxene in hypersthene granodiorite. Actinolite (a) rims pyroxene (cp) and is rimmed by a fine-grained biotite-chlorite (bc) mixture reaction rims. Reaction rims thin or pinch out where the pyroxene contacts quartz (q) and are thickest where it contacts microcline (m) or plagioclase (pg). Plane light, X 105.

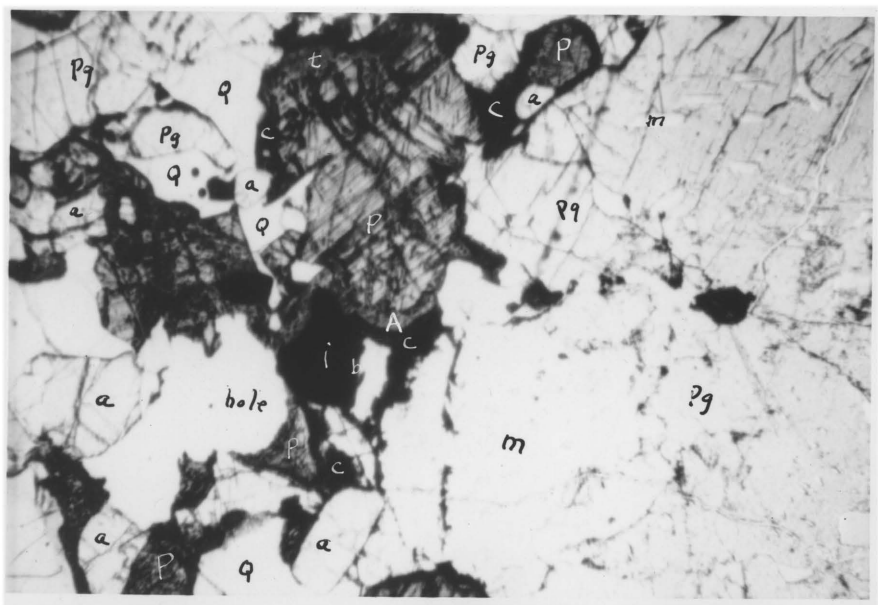
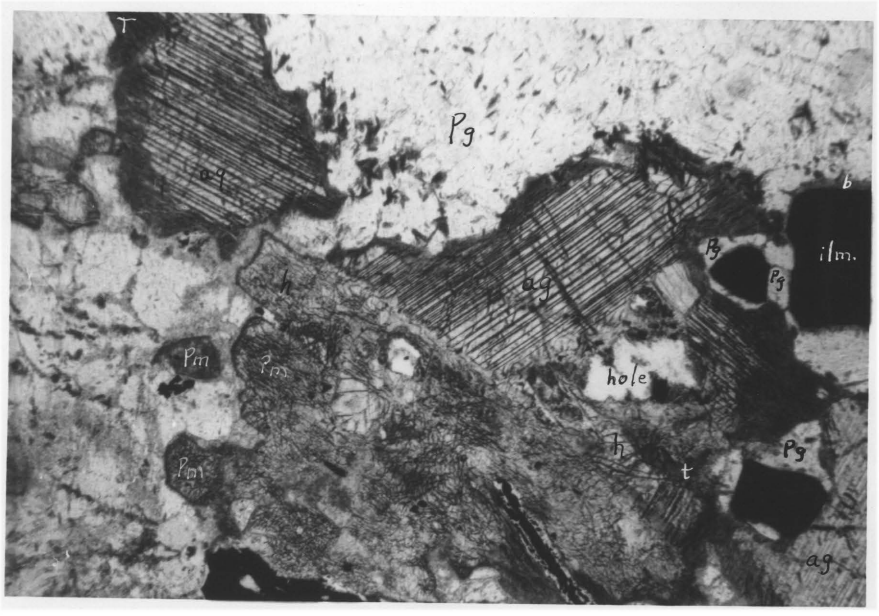


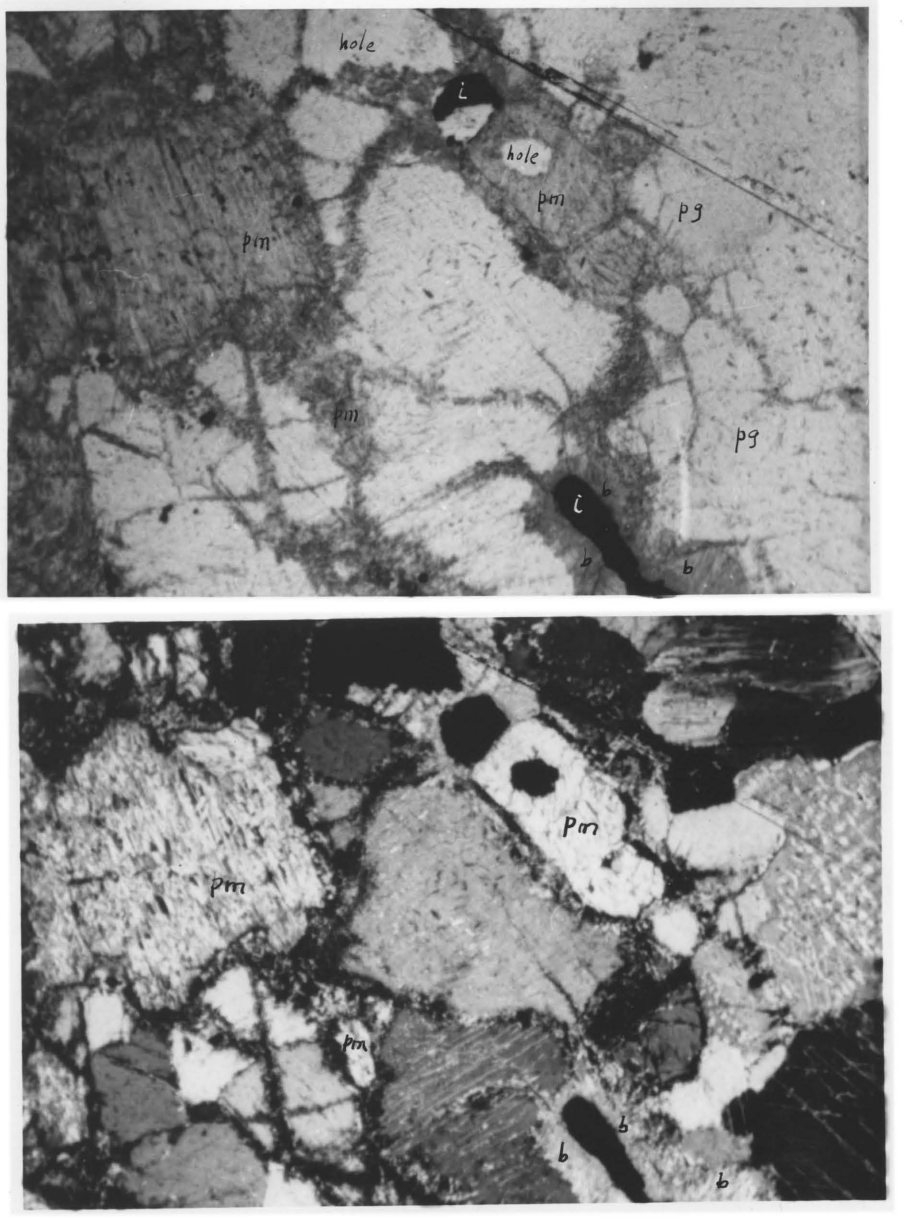
Figure 2 - Low magnification photograph showing surrounding antiperthitic plagioclase (pg), apatite (a) and quartz (q). Plane light, X 24.

Plate 5. - Photomicrograph of altered hypersthene granodiorite from drill core from Taylor property.



Augite (ag) is moderately fresh but rimmed by an inner layer of actinolite and a thin outer layer of tremolite. The hypersthene (h) is largely replaced by pseudomorphs (pm) after hypersthene. Biotite (b) rims the ilmenite. Plagioclase (pg) is strongly saussuritized. Plane light, X 24.

Plate 6. - Photomicrographs of tremolite pseudomorphs after hypersthene in altered hypersthene granodiorite.



Figures 1 and 2 - Pseudomorphs of fibrous tremolite (pm) retain outlines of former hypersthene grains. Inner reaction rim around the pseudomorphs consists of scattered anthophyllite needles and a lower birefringent mineral (u), probably clay. Outer reaction rim is biotite and rarely chlorite next to plagioclase. These outer reaction rims cross antiperthitic plagioclase (pg) matrix. Ilmenite (i) is surrounded by a rim of biotite.

Figure 1, Plane light, X 24.

Figure 2, Crossed nicols, X 24

Plate 7. - Photomicrographs of altered hypersthene granodiorite

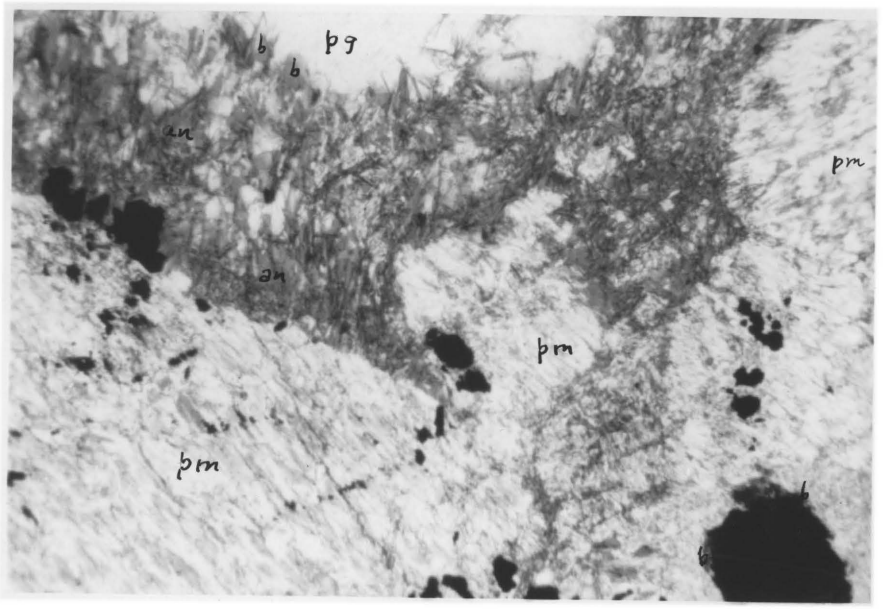


Figure 1 - Enlarged view of reaction rims around hypersthene (?) pseudomorph (pm). Hypersthene (?) is replaced by tremolite and directly bounded by anthophyllite needles and low birefringent mineral (clay mineral?). Outermost part of reaction rim adjacent to plagioclase (pg) is biotite. Note opaque minerals in pseudomorph resulting from conversion of hypersthene (?) to tremolite. Plane light, X 105.

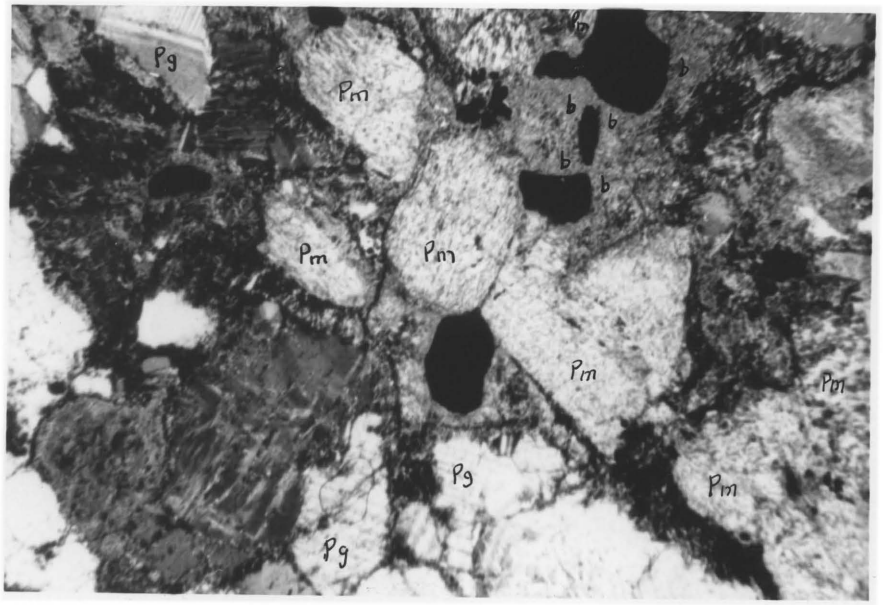


Figure 2 - Thick biotite (b) reaction rims around ilmenite adjacent to pseudomorphs (pm) of tremolite after pyroxene. Plagioclase (pg) is only slightly saussuritized. Note sharp boundaries of pseudomorphs. Crossed nicols, X 24.

Plate 8. - Altered layered hypersthene granodiorite from diamond drill core from old American Rutile pit.

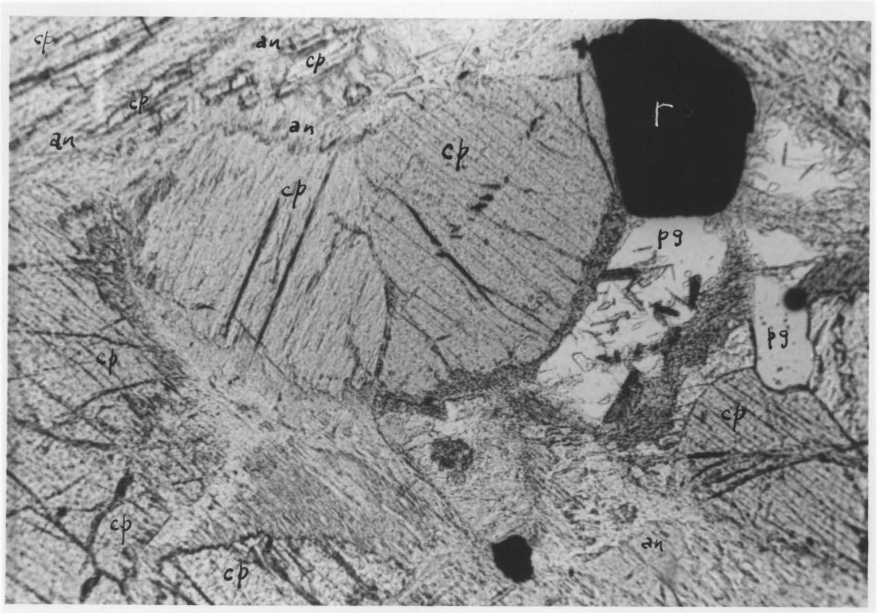


Figure 1 - Remnants of clinopyroxene (cp) in aggregates of anthophyllite (an) needles. Some of the small pyroxene remnants may be hypersthene. Rutile (r) in fresh contact with clinopyroxene. Reaction rim between plagioclase (pg) and clinopyroxene apparently is tremolite. Plane light, X 105.

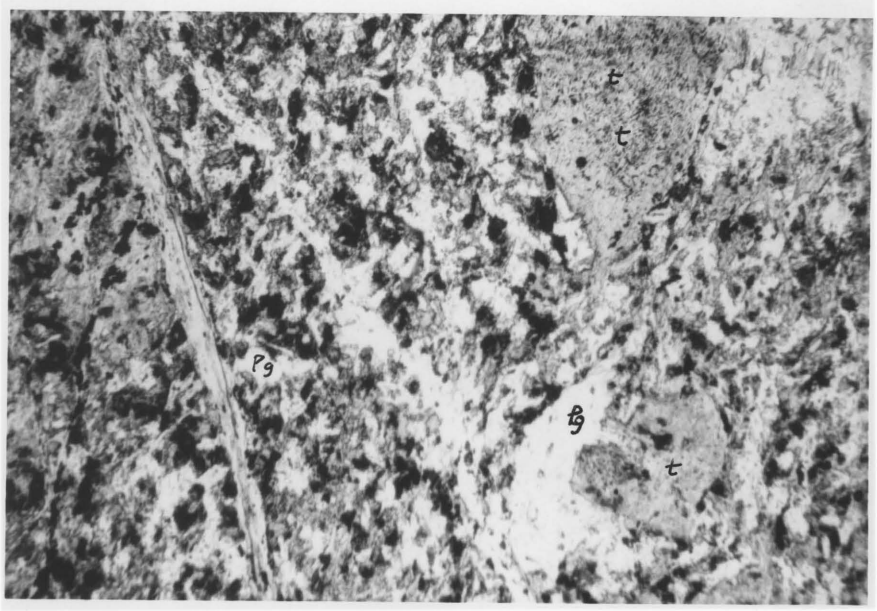


Figure 2 - Tremolite (t) probably after pyroxene. Plagioclase (pg) forms light areas and is filled with abundant high relief blebs of epidote. Shear veinlets contain low birefringent fibrous unknown mineral. Plane light, X 24.

except for better developed reaction rims around the mafic minerals. The most common reactions in the least altered rocks were the formation of biotite where hypersthene is in contact with feldspar, rims of biotite between ilmenite and feldspar, and leucoxene rims around ilmenite and rutile. In more advanced stages of alteration, the feldspars are saussuritized and the pyroxenes are surrounded by rims of amphibole and, less commonly, biotite and chlorite (Pl. 4). With greater alteration, the reaction rims are thicker and the hypersthene is largely replaced by tremolite (Pl. 5). Augite is typically less altered, but in still more advanced stages of alteration the pyroxenes are completely replaced by amphiboles (Pls. 6 and 7). At this stage, the amphiboles may still retain the crystal outlines of pyroxene. The secondary amphibole may be of an almost colorless, non-pleochroic variety, apparently tremolite, which replaces the hypersthene or it may be green, slightly pleochroic actinolite which replaces the clinopyroxene. The tremolite-bearing specimens were obtained from the altered hypersthene granodiorite along Tye River south of Roseland, the hornblende- and actinolite-bearing rocks typically occur in the vicinity of ilmenite ore-bodies. The tremolite is commonly replaced by anthophyllite along fractures and along boundaries. The green amphibole is commonly altered to chlorite. Plates 6 and 7 show fibrous aggregates of tremolite pseudomorphous

after pyroxene, with outer rims of anthophyllite and a colorless, low birefrigent unidentified mineral, possibly a clay mineral. The outer rims extend into fractures in the adjacent plagioclase. In many sections of altered hypersthene granodiorite, fine-grained, fibrous amphibole, probably anthophyllite, partially replaces hypersthene (Pl. 8, Fig. 1).

In the most advanced stage of alteration, the feldspars are highly saussuritized and the mafic minerals are completely replaced by fine-grained irregularly shaped aggregates of amphibole, biotite, muscovite, and chlorite.

An illustration of the intense degree of alteration adjacent to ore bodies is shown in Plate 15 (Fig. 2). This alteration has resulted in redistribution of the iron so that the mafic minerals, actinolite and biotite are acicular, and no pseudomorphism after pyroxene can be detected.

Border Gneiss

A heterogeneous association of diverse rock types commonly separates the distinctive and easily recognized pegmatitic anorthosite from the augen gneiss unit. The different rock types within this zone could not be mapped separately at the scale of the map and are included in the border gneiss unit (Pl. 1). This complex unit contains feldspathic gneisses, altered augen gneiss, garnet and graphite gneisses, and lenses of pyroxenite, amphibolite, and

pegmatitic anorthosite. The latter are most common near the main body of pegmatitic anorthosite.

The feldspathic gneisses of the border gneiss unit are light colored, consist predominantly of feldspar, and are interlayered with other rock types in layers ranging from a fraction of an inch to about 10 feet in thickness. The textures range from fine- to coarse-grained and from massive to gneissic. Feldspathic gneiss lenses from the northern part of the border gneiss unit are characterized by abundant elongate aggregates of blue quartz. These aggregates are as much as an inch long and clearly define a gneissosity which cuts across an essentially massive coarse-grained feldspar matrix. The blue quartz is highly rutilated and is cut by clear fine-grained quartz and mica. The mica defines a secondary schistosity which is more or less parallel to the general northeasterly-trending regional schistosity with southeasterly dip whereas the gneissosity defined by the elongate blue quartz grains has a similar strike but dips to the northwest.

The major minerals of the feldspathic lenses of the border gneiss, feldspar and quartz, constitute up to 98 per cent of the whole rock. The minor minerals are biotite, epidote-clinozoisite, sericite, apatite, ilmenite, and zircon. The feldspar is chiefly extensively saussuritized microperthite.

Layers of gneissic rock, similar in appearance to that described above, with the exception that minor biotite is evident in hand specimen, occur in the border gneiss unit near the bodies of layered hypersthene granodiorite. Thin sections of these rocks contain up to 5 per cent of biotite, 4 per cent of uralitic hornblende-pseudomorphous after pyroxene, and minor chlorite. The feldspar is antiperthitic calcic oligoclase which constitutes up to 80 per cent of some sections. The same accessory minerals are present as in the feldspathic gneiss lenses. Some of the ilmenite grains are surrounded by a thin rim of rutile which in turn is surrounded by a rim of leucoxene. Locally the titanium minerals have a rim of biotite and many are oriented along the gneissosity. Elongate grains of blue rutilated quartz are displaced by later shear planes which are now marked by mosaic textured, fine-grained clear quartz.

Along Piney River at Lowesville and Tye River 400 yards west of Highway 151, the border gneiss unit consists of alternating layers of medium- to coarse-grained, massive, almost pure feldspar rock with layers of altered augen gneiss. The layers are as much as 10 feet thick. The massive feldspathic rock is extremely similar to the rock in the main body of the pegmatitic anorthosite although it is finer grained. This rock probably forms injected lenses that were connected with the intrusion of the pegmatitic anorthosite. Thin

sections of the feldspathic layers consist chiefly of antiperthite and complexly twinned oligoclase. Some of the sections studied contain only minor interstitial quartz, but others are cut by coarse blue rutilated quartz grains. Rutile occurs widely scattered as small, nearly equidimensional grains. A few rutile grains are surrounded by rims of ilmenite. Some of the massive feldspathic layers have been considerably altered so that the plagioclase is saussuritized, the mafic minerals in contact with feldspar are surrounded by biotite rims, biotite and chlorite veinlets have formed along fractures, and titanium minerals are altered to sphene.

Locally there are medium- to coarse-grained massive feldspathic rocks that consist of micrographic microcline and quartz. However, because of poor exposures, it is not known whether these rocks are interlayered with the other feldspathic gneisses or are discordant with them.

The layers of somewhat altered augen gneiss are widespread but are believed to be most abundant in the wide area of border gneiss south of the Tye River. However, the exposures in that part of the area are poor. Exposures of the gneiss typically contain thin feldspathic laminae essentially parallel to the gneissosity. The laminae are largely altered to epidote and sericite. The general mineralogic composition and texture of the rock is similar to that of the augen gneiss in the adjacent augen gneiss unit.

Garnet-bearing hypersthene pyroxenite occurs as concordant lenses or tabular bodies up to 4 feet thick, interlayered with feldspathic gneiss, at the intersection of Highway 151 and County Road 781. Float of the same material is found on a low hill 1.8 miles due east of Bryant. A thin section of this rock consists of more than 90 per cent hypersthene in equidimensional grains 1 to 2 mm. across. Minor amounts of andesine, magnetite, sulfide, and dark green amphibole occur interstitially. All of the hypersthene grains are surrounded by thin rims of fine-grained, fibrous amphibole, which also extends into fractures in the pyroxene. The surfaces of the pyroxene grains are marked by small, parallel, rectangular pink to lavender, apparently thin films of ilmenite. Garnet was not present in the section studied but occurs in the rock as dark red crystals up to 2 cm. across.

Garnet- and graphite-bearing gneisses are widespread, although not abundant, in the border gneiss. Rocks of this type occur as regolith on an isolated knoll about 400 yards east of County Road 672 at the north end of Mars Mountain and as scattered float about one mile to the northeast.

Small outcrops of garnet- and graphite-bearing rock also are present along Maple Run Creek on the southeast side of the pegmatitic anorthosite. The best outcrops however, are found on both sides of the pegmatitic anorthosite along the Tye River. A traverse down the Tye River from the northwestern

side of the area reveals the following sequence: the garnet- and graphite-bearing gneiss is separated from the augen gneiss and granitic gneiss units to the northwest by a 600-foot covered interval. The most northwesterly garnet-graphite gneisses are dark gray and layered. They are rich in coarse, elongate blue quartz grains, graphite, and sulfides. These crop out for several hundred feet along the stream - this represents about 60 feet measured perpendicular to the strike. A small covered interval (50 feet) separates these from a more massive, lighter colored, garnet-graphite-bearing rock on the downstream side which in turn is separated by a 75-foot covered interval from exposures of feldspathic gneiss. The sequence is essentially reversed along Tye River on the opposite side of the main mass of pegmatitic anorthosite. On both sides, the garnet is restricted to a relatively narrow zone (not more than 50 feet thick) whereas the graphite is relatively widespread.

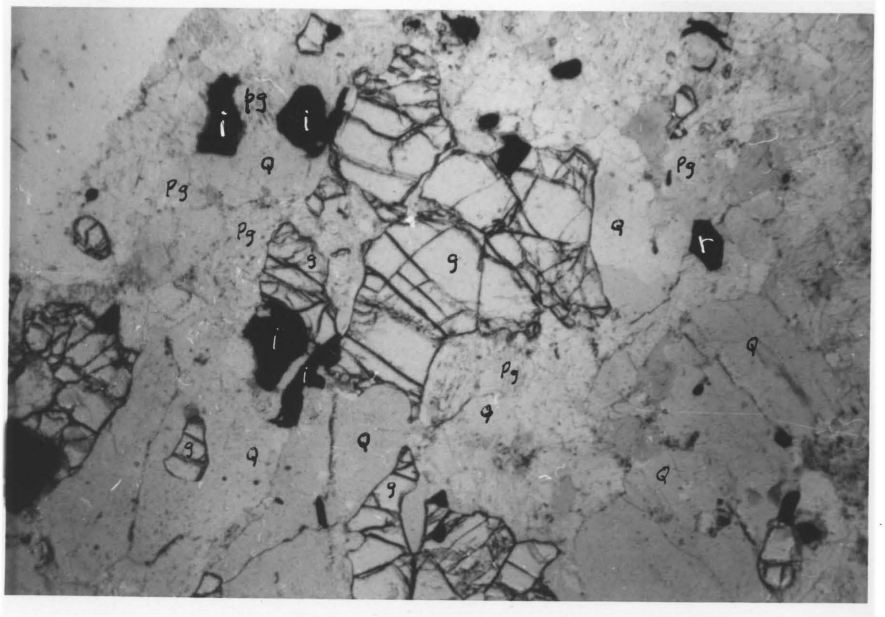
A thin section of the graphite- and sulfide-rich gneiss from the Tye River on the west side of the anorthosite consists of 45 per cent intermediate andesine, 26 per cent hypersthene which is largely altered to fibrous amphibole, 16 per cent quartz, approximately 8 per cent pyrite and 2-3 per cent graphite. A thin section of the adjacent garnet- and graphite-bearing gneiss contains anhedral garnets up to 1 cm. in length. These are filled with abundant inclusions of quartz. The remainder of the rock contains calcic

oligoclase, microcline, perthitic microcline, and a small amount of graphite. A specimen from the locality east of Mars Knob consists of approximately 70 per cent intermediate andesine, 10 per cent hypersthene, 10 per cent garnet, and minor quartz, microcline, magnetite, graphite, and epidote. The garnets range from 2 to 4 mm. in length and are extremely irregular in outline. Except for the garnet, the rock is identical in composition and in texture to the nearby hypersthene granodiorite bodies. Another specimen from one mile northeast of the Mars Knob area consists of 45 per cent microcline and perthitic microcline, 35 per cent quartz, 15 per cent garnet, and a trace of hypersthene. It also contains minor rutile, ilmenite, graphite and epidote (Pl. 9). The garnet contains minute needles that are believed to be rutile.

Pegmatitic Anorthosite

A coarsely crystalline, feldspar-rich rock which underlies most of the central part of the area is mapped as pegmatitic anorthosite. As previously noted, this rock was first referred to as pegmatite by Watson (1907) who later (1913) changed the name to syenite while suggesting that anorthosite might be a better term. Stose referred to the body as albitite on the geologic map of Virginia (1928). Jonas (1927, 1935) referred to it as pegmatite. In 1941,

Plate 9. - Photomicrograph of garnet-rich rock from the border gneiss unit.



Irregular garnet grains (g) in matrix of antiperthitic plagioclase (pg) and quartz. Rutile (r) and ilmenite (i) occur as scattered blebs in the rock. Plane light, X 24.

Ross proposed the name "Roseland Anorthosite", a term which has been accepted and used by all later workers.

From the foregoing, it is obvious that this rock is not easily classified. It does not correspond compositionally with any common rock type. It is much more sodic and potassic than common anorthosite, but more calcic than syenite. Based solely on composition, and assuming an igneous origin, the rock would be called leuco-monzonite; this would be misleading. The most striking characteristics of the rock are its abnormally highly feldspathic composition and its exceptionally coarse grain size. In view of these, it is felt that the term pegmatitic anorthosite is perhaps the most descriptive and appropriate term available. The term was chosen after detailed studies of the rock suggested that it may represent an intermediate phase between anorthosite and true granitic pegmatite.

Outcrops of pegmatitic anorthosite are rare owing to its susceptibility to weathering. There are exceptionally good exposures, however, at the three feldspar quarries near Piney River and in the old American Rutile mine near Roseland. Exposures are also present along Tye River. Although the detailed character of the pegmatitic anorthosite can be determined from examination of these exposures, distribution of the rock must be inferred largely on the basis of the presence of the characteristic white, kaolinitic soil to

which it weathers. This white soil is extensively developed over the flat central region of the map area, an area which is approximately 9 miles long, in a northeasterly direction, and about 2½ miles wide at its maximum width.

Evidence suggests that all of the pegmatitic anorthosite within the area does not belong to one continuous solid intrusive mass but that it forms a complex of related crosscutting dike-like bodies and possibly some sill-like layers in the older rocks. Exposures in the quarries all contain inclusions and remnants of sill-like masses of finer grained layered hypersthene granodiorite. Crosscutting contacts between pegmatitic anorthosite and other rocks are exposed at several localities. A 20-foot wide dike which cuts altered layered hypersthene granodiorite is exposed along the Tye River, 1¼ miles south of Roseland. Sill-like projections from the crosscutting bodies are exposed in the American Rutile pit. Lenses of the pegmatitic anorthosite have already been described in the border gneiss unit.

The pegmatitic anorthosite consists chiefly of a massive mottled cream to white rock with irregular bluish-gray patches. In places the anorthosite has been sheared almost to a schist; in others it exhibits a sugary texture; evidence of extreme brecciation is widespread. Based on its degree of deformation, some of the rock would probably be called a gneiss; however, there commonly are no contrasts in

colors or minerals because of the nearly monomineralic composition. In the well exposed feldspar quarries it is apparent that only a small part, possibly not more than 10 per cent, of the original rock texture is preserved. This original texture is characterized by bluish-gray, satin-lustered fresh plagioclase in broken crystals as much as 12 inches across (Pl. 10). Probably there are larger crystals. The plagioclase is antiperthitic and its composition as determined from the minimum indices of refraction of cleavage fragments is An_{30}, oligoclase-andesine. Intergrown microcline is fairly abundant and an apparently similar plagioclase analyzed by Ross (1941, p. 10) contained 25.1 mol per cent microcline.

The major part of the pegmatitic anorthosite consists of altered, light colored, fine-grained plagioclase which surrounds and crosses the original darker and coarser feldspar. This plagioclase is also antiperthitic (Pl. 11) but is less calcic in composition. It is saussuritized and replaced by clinozoisite and at least locally by sericite. The most extreme saussuritization results in textures similar to that shown in Plate 12. Where saussuritization is best developed, the plagioclase is now all albite-oligoclase (An_{10}). The alteration is clearly localized along shears and cracks. Commonly the alteration is so extensive that most of the rock consists of the lighter colored feldspar.

Plate 10. - Photograph showing broken oligoclase crystal from pegmatitic anorthosite. Darker gray irregular aggregate is part of a single somewhat broken crystal of antiperthite oligoclase-andesine (An_{30}). New quarry of Dominion Minerals Company.

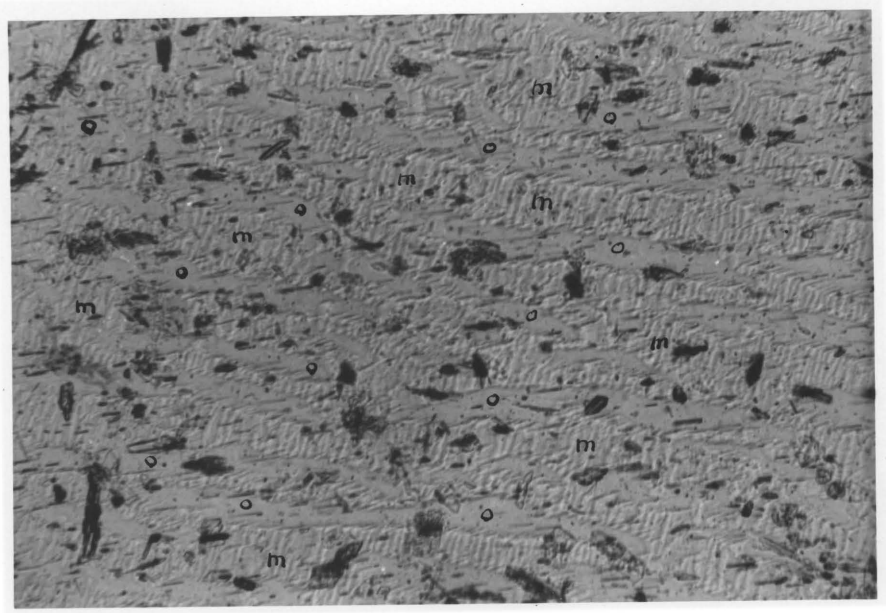


Plate 11. - Antiperthite from pegmatitic anorthosite.

Oligoclase (o) crosses twinning of microcline and small laths of oligoclase are aligned parallel to the microcline. Small, high relief grains are clinozoisite. Plane light, X 105.

Plate 12. - Photomicrographs of altered pegmatitic anorthosite

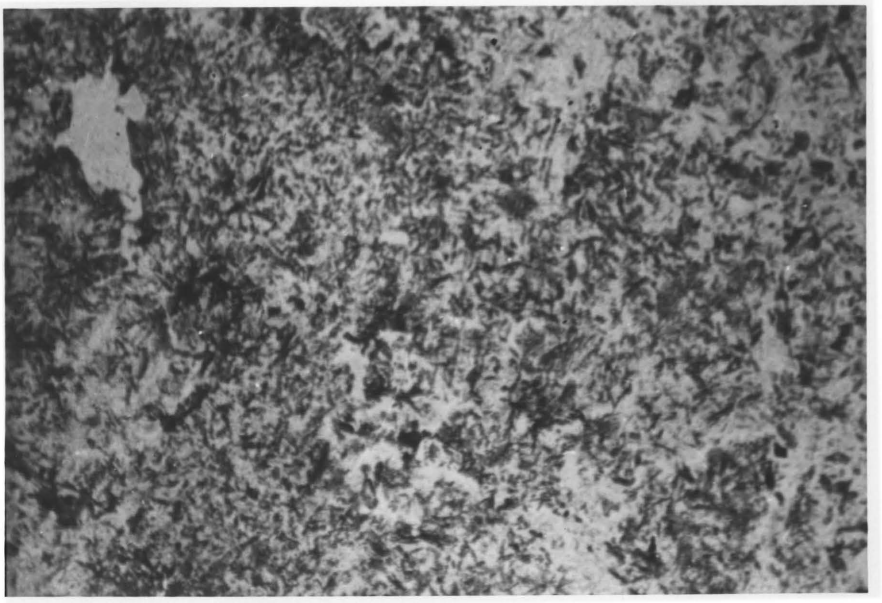


Figure 1 - Intensely saussuritized oligoclase. Small blebs are largely clinozoisite with minor amounts of mica. Plane light, X 24.

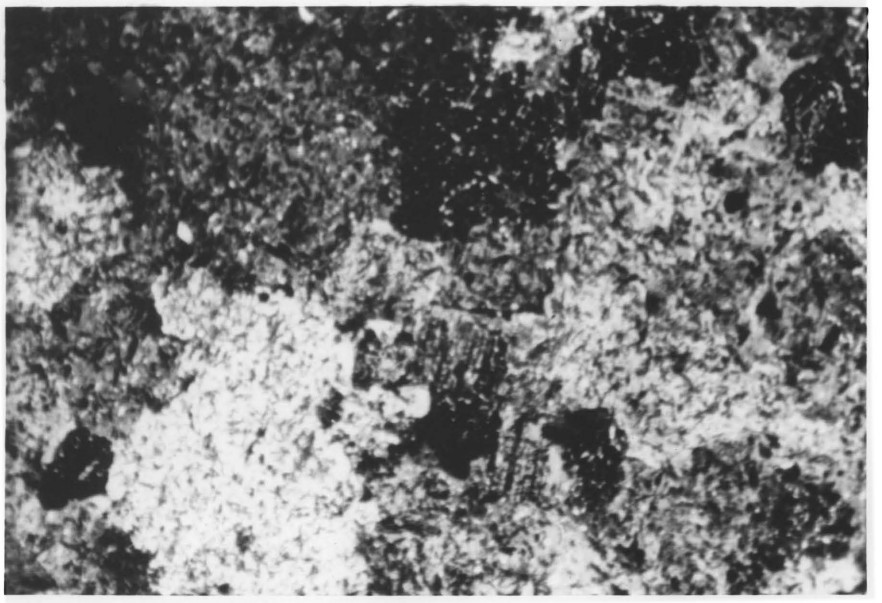


Figure 2 - Same as Figure 1 but with crossed nicols.

Locally, finer-grained altered feldspar is not lighter colored but is gray and except for grain size is similar in appearance to the original plagioclase. However, it also is albite (An_2- An_{10}) and is localized in small veinlets or crosscutting bodies that are younger than the lighter-colored altered areas. Much of the alteration apparently occurred with little chemical change other than the addition of volatiles. This is apparent in small crosscutting veinlets or dike-like bodies which change in composition where they penetrate different hosts. In the altered rocks there are commonly small irregular blebs of blue quartz which are surrounded by a darker rim - the latter apparently manifesting a greater concentration of rutile needles. This quartz was not found to occur in rock which is clearly part of the original pegmatitic anorthosite. However, the quartz does appear to have been embayed by the altering solutions so it appears that a small amount of quartz may have been present in the original coarse-grained rock. However, quartz has been introduced along cracks and fissures in some of the primary oligoclase-andesine.

One of the most striking features of the pegmatitic anorthosite is the included aggregates of ferromagnesian minerals. These aggregates range from narrow stringers or blebs a fraction of an inch thick to aggregates as much as 2 feet across. The average size is probably 3 inches and

the typical shape is roughly rectangular to oval. Locally, the aggregates have a poorly developed flattening or gneissosity. The gneissosity occurs only in layers 5 to 30 feet wide where the aggregates are exceptionally abundant - up to 40 per cent of the entire rock. In many quarry exposures there are no aggregates over areas of several hundred square feet. In most exposures, aggregates form only one or two per cent of the entire rock.

The aggregates contain somewhat different minerals in different parts of the area. At the American Rutile quarry, Ross (1941, p. 11) found some of the aggregates to have cores of large clinohypersthene crystals. These were altered around their edges and along fractures, to fine-grained amphibole. The writer was unable to find any of the large pyroxene crystals in the present exposures there, but did find single solid aggregates of amphibole as much as 11 inches long and 8 inches wide. These resembled single crystals in that they had a pyroxene-like cleavage, but they consist of very fine-grained anthophyllite (N = 1.625). The "pseudo-crystals" are commonly broken, bent, and cut by stringers containing a darker actinolite, biotite, and chlorite. Apatite, ilmenite, and rutile also occur in these stringers. A well developed reaction rim of needles of the darker actinolite surrounds the anthophyllite. These needles are commonly oriented subperpendicular to the contact, however.

The actinolite rim is bordered by another biotite-rich reaction rim and an outermost narrow rim of chlorite completes the aggregate. The biotite and chlorite are also commonly oriented nearly perpendicular to the rims. Fine-grained quartz commonly occurs with the biotite. An additional epidote-rich band is present in the anorthosite in contact with the chlorite rim and the remaining anorthosite is saussuritized. Apparently these "pseudo-crystals" of anthophyllite are actually pseudomorphs after pyroxene, either hypersthene or clinohypersthene. Except for the size of the crystals, they are similar to some of the replaced hypersthene in the previously described hypersthene granodiorite (Pls. 6 and 7).

The outermost reaction rims of the aggregates tend to depart from the exact boundaries of the pseudomorphs and penetrate shears and fractures in the anorthosite. This locally results in the almost gneissic texture which apparently led Ross (1941, p. 19) to conclude that the aggregates of ferromagnesian minerals represent replacement of the anorthosite.

In the feldspar quarries in the area there are many excellent exposures of the dark aggregates. However, in none of these were any fresh pyroxene nor any "pseudo-crystals" of anthophyllite found. Instead, the aggregates have an inner zone of largely unoriented fine-grained

needles of greenish tremolite-actinolite, surrounded by a biotite-rich rim and an outermost chlorite-rich rim (Pl. 13, Fig. 2). Ilmenite occurs in the edges of some of the reaction rims (Fig. 2) at the old quarry of the Dominion Minerals Company, and ilmenite, apatite and rutile are commonly associated with some of the aggregates in the Consolidated Feldspar Quarry. The titanium minerals, quartz, and apatite may penetrate the central "core" of the aggregates along fractures but these minerals are not restricted to the aggregates. Some occur in areas of the altered feldspar rock. Some of the aggregates have an innermost core of somewhat lighter brown amphibole which may be cummingtonite. Rutilated biotite is generally associated with this amphibole. Other aggregates have white roseate blebs of tremolite and some of the largest aggregates as well as some of the smaller ones resemble actinolite schist in their interiors. The minerals in the inner zones of the aggregates may vary considerably and it is doubtful that all of these aggregates are after pyroxene. There is a tendency for the aggregates to be most abundant near inclusions of hypersthene granodiorite, but the aggregates are clearly not fragments of hypersthene granodiorite. Contacts between pegmatitic anorthosite and the inclusions are sharp. The reaction rims around the mafic minerals in the hypersthene granodiorite are of the same type as those around the mafic aggregates,

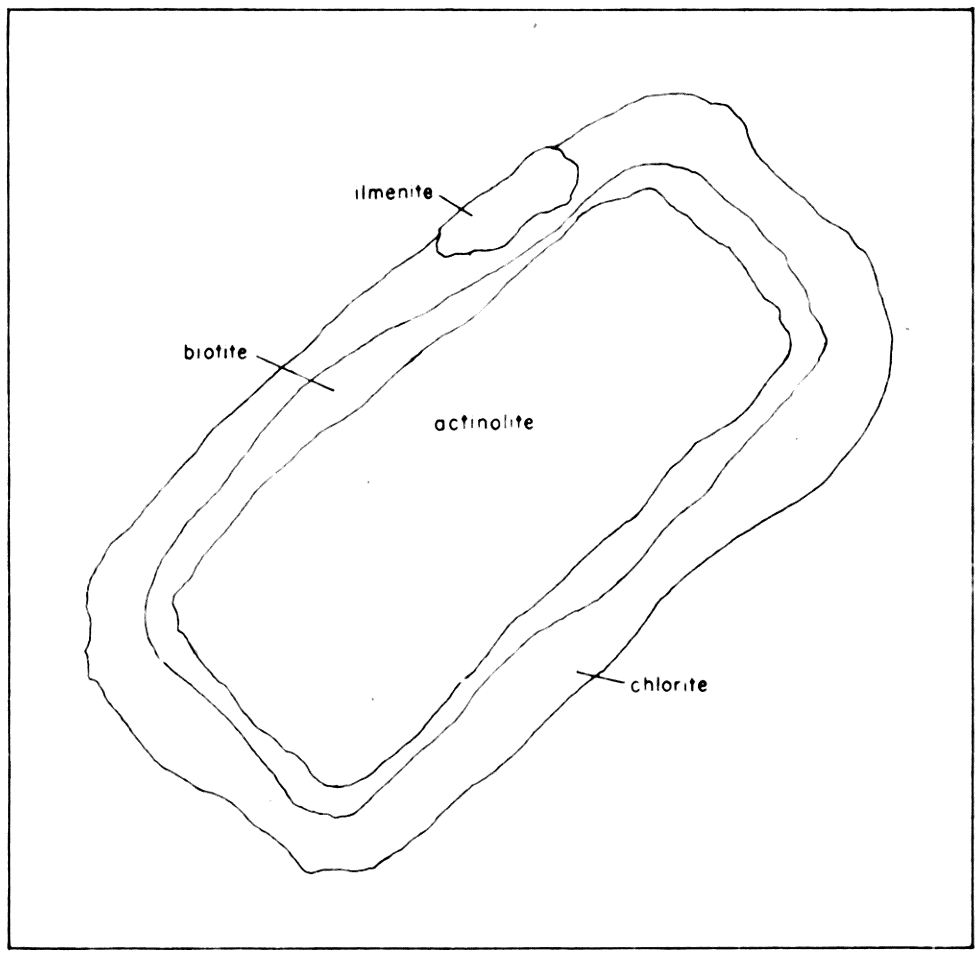
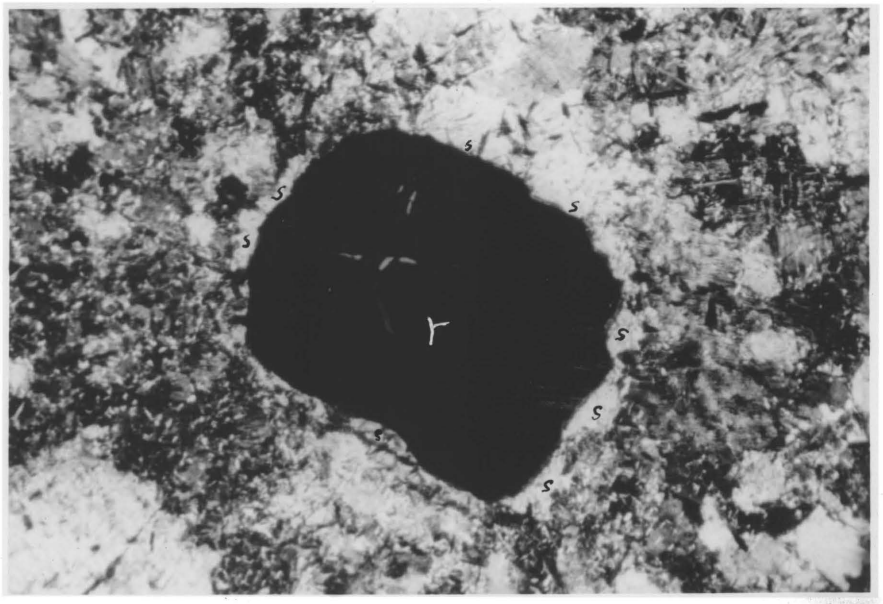


Figure 2 .- Diagramatic sketch of typical reaction rims around mafic aggregates, full size

Plate 13. - Photomicrographs showing reaction rims across aggregate of ferromagnesian minerals from the pegmatitic anorthosite. Photographs do not match precisely because of separation in original thin section. Cross section of aggregate represents approximately 10 mm. from top to bottom. Specimen from Dominion Minerals Quarry. Plane light, X 24.

Plate 14. - Rutile in saussuritized plagioclase



Rutile, the large opaque grain, is surrounded by a thin rim of sericite which is absent from the altered plagioclase that makes up the remainder of the rock. Crossed nicols, X 24.

but are small by comparison. Possibly, some of the aggregates whose inner cores have more variable compositions may represent xenoliths of pyroxenite or other mafic rock.

At least one dike-like body of amphibole-rich rock is exposed in the Consolidated Feldspar Quarry. However, because of the alteration and shearing it is not certain if the rock was intrusive or represents a relic country rock screen in the pegmatitic anorthosite. No thin sections of this rock were studied but it appears to be similar in composition to some of the cores of the aggregates.

The titanium minerals, ilmenite, rutile and sphene apparently occur chiefly if not entirely in altered areas of the pegmatitic anorthosite. The localization of ilmenite, rutile, and apatite near and in aggregates of mafic minerals has been mentioned. Some ilmenite and more of the rutile is disseminated locally through the altered feldspar-rich rock, but most tends to be associated with noticeable shears and fractures and is commonly surrounded by sphene or leucoxene rims. Rutile commonly is bounded by sericite in the saussuritized plagioclase (Pl. 14). However, some rutile is entirely fresh and contains only a trace of sericite along its contacts. One exposure in the Consolidated Feldspar Quarry contains a two inch long aggregate of ilmenite bordered by a reaction rim of pale rose-colored sphene nearly 0.3 inches thick.

Coarse-grained massive rutile is exposed at the Buffalo Mines Quarry. The rutile forms solid aggregates as much as one foot across in a blue-quartz-rich matrix bordered at least on one side by normal anorthosite. An adjacent aggregate of mafic minerals, although weathered, has the appearance of a single, altered pyroxene crystal 18 inches in diameter. The large crystal occurs in a five foot wide zone or lens consisting largely of altered coarse-grained mafic rock. The structural relationships are not clear but possibly the rutile and adjacent mafic rock are part of a coarser grained phase of the anorthosite.

Locally in the feldspar quarries there are thin dikes, a few inches thick, which resemble pegmatite. These contain albite, microcline, and a little muscovite and cut the altered anorthosite. One contains an aggregate of very pale rose-colored garnet.

The youngest feldspathic dike-rock cuts all of the other units. It is a fine- to medium-grained, gray, somewhat spotted rock. The rock consists of about 70 per cent albite, 20 per cent muscovite and the accessory minerals microcline, quartz, biotite, epidote, garnet, zircon and sphene. The albite is in elongate crystals with somewhat sutured borders but is entirely free from the characteristic saussuritization of the feldspars in the anorthosite. Probably this rock is related to the late pegmatitic dikes that also contain muscovite.

Nelsonite

The term "nelsonite" was given in 1907 by Watson to rocks in Nelson County that consist essentially of apatite and one or more of the oxides, ilmenite, rutile or magnetite. Rocks that fall within this category present a considerable range in composition. Watson and Taber (1913) named six types of nelsonite: ilmenite nelsonite, hornblende nelsonite, rutile nelsonite, magnetite nelsonite, biotite nelsonite and gabbro nelsonite. Of these, the ilmenite nelsonite is by far the most abundant and economically the most important. Almost all of the bodies shown on Plate 1 are of this type. Only one body of rutile nelsonite, 200 yards north of the intersection of Highway 151 and Tye River, and one of biotite nelsonite, 3/4 mile east of Roseland, are shown on Plate 1. Several hornblende-rich nelsonite bodies were encountered in the field, but these are mapped as ilmenite nelsonite because the two are completely gradational. Small bodies of rock classified as magnetite nelsonite are relatively abundant along the northwest side of the map area. No gabbro nelsonite was recognized by the writer, although it is believed that Watson and Taber (1913) may have used the term in reference to the rocks herein referred to as ilmenite- and magnetite-bearing hypersthene diorite layers of the layered hypersthene granodiorite.

The bodies of nelsonite range in shape from lenticular, dike-like bodies to disseminated and bifurcating pods and lenses. Their size ranges from large bodies 2000 feet long by 200 feet wide to small lenses less than 10 feet long. The dike-like bodies underlie small hills and are generally weathered to only shallow depths. Outcrops and float are abundant in the vicinity of these deposits. The disseminated and bifurcating lenses in amphibolite are weathered to depths of greater than 100 feet.

The bodies of nelsonite are most abundant in the border gneiss unit although a few occur in the pegmatitic anorthosite and in the augen gneiss units. The rutile-, ilmenite-, and magnetite-rich varieties have a definite zonal position relative to the pegmatitic anorthosite as noted by Watson and Taber (1913). The rutile nelsonite occurs within massive, pure pegmatitic anorthosite, the ilmenite nelsonite bodies are concentrated in the border gneiss unit close to the pegmatitic anorthosite, and the magnetite nelsonite bodies occur in the feldspathic gneiss and augen gneiss units along the western margin of the mapped area at a considerable distance from the anorthosite. The ratio of iron to titanium apparently increases away from the pegmatitic anorthosite.

The principal minerals in the nelsonite are ilmenite, apatite, magnetite, rutile, plagioclase, quartz, hornblende, biotite, and chlorite. The typical ilmenite nelsonite bodies

shown on Plate 1 consist largely of ilmenite and apatite. However, the composition is gradational and any of the previously mentioned principal minerals may be the most abundant constituent in certain specimens from different bodies. The color of the ilmenite and magnetite nelsonites ranges from green or gray to black depending on the type and proportion of silicates to oxides. The rutile-rich variety is reddish-brown. Ilmenite nelsonite is medium-grained, equigranular and has a distinct almost graphic or eutectic-like texture. Plate 15 (Fig. 1) illustrates the texture at a moderate magnification. Amphibole-rich varieties of nelsonite are commonly banded or slightly schistose.

Many hand specimens that appear to be bimineralic (apatite and ilmenite) can be seen to contain appreciable amounts of silicate minerals in thin sections. For example, a dark gray, highly metallic specimen from diamond drill core from the Johnson property, 2 miles north of Bryant, possesses the composition shown in Table 4. Watson and Taber (1913, P. 110) gave norms from chemical analyses of nelsonite that contain up to 60.65 per cent ilmenite and they stated (P. 111) that the content of ilmenite in some samples may be as high as 90 per cent. As much as 31 per cent normative apatite is shown in some of the analyses of Watson and Taber.

Plate 15. - Photomicrographs of nelsonite and adjacent amphibolite.

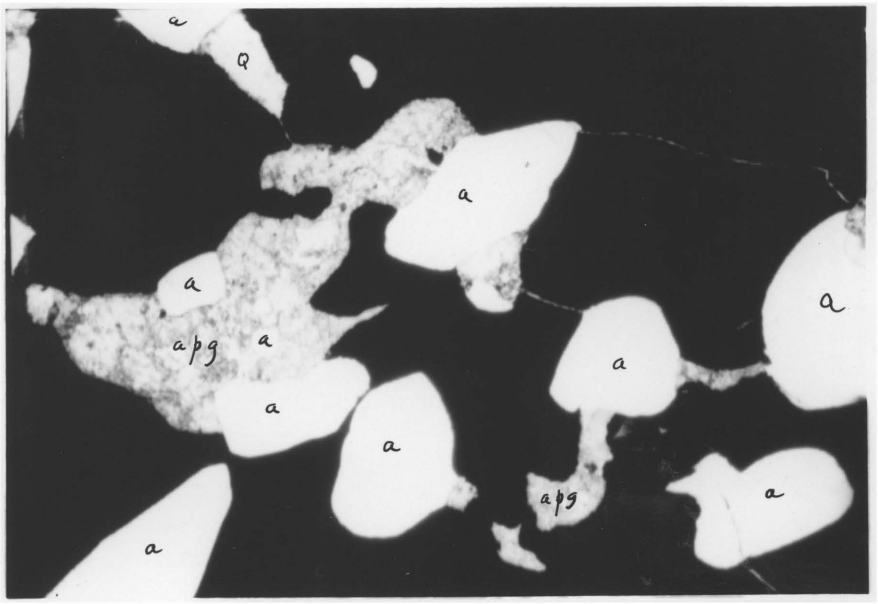


Figure 1 - High grade ilmenite nelsonite from Johnson property showing a typical texture. Apatite (a) and saussuritized plagioclase (apg) in opaque ilmenite. Plane light, X 24.

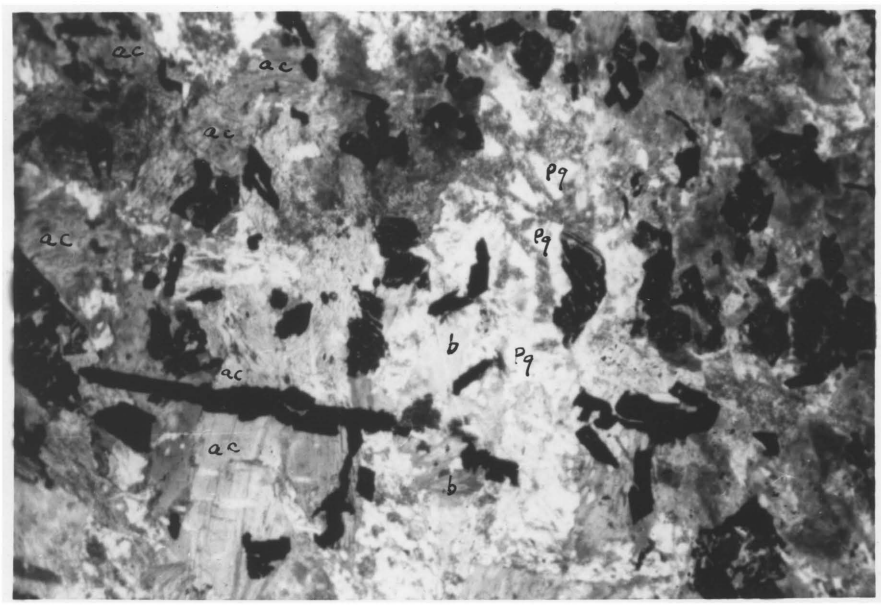


Figure 2 - Amphibolite adjacent to nelsonite, Johnson property. Ilmenite blades and aggregates in matrix of actinolite (ac), biotite (b), and saussuritized plagioclase (pg). Skeletal ilmenite aggregates are intergrown with small blades of biotite. Some ilmenite cuts actinolite laths. Plane light, X 24.

Table 4. - Modes of ilmenite nelsonite and adjacent amphibolite*

Mineral	Ilmenite nelsonite Per cent (volume)	Amphibolite Per cent (volume)
Ilmenite	45	12
Apatite	23	2
Plagioclase	18	27
Hornblende	5	45
Chlorite	8	-
Quartz	-	4
Biotite	1	Trace
Epidote	Trace	7
Sericite	Trace	-
Sphene	Trace	-
Sulphide	Trace	-
Calcite	-	Trace

*Modes calculated from point count analysis of one thin section each.

The silicate minerals in the nelsonite are highly altered and occur as irregular aggregates that are surrounded by ilmenite. Apatite occurs as subhedral to anhedral grains, 1 to 3 mm. in diameter. It embays the silicate minerals but is itself embayed by ilmenite. The ilmenite occurs as anhedral grains up to five mm. in diameter and appears to be interstitial between apatite grains and silicate aggregates (Pl. 15, Fig. 1). Rarely, ilmenite in the more silicate-rich specimens is broken and slightly deformed.

The ilmenite nelsonite of Table 4 grades into amphibolite, the mode of which is given in the same table. These modes indicate somewhat the degree of variation in the nelsonite within a few feet. The photomicrograph in Plate 15 (Fig. 2) shows the characteristic textures of the amphibolite. In polished sections, the ilmenite can be seen to be complexly intergrown with small laths of magnetite with a relationship suggesting exsolution. The amount of magnetite ranges from only traces in some nelsonite bodies to where magnetite is the host and ilmenite is the intergrown mineral in others. The bodies in which magnetite is more abundant than ilmenite, that is, the magnetite nelsonite bodies, occur at considerable distances from the pegmatitic anorthosite unit, as previously mentioned.

Time did not permit the writer to obtain enough data to determine whether there are irregularities or reversals in

the apparent regional distribution of ilmenite and magnetite.

In one polished section of rutile nelsonite from the Giles property, 200 yards northeast of the intersection of Highway 151 and Tye River, the rutile is in branching veinlets with apatite which cut across ilmenite nelsonite. Aggregates of the ilmenite nelsonite are surrounded by the rutile veinlets. The rutile is clearly younger than the ilmenite in this specimen.

Dolerite

Dolerite occurs as many thin dikes which cut the rocks of the border gneiss and hypersthene granodiorite units and as relatively rare dikes in other rocks of the area. The dikes which tend to be especially abundant in areas of altered hypersthene granodiorite and nelsonite, range from about one foot to 30 feet thick. Most of the dikes are vertical and strike about N10°E across the structure of the surrounding rocks. The dolerite is nearly aphanitic along the borders of the larger dikes and microphaneric in the interiors. Smaller dikes less than four feet thick are entirely aphanitic and some contain poorly developed columnar joints.

The dolerite which is highly altered in thin section, consists of fine-grained hornblende, biotite, and chlorite pseudomorphous after pyroxene, andesine (An_{40}), ilmenite, clinozoisite, and leucoxene. Although this composition

does not fit that of a dolerite (ie., labradorite and pyroxene), relicts of subophitic texture are preserved which indicate that the rock probably was similar to diabase before alteration. Although the alteration is intense, the rock apparently has not experienced the extensive deformation and metamorphism of the other rocks in the area. Possibly these dolerite dikes are related to the Triassic (?) diabase dikes of the Blue Ridge and other areas in the Appalachians.

Late Quartz Veins

All of the major rock units of the mapped area are cut locally by veins of quartz. Most of these veins are concordant with the gneissosity and the majority are less than one foot thick. These small veins were not mapped. However, a few large veins, up to 75 feet long by 35 feet thick, are shown on Plate 1. Most of these are near the contact between the border gneiss and the augen gneiss units.

Pegmatite

Small, crosscutting dikes of granitic pegmatite that range from less than one inch to a few feet thick are numerous in the border gneiss and hypersthene granodiorite units in the southwestern corner of the mapped area. The larger dikes cut across the gneissosity at various angles (Pl. 1). These dikes are coarsely crystalline and consist of quartz,

feldspar and books of muscovite up to one inch in diameter. Small pegmatitic stringers also occur in the pegmatitic anorthosite as previously noted; these were not mapped.

AGE RELATIONSHIPS OF THE ROCK TYPES AND UNITS

Although the precise age relationships cannot be determined for all of the rocks because of inadequate exposures and the repeated deformation they have undergone, one can obtain a fairly consistent picture from examinations of the structures and textures of the various rock types and units. The youngest rock is the unmetamorphosed or slightly metamorphosed dolerite which cuts all other rock types. Perhaps these are equivalent to the other Triassic (?) diabase dikes of the general province. The quartz veins also cut the other rocks; probably they were emplaced during or shortly after the main metamorphism of the area. The relatively undeformed granitic pegmatites that cut the augen gneiss and the pegmatitic anorthosite are younger than these units. The nelsonite crosscuts the pegmatitic anorthosite as well as most of the other rock types and therefore probably is the youngest of the major rock types. The nelsonite, however, has experienced some deformation and was therefore emplaced before the end of the latest effective deformation. The pegmatitic anorthosite is locally gneissic and has experienced considerable deformation and alteration. However, it has been described as a group of sills and dikes which crosscut and extend apophyses into the feldspathic gneiss and the layered

and altered hypersthene granodiorite. This suggests that the pegmatitic anorthosite is younger than these rock types.

The age relationships between the different hypersthene-bearing rocks is not clear. The altered hypersthene granodiorite has relicts of hypersthene grains and layered structures which indicate that it was related to or was identical to the layered hypersthene granodiorite. The crosscutting relationships of the pegmatitic anorthosite with the altered hypersthene granodiorite have been previously described. These relationships indicate that the original crystallization of the altered hypersthene granodiorite occurred prior to the intrusion of the pegmatitic anorthosite. However, the altered hypersthene granodiorite acquired much of its present character as a result of alteration that was apparently contemporaneous with titanium mineralization, that is, later than the intrusion of the pegmatitic anorthosite. The massive hypersthene granodiorite has experienced little or no metamorphism and retains a typical "igneous" appearance. In the centers of the massive hypersthene granodiorite bodies there is virtually no gneissosity or any suggestion of relict structures. This plus the roughly circular shape and the general crosscutting relationships of these bodies to the regional structure suggests that this rock resisted deformation or, more probably, that it is younger than all of the major rock types with which it is in contact. These include the

augen gneiss and layered hypersthene granodiorite. The peripheral relationship of some of the layered hypersthene granodiorite to the massive variety might suggest that the latter is merely the undeformed center of a large intrusive body. However, the body of similar massive hypersthene granodiorite north of Jonesboro has no associated layered rocks and thus one can best infer, it appears, that the massive hypersthene granodiorite is younger than and distinct from the layered varieties. Nonetheless, the massive hypersthene granodiorite is almost identical mineralogically to the layered type and it has undergone some similar alteration, which suggests that the two types are probably genetically related. This might indicate that the massive hypersthene granodiorite is older than the pegmatitic anorthosite, However, the relative lack of gneissosity in the massive hypersthene granodiorite compared to the pegmatitic anorthosite suggests that the massive hypersthene granodiorite is the younger. These two rock types were not seen in direct contact; therefore, their absolute relationship is not known, but they may be of approximately the same age. Age relationships between massive hypersthene granodiorite and nelsonite are unknown.

The granitic gneiss occurs in bodies that partially or completely encircle bodies of massive hypersthene granodiorite in the northern part of the mapped area. This spatial relation-

ship suggests that the two rock types may also be related temporally and genetically. This would mean that the granitic gneiss is related to some of the youngest rocks in this area. However, the general shape and relationships of the bodies of granitic gneiss relative to the bodies of layered hypersthene rocks indicate that the granitic gneiss is somewhat older than the latter. The mineralogical similarity between the granitic gneiss and the augen gneiss also suggests that the granitic gneiss is related to the older rocks of the area.

The feldspathic gneiss unit cuts almost perpendicularly across the contact between granitic gneiss and augen gneiss units on Turkey Mountain; this suggests that it is younger than either of these units. However, west of Mars Knob, the feldspathic gneiss unit is truncated by an area of granitic gneiss. Furthermore, the feldspathic gneiss generally exhibits a well-developed gneissosity which parallels the regional structure suggesting that it is older than the granitic gneiss. In view of these evidences, apparently conflicting, it can be concluded that the feldspathic gneiss is of approximately the same age as the granitic gneiss, and possibly directly related to its emplacement. Another possibility is that similar rock types are of different age in different parts of the area. A large, isolated boulder, west of Mars Knob, contains both feldspathic gneiss and pegmatitic

anorthosite in sharp contact. The feldspathic gneiss is penetrated by apophyses of pegmatitic anorthosite; this indicates a younger age for the latter.

The areas of biotite aplitic gneiss and biotite pencil-gneiss units are in contact with only each other and the augen gneiss unit. If the augen gneiss unit trends generally northeasterly, parallel to the regional trend, these rocks must cut the augen gneiss. Both the biotite aplitic-gneiss and the biotite pencil-gneiss have a granular "igneous-like" appearance and contain no relics of bedding or other structures. Possibly they were emplaced during the same cycle of igneous activity that produced the granitic gneiss. However, their much more intense degree of deformation suggests that they are older than the granitic gneiss.

The augen gneiss of the augen gneiss unit is obviously one of the oldest if not the oldest rock type in the mapped area. Essentially all of the other rock types apparently cut the augen gneiss at some locality. The augen gneiss apparently represents the "basement" or country rock of the other rock types.

A summary of the observed and inferred crosscutting relationships between the major rock types is given in Table 5, and the inferred relative ages of the rock units are given in Table 6.

Table 5. - Crosscutting Relationships Between Major Rock Types

The units on the left are cut by those on the right*

Pegmatitic anorthosite	-	nelsonite, pegmatite, quartz veins, dolerite
Layered hypersthene granodiorite	-	pegmatitic anorthosite massive hypersthene granodiorite
Feldspathic gneiss	-	pegmatitic anorthosite granitic gneiss
Granitic gneiss	-	feldspathic gneiss
Augen gneiss	-	all of the above rock types plus biotite pencil gneiss and biotite aplitic gneiss

*Some of the crosscutting relationships are based on overall relationships between the bodies as indicated on the map (Pl. 1).

Table 6. - General Age Relationships of the Rock Units [1]

Dolerite dikes

Quartz veins

Pegmatite?

Nelsonite

Pegmatitic anorthosite

Massive hypersthene granodiorite [2]

Altered hypersthene granodiorite

Layered hypersthene granodiorite

Feldspathic gneiss?

Granitic gneiss?

Biotite pencil gneiss [3]

Biotite aplitic gneiss

Augen gneiss

1 The age of the units decreases from bottom to top

2 May be younger than pegmatitic anorthosite in part

3 Relative ages unknown

The relative ages of the questioned units in Table 6 are largely inferred. The border gneiss unit is not assigned a position in the scale of relative ages because it consists of a composite of rock types of eidely differing age.

PETROGENESIS

It is obvious from the preceding section that the writer considers most, and possibly all of the rock units and rock types to be of igneous origin. The nelsonite, although described as a rock unit, is actually ore, and its origin is discussed in the section about economic geology, the igneous textures and compositions, and the absence of relict structures which could be construed as relics of earlier sedimentary rocks are evidence for the igneous origin. The layered structures in some of the hypersthene granodioritic rocks are common in such rocks - especially in the more mafic phases - and also are believed to be of igneous origin. The hypersthene rocks and the pegmatitic anorthosite are probably comagmatic. This is suggested by their spatial relationship, their similarities in mineralogy and textures (although on different scales), and the occurrence of anorthositic layers in the layered hypersthene granodiorite. The pegmatitic anorthosite has been deformed extensively. It is not clear how much of this deformation may have been related to the emplacement of the coarsely crystalline pegmatitic anorthosite in a more or less solid state as advocated by Bowen (1928) for other anorthosite bodies. Much later deformation associated with the alteration and mineralization of these

rocks is evident. The relatively high potassium content of the plagioclase suggests more nearly an "end stage" of differentiation in the pegmatitic anorthosite than in true anorthosites. This would imply a somewhat higher volatile content and might account for the pegmatitic texture of the feldspars and pyroxene. However, in order for pyroxene to have crystallized in the presence of volatiles, the temperature of crystallization must have been extremely high.

The granitic gneiss and feldspathic gneiss are intimately associated with, and are cut by the younger igneous rocks and might represent earlier differentiates. However, this would suggest that the trend of the differentiation was toward more mafic rocks, which does not agree with the classic ideas of magmatic differentiation. Possibly these salic rocks represent a somewhat earlier stage of igneous activity.

The relationships of the biotite pencil gneiss and biotite aplitic gneiss are poorly known and both of these gneisses may represent separate intrusions at an earlier time. This is suggested by their pronounced cataclastic textures.

In addition to structures which indicate the rocks to be of igneous origin, the pegmatitic anorthosite, hypersthene-rocks, granitic gneiss, and feldspathic gneiss are all characterized by well developed microantiperthitic and

microperthitic feldspars. These, according to Bowen and Tuttle (1950), are indicative of high temperatures of crystallization if of exsolution origin as is believed to be true in the above rocks.

The augen gneiss is the only rock type which is believed to be even partially of metasedimentary origin. The rock locally has variations in texture across the strike of the gneissosity which may represent original sedimentary differences. However, these are not prominent and one can not help but be impressed by the overall homogeneity of much of the rock and also by its granitic composition and microperthitic and antiperthitic feldspar content. These all tend to suggest an igneous origin although there may well be, locally, inclusions and remnants of earlier metasedimentary rocks in the augen gneiss unit proper. The rock is apparently very similar to some of the rocks described by Mawdsley (1927, P. 9-16) in association with another rather potassic anorthosite body in the St. Urbain area, Quebec. It is interesting that all of the rocks described by Mawdsley are similar to all of those in the Piney River-Roseland area. Associated with the St. Urbain anorthosite are granites and augen gneisses and what Mawdsley termed "foliated intrusives" rich in antiperthite and perthite but generally poor in mafic minerals. Both areas also contain exceptionally large concentrations of ilmenite.

Whether the igneous characteristics of the augen gneiss resulted from primary magmatic intrusion or from anatexis of older sediments is not known. However, the writer believes that the most logical explanation is that the rock resulted from partial anatexis of an older sediment. This more or less agrees with Bloomer and Werner (1955) who concluded that the Lovingston, which is equivalent to the augen gneiss, is a "granitized meta-sediment". However, they also believe that the other rocks of the Piney River-Roseland area are all products of granitization. The present writer's data completely disagree with this conclusion. The ultimate origin of most of the magma that was emplaced in the Roseland-Piney River area is not known of course. It could have originated from the melting of sediments at a deeper zone in the crust. All that can be stated here is that it appears that all of the rocks of the area, with the possible exception of the augen gneiss, once were molten and were intruded into their present relative positions.

STRUCTURE

The structure of the Piney River-Roseland area is extremely difficult to decipher largely because it is almost impossible to differentiate between the diverse types of planar structures that may be present. Some of the planar structures may be metamorphosed primary bedding and others may be metamorphosed primary igneous structures such as flow or intrusive layering. Probably most of the planar structures are the result of the deformation of moderately homogeneous rock units.

The lack of knowledge of the precise origin of some of the rock types and the structures make it impossible at present to give a completely correct stratigraphic and/or intrusive sequence. Furthermore, the lack of outcrop prohibits any detailed analysis of the structure.

The general distribution of the rock types might be described either as anticlinal, if one ignores the general concept that older rocks occur in the cores of anticlines, or peripheral in that several of the rock units surround the central area of pegmatitic anorthosite. The regional trend of the rocks is to the northeast and the dominant dip is to the southeast.

Foliation

Most of the foliation symbols on Plate 1 represent determinations of the gneissosity of, for example, the augen gneiss or one of the other gneisses and do not represent any well defined, layered structures that might be relict bedding. An exception to this occurs in the few measurements in the layered hypersthene granodiorite where there are layers of diorite, etc. which apparently represent original igneous structures rather than metamorphosed bedding in metasediments. Also, most of the symbols in the border gneiss unit represent coarse compositional layering as well as gneissosity and thus are indicated as layering on Plate 1. However, most of these "layers" in the border gneiss probably represent sill-like bodies or lenses of igneous rocks.

The strike of the gneissosity in the augen gneiss unit and in most of the other units in the area is between N 30°E and N 60°E. Most of the dips are between 40° and 78° to the southeast. Deviations in the strike of the foliation of the augen gneiss unit correspond roughly to changes in the direction of the contact of the augen gneiss and the border gneiss unit or in changes in the contact with the granodioritic rocks. In some of the rock units the gneissosity is clearly discordant with the contacts, e.g., in the southern part of the area, but these examples are in rocks that are believed to be of igneous origin and thus the gneissosity is clearly a superimposed structure.

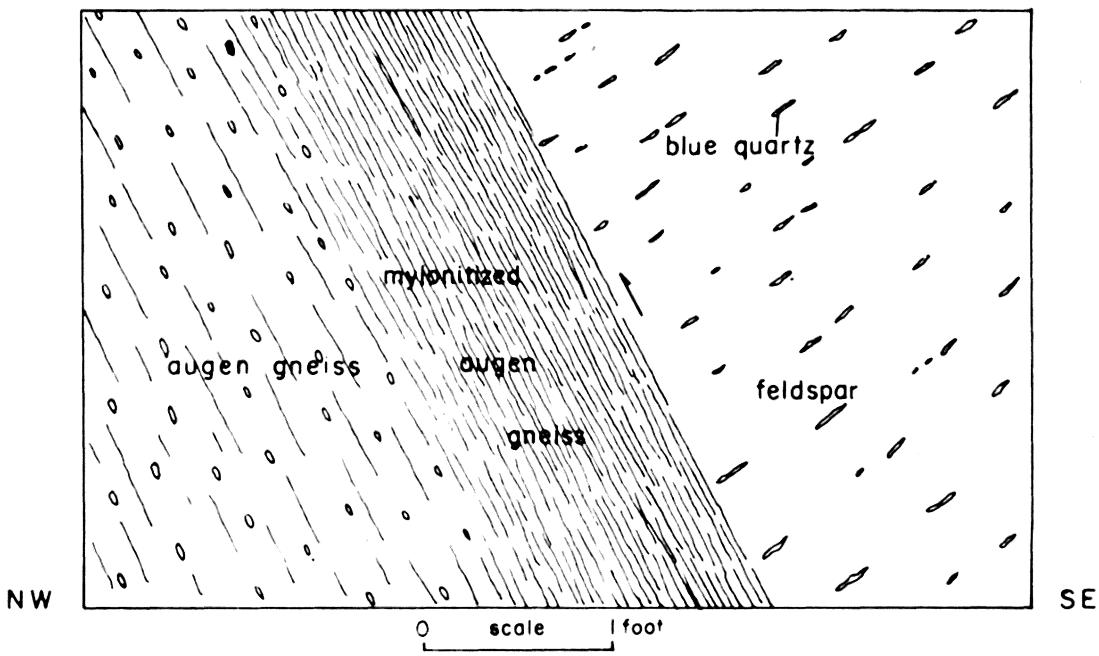


Figure 3. - Contact between augen gneiss and massive feldspathic lens of the border gneiss unit.

A well developed gneissosity delineated by large flattened blue quartz aggregates occurs in layers of almost pure feldspar in the border gneiss unit in the northern part of the area. This gneissosity is unique in that it typically dips to the northwest instead of the southeast. Furthermore, in a few exposures it is apparent that the gneissosity dips almost normal to the contact with the adjacent augen gneiss unit (Fig. 3) which dips in a normal southeasterly direction. A younger southeasterly dipping gneissosity locally characterized by mylonitic material cuts the northwesterly dipping structure. The probable explanation of this structure is that differential movement along the contact of the micaceous augen gneiss and the competent feldspathic layers caused tensional cracks along which the large flattened blue quartz aggregates were emplaced. The quartz may have been introduced or it may merely represent recrystallized quartz derived from the feldspathic layers.

Folds

Clearly defined folds outlined by relict bedding are rare if they even exist. In the extreme southwestern part of the area, two isolated outcrops of augen gneiss in the border gneiss unit have small folds in the gneissosity that are cut and offset by aplitic dikes. The folds plunge to the northeast. Along Tye River one mile south of

Massies Mill there are small metaquartzite (?) layers with U-shaped outlines suggestive of small fold noses. If these do represent relict folds, they are nearly isoclinal and plunge steeply to the southwest.

Reversals of dip of gneissosity are common near the center of the northeastern part of the area. However, there is no certainty that these reversals really indicate folds other than minor warps in the gneissosity. Further, many of these reversals of dip involve layers in igneous rocks so that they probably do not represent folds directly but may follow irregularities in the contact. Gentle, dome-like flexures or folds of the gneissosity of some of the altered hypersthene granodiorite have been previously described.

The structure is very poorly known within the pegmatitic anorthosite unit. The many separate sills and dikes of the pegmatitic anorthosite would probably give a clear picture of the structure if the attitudes of all of the individual bodies could be measured. However, the exposures are so poor that there are only a few parts of the area where the relations can be determined. In the American Rutile pit, north of Tye River, the structure of the layered hypersthene granodiorite is essentially flat and is both paralleled by sills of pegmatitic anorthosite and cut at high angles by dikes of the pegmatitic anorthosite. The flat dip on the

southeastern side of the quarry and steeper dip on the northwestern side suggests an anticlinal or domal structure. Southeast of this quarry, along Tye River, there is another gently anticlinal-like sill of anorthosite. The rocks of the few exposures of contacts between the anorthosite and inclusions of country rock screens between Tye River and Piney River on the southeast side of the main pegmatitic anorthosite body have a relatively flat dip to the south and southeast whereas those on the northwest side of the main unit tend to have a steeper dip to the southeast. Although this is admittedly very limited evidence, it suggests to the writer that the pegmatitic anorthosite does have a domal or anticlinal structure. The central part of this domal structure, if it exists, is probably relatively flat whereas the edges would be isoclinal and overturned to the northwest.

Faults and Shear Zones

Only one sizeable fault is believed to be present in the mapped area although considerable total movement may have occurred along shear zones. The major fault is believed to bound the northeastern border of the pegmatitic anorthosite unit and thus strikes nearly north-south. The fault is postulated largely from the absence of rocks characteristic of the border gneiss unit and from the local

development of cataclastically deformed rocks along the postulated trace of the fault. The gneissosity of the deformed rocks along the trace of the fault trends about north-south, in marked contrast to the regional trend. The general irregular trend of the fault suggests that it is a low-angle easterly-dipping thrust fault. The augen gneiss unit at Mars Knob is postulated to be thrust over the border gneiss. The displacement of the fault is not known but was apparently adequate to remove or cover the border gneiss unit of this area.

Locally in the border gneiss unit there are other small faults which strike about N 10°E and dip 80°W to vertical. The displacements on these faults are only a few inches or a few feet. Many of the dolerite dikes are parallel to these faults and were apparently emplaced either along the faults or along similar planes of weakness which possibly resulted from the forces which produced the faults.

A major shear zone trends northeast across the northern part of the area. Rocks in this zone have been cataclastically deformed so that many resemble schist. However, the relict rock structures are adequately preserved to identify the original rocks. This shear zone dips to the southeast essentially parallel to the regional structure. Similar shear zones are common in the mapped area as has been indicated in the descriptions of many of the rocks.

In the pegmatitic anorthosite there is much evidence of shearing during alteration and the local mineralization of the rock. However, much later shear zones cut the altered rocks and deform the titanium minerals. The former are characterized by brecciation of the anorthosite whereas the latter are characterized by the development of sericite within the feldspathic rock. In the east end of the old quarry of the Dominion Minerals Mine, a shear or fault zone has reduced the pegmatitic anorthosite to a grayish phyllonite. This deformation was such that the shear zones themselves have been folded and streaked out so as to resemble drag folds.

ECONOMIC GEOLOGY

Feldspar Deposits

Feldspar quarries are operated on the south side of Piney River by the Dominion Minerals Division, Riverton Lime and Stone Company, Chadbourn Gotham Inc., and on the north side of the river by the Consolidated Feldspar Department, International Minerals and Chemical Corporation, and Buffalo Mines Company (Pl. 1). All of the quarries are situated near the center of the low flat area which is probably underlain by the largest pegmatitic anorthosite body or bodies in the region.

The pegmatitic anorthosite is quarried by using wagon drills and steam shovels. The feldspar is generally so pure that there is almost no waste except where mafic aggregates are present and where inclusions or partings of country rock are encountered. The mined rock is trucked to nearby grinding mills where it is crushed and ground to various sizes depending on the usage. The main utilization is by the glass industry. The poorer grade material is crushed for use as road metal or poultry grit. The feldspar product for the glass industry is fairly rich in calcium and is not the premium grade, hand-cobbed potassium feldspar needed for glazes, etc.

The reserves of feldspar are very large. However, because of the lack of outcrops and the sill- and dike-like occurrence of the pegmatitic anorthosite, one cannot estimate the reserves of mineable rock at any particular location without an exploratory drilling program. Many occurrences are unsuitable for mining because of the abundance of country rock inclusions and/or screens and/or shear zones. Only one exposure, other than those at the operating quarries can be considered, on the basis of field evidence, to be large enough and pure enough to be of economic importance. This exposure occurs in a bluff along Tye River, about 1½ miles south of Roseland. The exposure is about 150 feet wide and 40 feet high and consists of essentially pure feldspar.

Titanium Deposits

Commercial and potentially commercial deposits of ilmenite and rutile occur in the border gneiss unit and in adjacent parts of the pegmatitic anorthosite, altered hypersthene granodiorite, and augen gneiss units. Although ilmenite and rutile generally occur together, one of the minerals typically predominates. The deposits can be divided into the two major classes on the basis of the major constituent. The economically important deposits of ilmenite include both dike-like bodies of ilmenite nelsonite and disseminated ore; the commercial deposits of rutile are almost

exclusively disseminated rutile in the pegmatitic anorthosite. Rutile nelsonite is rare. Unweathered and weathered ore are locally referred to as "hard ore" and "soft ore", respectively. Most of the present mining is in the "soft ore" bodies which can be mined relatively inexpensively.

Ilmenite Deposits

Ilmenite Nelsonite

Ilmenite nelsonite, as previously mentioned, consists largely of ilmenite and apatite in dike-like bodies or lenses. The bodies range from a few feet to 2000 feet in length and from a few inches to 200 feet in width (Pl. 1). Drilling indicates that they extend to at least a 400 foot depth; some probably extend much deeper. In shape, they range from tabular, dike-like bodies and lenses to bifurcated stringers and pods. The dike-like bodies are massive and are richest in ilmenite. Typically the pods and stringers occur more or less concentrated in extremely sheared and altered zones which form lower grade deposits. All of the ilmenite deposits are most abundant in the border gneiss unit and in adjacent parts of the pegmatitic anorthosite. They also occur to a limited extent in the altered hypersthene granodiorite and augen gneiss units. The dike-like bodies are most common in the northern half of the area whereas the zones of bifurcated stringer and pod concentrations occur chiefly in

the southern part of the area. The latter are typically more deeply weathered. The Piney River deposit of the American Cyanamid Company is of this latter type. Although this deposit is generally considered to be ilmenite nelsonite, it actually consists of small lenses and pods of ilmenite nelsonite plus disseminated ilmenite, next described, in the associated rocks. This "ore zone" is nearly 300 feet wide.

The ilmenite nelsonite invariably contains some feldspar, quartz, amphiboles, biotite, and chlorite and commonly also some rutile. Complete gradation appears to exist between ore of essentially pure ilmenite and apatite and ore in which silicates predominate. A typical thin section of the rich ore is shown on Plate 15 (Fig. 1). In the less rich ores, the general textures suggest that the ilmenite and apatite were introduced along shears and stringers; in the richer ore, these relationships are not clear.

Although several of the massive dike-like bodies encountered in the field occur in apparently sharp contact with relatively unaltered rock (Watson and Taber, 1913, P. 102), most of the ilmenite nelsonite bodies occur in zones of intense alteration. However, exposures are generally too poor to permit a clear determination of the extent of the associated alteration. All of the ilmenite nelsonite encountered in drill cores is associated with highly altered

rock. The zones of alteration traced in the field are up to 2 miles in length and ½ mile in width. Diamond drill holes have penetrated more than 360 feet of altered rock near some of the ilmenite nelsonite without showing a noticeable decrease in intensity of alteration. The alteration is marked by an abundance of hornblende, actinolite, anthophyllite, chlorite, biotite, calcite, and saussuritization of the feldspars in the adjacent wall rock. Where less intense, relict mineral outlines of the previous rock are preserved (Pl. 8). The proportional amount of ilmenite and apatite in the altered country rock is greater than in unaltered areas. Small amounts of sulfides also occur in the altered rocks. The alteration results in a fine- to medium-grained, dark green rock which commonly has a mottled, massive texture, or a gneissic-schistose texture. The texture generally grades from massive to schistose towards ore bodies. The massive altered rocks consist of isolated, rounded grains of altered feldspar surrounded by aggregates of mafic minerals. The mafic minerals are commonly arranged as reaction rims with the outermost rim of chlorite in contact with the feldspar. Inner rims are commonly some amphibole pseudomorphous after a pre-existing pyroxene. Biotite generally occurs at the contacts between feldspar and ilmenite; this may indicate longer-lived or later alteration. The gneissic altered rocks show essentially the same relationships, except that the feldspar

grains are oval-shaped. These rocks commonly contain up to 20 per cent ilmenite, some or most of which appears to have been introduced. In the zones of most intensive alteration, the altered rock is schistose and contains little or no megascopically discernible feldspar. Some bodies of ilmenite nelsonite occur in these schistose zones but other nelsonite bodies grade directly into the gneissic or massive altered wall rocks.

Piney River Deposit. - The large ilmenite-apatite deposit at Piney River was first mined chiefly for its apatite content by the Vanadium Corporation in the early 1930's (Gillson, 1949). The apatite was converted to monocalcium phosphate and TiO_2 was recovered only as a by-product of the operation. The Southern Mineral Products Corporation later acquired the property and operated the mine for the recovery of TiO_2 until the late 1940's when it was acquired by the American Cyanamid Company. American Cyanamid recovers only the ilmenite which is converted to TiO_2 for use in the manufacture of paint pigment. Presently, only the deeply weathered, or "soft ore", which extends to a depth of about 100 feet, is being mined.

The ore zone strikes about N 43°E and dips approximately 45° to the southeast. It is 2300 feet long and ranges in thickness from 60 feet to 283 feet (Hess and Gillson, 1937). As noted above, drilling has proved ore to a depth of 400

feet, and it may extend much deeper.

The ore body is located in a shear zone which cuts rocks included in the border gneiss and altered hypersthene granodiorite units (Pl. 1). Apatite-rich ilmenite nelsonite occurs as irregular lenses, pods, and small pinching, swelling, and bifurcating "dikes" in highly altered, schistose amphibole-chlorite-biotite rock which is interlayered with pegmatitic anorthositic lenses and stringers. The original nature of the altered rock cannot be determined. It now contains abnormally high amounts of disseminated ilmenite and apparently is the source of a large proportion of the ilmenite found in the weathered material. The green amphibole-chlorite-biotite schist extends northeast of the orebody, across Piney River, almost to County Road 675, a distance of approximately one-half mile. The zone of alteration extends to the southwest across Highway 151 and along Maple Run to give a total length of approximately 3000 yards for the altered zone. The width of this zone is probably nowhere greater than 500 feet. The intensely altered rock grades outward into granodioritic rocks or anorthositic rocks everywhere except along its southeastern border where it is in sharp contact with augen gneiss.

Johnson deposit. - The Johnson property deposit occurs on the small hill on the west side of Highway 151, opposite County Road 623 in the northeastern part of the mapped area.

This is the most northerly titanium deposit in the area. The hill is underlain by an ilmenite-nelsonite body which has yielded abundant float on the southeastern slope. Thorough exploration of this deposit, by diamond drilling, trenching, and prospect pitting was conducted some years ago by persons unidentified to the writer. However, some of the diamond drill core from the exploration was found and made available to the writer by the U.S. Bureau of Mines.

The ore body is bounded by mylonitic augen gneiss to the west, anorthositic rocks of the border gneiss unit to the north, and amphibolite and hypersthene granodiorite to the east and south. The body strikes N 79° W, that is, oblique to the regional gneissosity, and dips about 55 degrees to the north. The length as known is about 600 feet, and the width ranges from 30 feet to 80 feet. The downward extent is unknown, but it is known to extend at least 300 feet down the dip. The grade of ore in the rich ilmenite nelsonite ranges from about 20 per cent to 40 per cent TiO_2. The contact between the rich ilmenite nelsonite and amphibolitic rock is gradational. The gradation occurs through a zone approximately 10 feet thick. The amphibolitic rocks grade, in turn, into hypersthene granodiorite and pegmatitic anorthositic rocks.

A small body of ilmenite nelsonite exposed in an old prospect pit about 250 yards west of this deposit may be

part of the same ore body. However, at the present surface the prospect is separated from the main deposit by a broad zone of highly sheared augen gneiss. The nelsonite in the pit contains numerous slickensided surfaces.

Bryant Deposits. - A series of small outcrops and abundant float occurs along the east side of Highway 151 from 300 yards northeast of Bryant for a distance of 4500 feet in a northeasterly direction. Whether or not these are continuous in subsurface is unknown. It appears from surface distribution of float that they are probably bifurcating, lenticular bodies of a single mineralized zone. The southernmost body is apparently surrounded by massive feldspathic layers of the border gneiss unit whereas those to the north are in contact with massive feldspathic rocks on the west and altered hypersthene rocks on the east.

Blue Rock Deposit. - On the Blue Rock farm, 600 yards east-southeast of Jonesboro, abundant float of coarse-grained, dark blue nelsonite occurs over an area 2,000 feet long and up to 200 feet wide. The exact dimensions of the ore are unknown. The southern end of this body is bounded by pegmatitic anorthosite. The northern end of the deposit is within altered massive feldspathic rocks included in the border gneiss unit.

A small outcrop, exposed in an old prospect pit about midway between the Blue Rock deposit and those at Bryant,

possibly indicates a connection between the zones of mineralization at those two places.

Hite Farm Deposit. - Abundant float of ilmenite nelsonite occurs on the slightly curved ridge north of Tye River and about 700 feet west of Highway 151. This is known as the Bob Hite farm. Watson (1913, P. 115) showed that exploration revealed an ore body 600 feet long by as much as 65 feet thick at the southeastern end of the ridge. Field mapping indicates, however, that the ore zone extends at least 3,000 feet along the ridge, far north of the established ore body. It is probable that this whole area is not underlain by a continuous deposit, but rather by a series of lenses. The northwestern limit of the ilmenite nelsonite float is in feldspathic rocks included in the border gneiss unit, within 200 yards of the augen gneiss contact. Throughout its extent the body is bounded by rocks of the border gneiss unit and altered hypersthene granodiorite.

An outcrop of ilmenite nelsonite occurs on the hillside on the south side of Tye River, on strike with the Bob Hite deposit. It seems probable that this body and the Bob Hite deposit are part of the same deposit. Although exposures are not continuous along the river, a 100-foot covered interval could be underlain by ilmenite nelsonite.

Other Deposits. - Ilmenite nelsonite underlies the low ridge on the eastern edge of the pegmatitic anorthosite unit, about

1¼ miles south of Roseland. This ridge is about 2000 feet long. Most of the outcrop consists of ilmenite-rich amphibolite. However, float of ilmenite nelsonite is scattered over much of the ridge and may indicate that this body is a series of pods or lenses in amphibole-rich altered wall rocks. The trend of this deposit is curved and cuts obliquely across the regional gneissosity. Throughout most of its extent, the deposit is in contact with altered hypersthene-bearing rocks, although for a short distance on the western side, it is apparently in contact with rutile-bearing pegmatitic anorthosite.

Ilmenite-nelsonite float is also found at the following localities: just east of County Road 672, 1500 feet northeast of its intersection with County Road 673; on the top of the hill on the west side of Hat Creek at the end of County Road 765. A small layer or dike of biotite-nelsonite, 2 feet wide crops out 250 feet west of County Road 672, 1 mile northeast of Roseland.

Disseminated Ilmenite

Ilmenite occurs disseminated in many of the diverse rocks in the area. At one deposit - the Tom Wood deposit - it is being mined. This deposit occurs in highly altered rocks of the hypersthene granodiorite, pegmatitic anorthosite, and border gneiss units. The deposit is oval in outline and apparently trends northwestwardly across the trend of the

enclosing rocks. The deposit is poorly exposed and its structure is unknown. It apparently consists of altered hypersthene rocks and altered layers of pegmatitic anorthosite. The ilmenite is extremely fine-grained and is disseminated throughout the altered rock. The alteration is assumed to be similar to that adjacent to the ilmenite nelsonite bodies.

Disseminated ilmenite and titaniferous magnetite are widespread in the unaltered hypersthene-bearing rocks. Most of the ilmenite in these rocks appears to be primary. Some has been attacked by whatever caused some of the rock alteration and is rimmed by biotite.

Small amounts of disseminated ilmenite were noted in all of the feldspar quarries in the pegmatitic anorthosite. All of the ilmenite is in altered pegmatitic anorthosite and commonly it is associated with the included aggregates of ferromagnesian minerals. At most occurrences, the ilmenite occurs either in and along the outer chloritic or biotite reaction rims of the aggregates (Fig. 2) or in shear zones that penetrate the aggregates. Many occurrences are associated spatially with apatite. None of the ilmenite grains in these rocks is clearly primary and some has been altered after its introduction. The occurrences of disseminated ilmenite in relatively pure pegmatitic anorthosite do not

form mineable deposits although locally ilmenite concentrations are relatively high. The disseminated ilmenite in highly altered hypersthene rocks is probably more widespread and may possibly prove to be of greater economic value in the future than the ilmenite nelsonite deposits. Ilmenite constitutes up to 30 per cent of some specimens of this rock; an average grade of 10 per cent occurs over extensive areas.

Tom Wood Deposit. - The American Cyanamid Company began to produce "soft ore" in 1958 from a large disseminated ilmenite deposit known locally as the Tom Wood property. This deposit is situated a few hundred feet north of St. Marys School (Pl. 1) and underlies the northwestern end of a long low hill that extends in a southeasterly direction for about one mile, to within 800 feet of the intersection of County Roads 665 and 735. The length of the ore body is unknown, but if it underlies the entire length of the hill, it may extend as much as one mile to the southeast. The orebody is approximately 1,000 feet wide where mined by the American Cyanamid Company. As at Piney River, only the weathered rock is mined. This is done by open-cut methods. The ilmenite in the weathered rocks is extremely fine-grained and generally not visible to the naked eye. The depth of the weathered ore is approximately 100 feet. The main part of the deposit is so thoroughly weathered that one cannot determine the details of the mineralization. In small, scattered outcrops

and roadcuts around the deposit, and in the limited amount of drill core obtained by the U.S. Bureau of Mines from an adjacent property, which is underlain by a probable extension of the same ore body, the ilmenite occurs as disseminated aggregates and grains in altered pegmatitic anorthosite, hypersthene granodiorite, and feldspathic layers of the border gneiss unit. The altered rock ranges from essentially massive anorthosite with irregularly-shaped mafic aggregates near the edge of its contact to a dark green gneiss, in which the mafic content is equal to or greater than the feldspar. The ilmenite is spatially related to the concentrations of mafic minerals and to fractures in the rock. This is particularly well demonstrated in the diamond drill core which consists of alternating layers of mafic-rich rock and almost pure feldspar rock in layers up to ten feet thich. The ilmenite content is almost proportional to the content of mafic silicates except in the almost purely mafic rock. Only minor amounts of rutile occur in the pure feldspar rock. Apatite is commonly associated with the ilmenite concentrations. In thin sections the main mafic minerals are fine-grained, fibrous amphibole- probably actinolite-chlorite, and biotite. Some of the amphibole aggregates are pseudomorphous after pyroxene. In the weathered mantle, above the ore body on the Wood property one cannot recognize these different rock types. However, small pegmatites that cross the weathered

rock retain their structure rather well and contain some ilmenite in grains up to one cm. across.

The deposit is similar in many respects to the Piney River deposit. The ilmenite in the latter deposit, however, is much coarser grained and commonly occurs in pods or lenses of ilmenite nelsonite. Ilmenite nelsonite is not known to be present in the Tom Wood Deposit.

Reserves

Exact figures on the quality and quantity of reserves of ilmenite are not available. However, some idea of the magnitude of the reserves can be obtained from considerations of the surface distribution of ore deposits and published data.

Hess and Gillson (1937) estimated the reserves at the Piney River deposit to be 24,000,000 tons of ore containing 18.5 per cent TiO_2, or 4,400,000 tons of TiO_2, based on a depth of 400 feet. Subsequently the upper 100 feet, that is, the soft ore, has been largely removed, and the average grade is probably somewhat lower than that used in their estimate. However, there are indications that the ore extends much deeper than 400 feet, so their estimate is probably of the right order of magnitude.

The Tom Wood Deposit may well have reserves at least as great as those at Piney River.

Many of the ilmenite-nelsonite dike-like bodies are potential ore if the proper mill facilities become available. Although most of these deposits are small, a few are large enough to support substantial mining operations. An example of one of the larger of these deposits is the Johnson body. Assuming a length of 600 feet, an average width of 50 feet, a depth of 100 feet, an average grade of 25 per cent TiO_2, and a density of 200 pounds per cubic foot, the reserves in this body would be approximately 75,000 tons of TiO_2. This is probably an extremely conservative estimate because the ore body extends to a much greater depth than 100 feet and furthermore, much of the lower grade adjacent amphibolite, which was not considered, would probably constitute ore once an operation is started. The density assumptions used above are based on Watson and Taber's (1913, P. 109) reported specific gravity of 4.073 for ilmenite nelsonite containing 37 per cent TiO_2. Further exploration might reveal reserves on the Giles property, the Bryant deposits, and the Blue Rock deposits.

From the foregoing, an estimate of reserves of 10 to 12 million tons of TiO_2 in the area seems conservative. However, much of the reserve is "hard ore" which is not being mined at present.

Rutile Deposits

Rutile occurs as disseminated grains in pegmatitic anorthosite, as small rutile-nelsonite lenses, and as small bodies of coarse grained rutile. Only the disseminated deposits appear to be extensive enough to be of commercial importance. They occur principally in a zone 3½ miles long by ¼ mile wide near the eastern side of the pegmatitic anorthosite unit north of Highway 158 (Pl. 1). Lenses or pods of rutile nelsonite, only one of which was seen by the writer, occur in the same zone; although rich in rutile, they are too small to be of much importance. A small body of coarse grained rutile and quartz is exposed in the pegmatitic anorthosite at the Buffalo Mines quarry and has been described previously.

Disseminated Rutile Deposits

The size and shape of the individual deposits cannot be determined from available data. However, the surface accumulations of rutile nuggets suggest that the mineralized zone consists of a series of deposits, each approximately ¼ mile long and 1/8 to ¼ mile wide and distributed more or less en echelon. The areas of disseminated rutile are largely in the pegmatitic anorthosite unit (Pl. 1). The rutile mineralization as shown in surface outcrops and diamond drill cores, occurs in layered rocks that consist

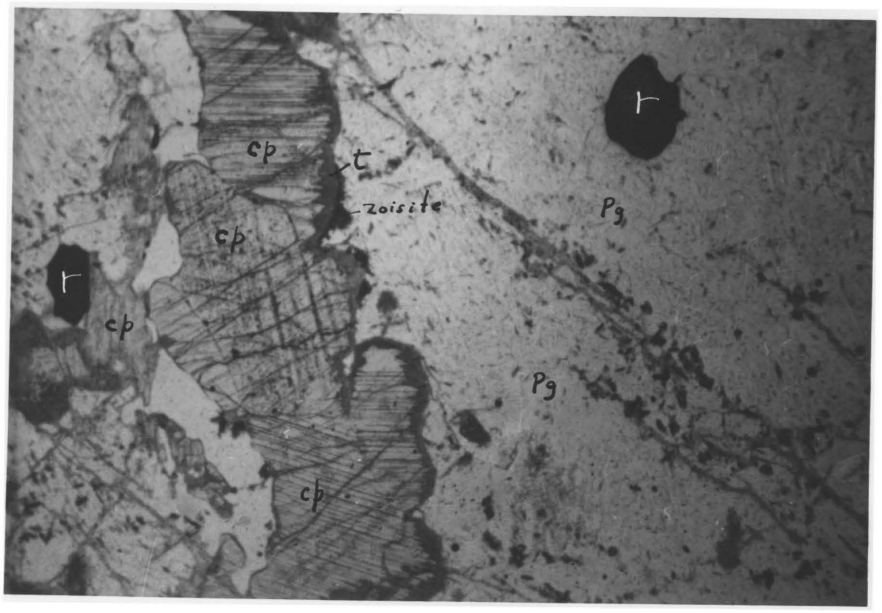
of alternating layers of pegmatitic anorthosite and altered hypersthene granodiorite as well as dike-like bodies of pegmatitic anorthosite. The individual layers range from a few inches to 60 feet thick. The rutile is disseminated in or concentrated along shear planes in both rock types. These rocks are characterized by alteration very similar to that described for the ilmenite deposits. The pyroxenes are altered to anthophyllite or tremolite-actinolite (Pl. 16) and bounded by reaction or alteration rims of amphiboles, biotite or chlorite. The pegmatitic anorthosite is highly saussuritized and contains abundant altered aggregates of ferromagnesian minerals. The latter aggregates appear to be more abundant and larger near contacts with the altered hypersthene granodiorite. Some of the granodioritic rocks have been sheared and altered to the extent that they resemble chlorite schist. The relatively pure pegmatitic anorthositic rocks contain up to 10 per cent of rutile in grains ranging from 0.2 mm., to 4 cm. across. The average grade of the disseminated rutile is estimated to be approximately 5 per cent. Almost all of the rutile was introduced - it occurs along fractures, commonly in contact with late, coarse, rutilated quartz aggregates; most of the rutile grains are surrounded by thin rims of muscovite. Although a few grains show little or no evidence of secondary origin, even they may have been introduced. The altered hypersthene

granodiorite layers more commonly contain ilmenite (Pl. 17) which may comprise up to 15 per cent of the rock. Ilmenite also tends to occur in contact with, or penetrating the mafic aggregates in the pegmatitic anorthosite - even where rutile is present just a few inches away in the surrounding feldspar. Apatite almost invariably accompanies the ilmenite and is locally abundant in association with the rutile, especially in the crosscutting anorthosite bodies. Apatite is generally absent from the sill-like pegmatitic anorthosite rocks.

American Rutile Deposit. - The only deposit of disseminated rutile that has been mined is situated on the north side of the Tye River $\frac{1}{4}$ mile east of Roseland. This deposit was mined by the American Rutile Company prior to 1941. Ross (1941) has described many of the details of mineralization. Mining was done by open cut methods and all of the soft weathered ore was removed. The quarry consists of two parts. The larger quarry, adjacent to Tye River, is about 1200 feet long by 500 feet wide. The smaller quarry, a few hundred feet to the north, is approximately 1000 feet long and 200 feet wide. Both quarries are approximately 50 feet deep.

The rutile occurs in both sill-like and crosscutting anorthosite in contact with essentially horizontal altered layered hypersthene granodiorite. The pegmatitic anorthosite is not connected to the main body of pegmatitic

Plate 16. - Photomicrograph of rutile-bearing altered hypersthene granodiorite from the American Rutile pit.



Rutile (r) is in contact with clinopyroxene (cp) and is embedded in saussuritized oligoclase (pg). Reaction rims of tremolite are thickest where pyroxene is in contact with oligoclase and are absent or thin where it is in contact with quartz (q). Aggregates of zoisite (z) locally rim the tremolite border. Plane light, X 24.

Plate 17. - Photomicrographs of ilmenite-rich altered hypersthene granodiorite from near American rutile pit.

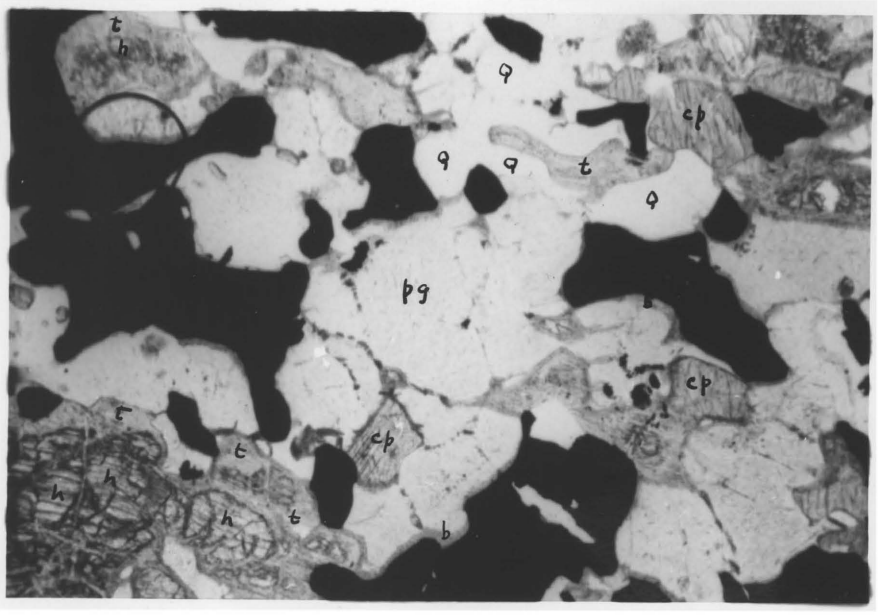


Figure 1 - Biotite reaction rims around ilmenite (opaque) hypersthene (h) is bordered by fibrous tremolite (t) and apparently represents an intermediate step in the development of pseudomorphs such as those shown in Plate 6. Clinopyroxene (cp) is less altered. Matrix is antiperthitic plagioclase (pg) and quartz (q). Plane light, X 24.

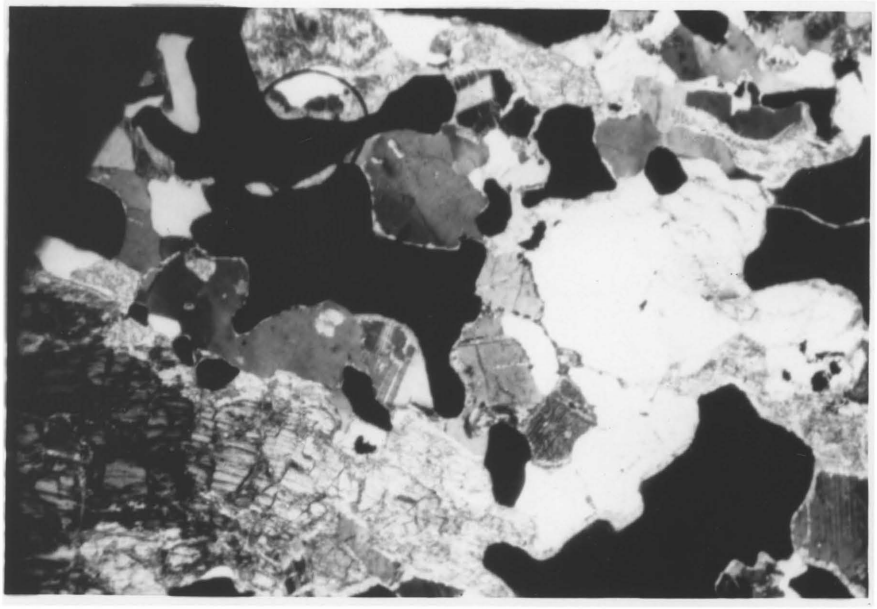


Figure 2 - Essentially the same as Figure 1 but with analyzer partially inserted. Note the biotite reaction rims around ilmenite. Crossed nicols, X 24.

anorthosite except possibly through a narrow band to the north. Altered hypersthene granodiorite crops out on the other three sides of the deposit. Previous descriptions of the rutile mineralization and rock alteration are largely based on the exposures in the main open pit and are not repeated here.

Other Deposits. - Similar relationships to those described above are indicated by the data obtained from diamond drill core obtained from C.E. Craven and Associates from the Taylor property, ¼ mile north of the American Rutile pit and from the Bourne property, 300 yards northeast of Rose Union Church.

A pegmatitic anorthosite body 20 feet thick cuts across the structure of altered hypersthene granodiorite on the south bank of Tye River, about 1½ miles south of Roseland. This body contains coarse-grained rutile along irregular small veinlets in feldspar associated with granular apatite and blue quartz. The adjacent altered hypersthene granodiorite also contains considerable rutile and ilmenite.

Small amounts of disseminated rutile were also seen to occur in the Consolidated Feldspar Quarry.

Rutile Nelsonite

A small body of rutile nelsonite was mined by the American Rutile Company on the Giles property, 200 yards northeast of the intersection of Highway 151 and Tye River (Ross 1941). The ore body was only 25 feet long by 8 to 10 feet wide and 14 feet deep according to Ross (1941). Much rutile nelsonite was found as float around the old pit. Mineralogical relationships of this rock are described on Page 72.

From 1907 to 1909, the General Electric Company operated an underground mine to recover rutile from two rutile nelsonite dikes on the north side of Piney River (Watson and Taber, 1913) and on strike with the American Cyanamid Company's pit. Apparently these rutile nelsonite bodies graded into ilmenite nelsonite to the south. Although Watson and Taber described the deposits as occurring in syenite, their detailed description of the country rock suggests that it was similar to the altered hypersthene granodiorite associated with the disseminated rutile deposits.

Rutile-quartz Deposits

Several small rutile-bearing blue quartz veins occur in the area. One such vein crops out along Tye River, about ½ mile south of Roseland. It is only about 4 feet wide, and 12 feet long, and contains approximately 10 per cent

of rutile in grains up to 2 cm. This vein cuts altered hypersthene granodiorite. Another small deposit is that described on Page 65. Other rutile-bearing quartz rocks are found throughout the area as small veins and float. Although none appear to be of commercial importance they may indicate mineralized areas of possible future value.

Reserves

It is difficult to give a reliable estimate of the rutile reserves of the whole area with the amount of data available. However, the TiO_2 content of the disseminated deposits ranges from about 2 per cent to 10 per cent, with an average of between 4 and 5 per cent. Distribution of surface accumulations of rutile nuggets and drill core data indicate that the larger deposits are roughly equant in plan and from 500 to 800 feet across. A deposit 500 feet square with 5 per cent rutile would contain approximately 1000 tons of TiO_2 per foot of depth or 100,000 tons per hundred feet. The deposits probably extend to depths of several hundred feet. At least three, and possibly seven deposits are at least this large. The reserves of TiO_2 as rutile may range, therefore, from 300,000 tons to 1,000,000 tons.

Origin

Several hypotheses have been proposed for the origin of the titanium deposits. Watson and Taber (1913, P. 69) believed that the nelsonites were magmatic segregations of the magma that produced the "syenite" (pegmatitic anorthosite). Also, they thought that some of the ilmenite nelsonites may have intruded the still hot enclosing rock. Watson and Taber (1913) also believed the disseminated rutile to be primary. Moore (1940) proposed that the nelsonites resulted from magmatic differentation of the hypersthene granodiorite and were not directly associated with the anorthosite except incidently because they were both differentiates of the same magma. Ross (1941) proposed that the bodies were largely or entirely of replacement origin. This was strongly criticized by Davidson, Grout, and Schwartz (1946, P.738) who believed that the ilmenite in the Piney River deposit was of primary origin and that the deposit was a "segregated dike intrusive into earlier closely related anorthosite".

A summary of the salient points regarding the occurrence of titanium in the area is as follows:

(1) The deposits show a definite spatial association with the pegmatitic anorthosite.

(2) The deposits are arranged zonally with respect to the iron-titanium ratio: pure rutile occurs largely within the pegmatitic anorthosite; ilmenite occurs

within the edges or near the border of the pegmatitic anorthosite; and, magnetite is in rocks at a greater distance from the pegmatitic anorthosite rocks.

(3) Most of the ore-bodies are associated with zones of intense shearing and brecciation which are discordant to the regional shearing and regional trend of the foliation of the host rocks

(4) Practically no titanium minerals that appear to be primary occur except in the fresh hypersthene granodiorite.

(5) Much of the titanium mineralization was accompanied by the introduction of fluorapatite.

(6) Most of the deposits are associated with extensively altered hypersthene-bearing rocks.

(7) The wall rock alteration is characterized chiefly by the development of hydrous minerals. Some CO_2 apparently was also added locally.

(8) Ilmenite tends to be associated with iron-rich rocks or mafic aggregates, whereas rutile is commonly in the pure pegmatitic anorthosite.

Points 1 and 2 suggest that the titanium is related to the anorthosite. Points 3 and 4 indicate that it is secondary. This seeming contradiction can be reconciled if it is assumed that the titanium was derived from the same general source that produced the pegmatitic anorthosite but at a

somewhat later stage of differentiation. Most of the igneous rocks in the area tend to be rich in titanium. Differentiation of their source magma would probably be favorable to concentration of titanium. Ross (1941) referred to the fluids producing the mineralization as being "segregations" from the pegmatitic anorthosite. This may be more or less true. However, Davidson, Grout and Schwartz (1946, P. 747) criticized Ross for this usage of "segregation" because many geologists think of a segregation as being an accumulation of crystals or reaction products inside a magma chamber. The field and petrographic work indicate that the pegmatitic anorthosite and other hypersthene-bearing rocks (and possibly other associated rock types) are genetically related (comagmatic) as originally stated by Watson and Taber (1913), and that the titanium is late. The titanium was probably derived from the differentiation of magma similar to that from which the anorthosite and associated rocks were derived, but at a presumably greater depth - not as a segregation from the pegmatitic anorthosite as now exposed.

Points 5, 6, and 7 indicate that the titanium mineralization was accompanied by fluorine, phosphorous, water, and some carbon dioxide which produced considerable changes or alteration in the associated wall rocks. These changes and alterations are not unlike those found in some deep pyrometasomatic deposits. Ross (1941, P. 34-37) concluded that the

titanium and phosphorous may have been transported in a vapor and specifically that the titanium was carried as TiF_4. Ross also concluded that the phosphorous preceded the titanium. The method of transport as described by Ross may well be correct but the general intimate association of titanium and phosphorous minerals suggests to the writer that the two were introduced together.

If it is assumed that the mineralizing material added the constituents mentioned above, then the question might be raised as to how much other material may have been added and when was it added. Alteration of the early ferromagnesian and other minerals in the hypersthene-bearing rocks without noticeable accompanying mineralization is common in many samples. Many of these alterations appear to be simple hydration and reaction between adjacent minerals. Water is essentially the only material that needs to have been added, in this stage. This is especially evident in many of the altered areas in the pegmatitic anorthosite where small veinlets are largely saussuritized feldspar where they cross anorthosite and chlorite, biotite, or amphibole where they cross aggregates of ferromagnesian minerals. This alteration also attacked apparently primary ilmenite in the finer-grained hypersthene rocks. In many respects it resembles "deuteric" alteration although the rare occurrence of some of the clay minerals is generally considered to be "deuteric". However,

except for the evidence of addition of water and at least local migration or removal of iron, the other constituents appear to have been fixed. The pseudomorphs and reaction rims of tremolite and anthophyllite suggest that iron has migrated. Tremolite and anthophyllite are not characteristic deuteric products of most igneous rocks. Although the stabilities of these amphiboles with respect to temperature and pressure are not known one would generally infer that they formed at considerably lower temperatures than the original pyroxenes. This would suggest that the mineralization was considerably later than the crystallization of the enclosing rocks. Some of the alteration, such as the development of sphene, green biotite, chlorite, and possibly the rare clay minerals probably was caused by later, more "normal" hydrothermal activity.

Point 8 indicates that the iron may be important so far as controlling the deposition of titanium. Ross (1941, P.35) made a similar conclusion, and Barksdale (1949) shows that iron will replace titanium in TiF_4. The regional relationship of the iron-titanium ratio obviously could result from a change in the composition of the mineralizing solutions, from a change in the physical conditions controlling the deposition, or from a combination of the two. An idea of the source and the time of introduction of the iron is therefore important.

Ross (1941, P. 19-22) believed that most of the iron was introduced at a later stage than the titanium and volatiles, but that the iron of the pyroxenes, which he believed formed by replacement of anorthosite, entered earlier than the mineralizing fluids. The observations made by the present writer indicate that the pyroxenes were not introduced but were part of the original pegmatitic anorthosite. Alteration of these original mafic minerals by the mineralizing fluid provided some iron which was then redistributed. This redistribution of the iron is indicated by the fact that the materials of the outer reaction rims of the mafic aggregates in the pegmatitic anorthosite also follow along fractures. It seems to the present writer that it was not necessary for any iron to have been added from a completely extraneous source during or after mineralization. The titanium deposits in the pegmatitic anorthosite which was and is very low in iron, consists largely of rutile. From this we can infer that the original mineralizing fluids did not contain much, if any, iron. In the hypersthene-bearing rocks around the pegmatitic anorthosite, iron could have been removed by the early stages of alteration and subsequently have combined with the titanium-rich fluids to produce deposits of ilmenite. This would lead to a regional zoning wherein the rutile deposits were in the center of the district, associated with, the ilmenite formed the next

outer zone and magnetite deposits formed at a considerable distance from the pegmatitic anorthosite.

Although the present writer believes that the titanium was derived from differentiation of a magma, it is possible that it could have been obtained from alteration of the pyroxenes as advocated by Ramberg (1948). Many chemical analyses of altered and unaltered rocks would be necessary to prove or disprove the applicability of this theory to these rocks.

Based on the evidence presented above, the writer's conclusions on the origin of the titanium deposits are as follows:

(1) Titanium was introduced into the presently exposed rocks, except in some of the hypersthene granodiorites, from an underlying source.

(2) The transporting fluids were probably late differentiates of the same magma that produced the hypersthene granodiorite and the pegmatitic anorthosite.

(3) The mineralization resulted in considerable alteration of wall rock, the first stages of which were largely hydration.

(4) The mineralizing fluid was originally rich in titanium, fluorine and phosphorous, and relativ ely low in iron. (Much of the iron in some of the peripheral deposits may have been derived from alteration of wall rocks nearer the source of the solutions.

(5) The passage of the mineralizing fluids and their access to overlying rocks was facilitated by brecciation, possibly associated with the emplacement of the pegmatitic anorthosite.

(6) The mineralization occurred under conditions of relatively high temperature and pressure.

(7) As the ore fluid moved outward from the pegmatitic anorthosite it became relatively richer in iron and poorer in titanium. This resulted in the regional zonation of the iron-titanium deposits.

(8) Deposition of the titanium was controlled by temperature gradients, by shear zones and brecciation zones, as well as by chemical reaction.

(9) A slight hydrothermal activity continued after the deposition of the ore minerals, resulting in alteration of the ore minerals themselves.

Suggestions for Prospecting

Massive ilmenite nelsonite is relatively resistant to weathering. Therefore, its presence can commonly be detected in the field. Its presence is expressed topographically by small oval hills, often oriented diagonally to the regional strike. Although many of these deposits can be detected with a magnetometer, others cannot. This type of deposit also has served as a source for small placers of

ilmenite in ditches, roads, and gullies. However, such placers are not derived only from ilmenite nelsonite, - all of the rocks contain ilmenite and even the augen gneiss, which only contains one to two per cent of ilmenite locally develops such placers. Nonetheless, if the placers are exceptionally rich the writer believes that they probably suggest a relatively nearby source.

The only surface evidence for disseminated rutile deposits is the occurrence of abundant rutile nuggets, typically associated with white kaolinitic soil and blue quartz "gravel". All occurrences of these are within the previously described 3½ mile long zone along the east side of the main mass of pegmatitic anorthosite. A few outcrops of fresh, disseminated rutile ore were seen along Tye River.

Regions of phosphate-rich soil, such as those on the west side of the highway at Bryant and on the south end of Mars Knob, may warrant further prospecting for rutile nelsonite and/or disseminated ilmenite deposits. Such areas are readily recognized by the farmers, because of the favorable effect of the phosphate on crop growth.

All previously worked deposits of rutile are concentrated in the border gneiss unit or in the adjacent pegmatitic anorthosite, especially in or near contacts with layered hypersthene granodiorite. Therefore, such contact zones are considered to be the most favorable for prospecting for this type of deposit.

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GEOLOGY OF THE PINEY RIVER-ROSELAND TITANIUM AREA, NELSON AND AMHERST COUNTIES, VIRGINIA

ABSTRACT

The titanium deposits of Nelson and Amherst counties, Virginia, occur in Precambrian (?) rocks that constitute part of the core of the Blue Ridge-Catoctin Mountain anticlinorium. Approximately 72 square miles were mapped in this study. The central part of the mapped area is underlain by a mass of pegmatitic anorthosite, about which other mappable rock units are distributed more or less peripherally. The chief units, listed from oldest to youngest, are: augen gneiss, biotite pencil gneiss, biotite aplitic gneiss, granitic gneiss, feldspathic gneiss, hypersthene granodiorite, pegmatitic anorthosite, and nelsonite.

The pegmatitic anorthosite occurs as sills and dike-like bodies. It originally consisted of coarse-grained, antiperthitic plagioclase (An_{30}). Most of the primary textures in this rock have been obliterated by alteration so that the present rock consists of saussuritized feldspar and minor amounts of altered mafic minerals, plus introduced or recrystallized quartz, rutile, and ilmenite. The mafic minerals include tremolite or anthophyllite, in complete or partial pseudomorphs after coarse-grained pyroxene crystals, and abundant alteration halos of biotite and chlorite.

Most of the rocks have a well developed, generally northeasterly striking, southeasterly dipping gneissosity. The rocks were deformed prior to and after alteration and mineralization. Layered structures in hypersthene granodiorite suggest that the rocks have a domal arrangement. A low angle fault in the northeast part of the mapped area apparently resulted in thrusting of the augen gneiss over part of the pegmatitic anorthosite.

Most of the rock types are believed to be of igneous origin, although the augen gneiss may be all or in part metasedimentary. The pegmatitic anorthosite and the hypersthene bearing rocks are believed to be comagmatic.

Most of the titanium occurs as ilmenite in ilmenite nelsonite bodies and disseminated in highly altered rocks adjacent to the pegmatitic anorthosite. Lesser amounts of rutile occur disseminated in relatively pure but altered pegmatitic anorthosite, in rutile nelsonite and in rutile-bearing quartz veins. The titanium deposits are associated with zones of intense alteration characterized by the development of chlorite, biotite, and amphiboles from mafic minerals in the wall rock, and by saussuritization of the feldspars. Evidence indicates that most or all of the deposits formed by replacement of the wall rock.

Titanium, fluorine, phosphorous, water and minor carbon

dioxide were added to the wall rocks during alteration and mineralization. The iron-titanium ratio increases outwardly from the central pegmatitic anorthosite. The original mineralizing fluids may have acquired iron from alteration of the wall rocks. Although the mineralizing fluids may have been derived by differentiation of the same magma from which the hypersthene granodiorite and pegmatitic anorthosite were derived, the mineralization was later than the crystallization of the relatively titanium-rich wall rocks.

The purer pegmatitic anorthosite is quarried and ground principally for use in the glass industry. Reserves are probably large, but the discontinuity of the pure feldspar rock units demands that each prospective quarry site be drilled thoroughly to determine the quality and extent of the feldspar.

A conservative estimate places the reserves of TiO_2 at approximately 12 million tons. Only weathered deposits of ilmenite, at Piney River and the Wood property, are being mined at present, but some of the dike-like ilmenite nelsonite bodies and the disseminated rutile deposits are of present-day ore grade.

Areas of intensely altered rocks near or adjacent to the border of the pegmatitic anorthosite should be investigated further so far as their containing economically recoverable titanium.

LEGEND

Triassic ?

- Td — Dolerite

Precambrian

- Quartz veins
- P — Pegmatite
- p€n — Nelsonite; • Mag - magnetite nelsonite
- p€pa — Pegmatitic anorthosite
- G p€bg Px — Border gneiss; G garnet graphite rocks; Px pyroxenite
- p€hg — Massive hypersthene granodiorite
- p€hga — Altered hypersthene granodiorite
- G p€hgl — Layered hypersthene granodiorite; G garnet graphite rocks
- p€fg — Feldspathic gneiss
- p€gg — Granitic gneiss
- p€ag — Augen gneiss
- p€ba — Biotite aplitic gneiss
- p€pg — Biotite pencil gneiss

Contacts
Dashed where approximately located
Dotted where inferred

Probable fault

Shear zone

68 — Strike and dip of layers

75 — Strike and dip of foliation

Strike of vertical foliation

Disseminated rutile

Areas of intense alteration

Mine or quarry

Abandoned mine or quarry

Trench

Prospect pit

MN N

Cat Rock Mtn
BM 1458 Brent Gap
Mag
Shields Gap
BM 1517
BM 894
Bryant
Pats Knob
Gentian Hol
Mars Knob
Jonesboro
BM 738
Massies Mill
Hol Creek
East Branch
Roseland
American Rutile Pit
Thompson Mtn
St James Ch
Allen Ridge
Blue
Virginia
Buffalo Mines Quarry
Lowesville
Piney River
Shady Lane
Consolidated Feldspar Quarry
Dominion Minerals Quarry
American Cyanamid Pit
St Marys Sch
Temperance Sch
Maple Run
Mill Creek
BM 900
BM 798
Turkey Mtn
Mt Moriah Ch
NELSON CO
AMHERST CO

78°55′ 37°50′ 79°00′ 37°45′ 79°05′ 37°40′

0.5 0 0.5 1.0 mile

Contour interval 200 feet
(Dashed contours estimated from aerial photographs)

GEOLOGIC MAP
OF THE
PINEY RIVER - ROSELAND AREA,
NELSON and AMHERST COUNTIES,
VIRGINIA

Topography from U.S. Geological Survey Amherst, Lovingston and Vesuvius quadrangles

Geology by D. Neil Hillhouse
1958-1959

LEGEND

Triassic ?

- Trd — Dolerite

Precambrian

- Quartz veins
- P — Pegmatite
- pC n — Nelsonite
  - Mag - magnetite nelsonite
- pC pa — Pegmatitic anorthosite
- pC bg — Border gneiss
  - G garnet graphite rocks
  - Px pyroxenite
- pC hg — Massive hypersthene granodiorite
- pC hga — Altered hypersthene granodiorite
- pC hgl — Layered hypersthene granodiorite
  - G garnet graphite rocks
- pC fg — Feldspathic gneiss
- pC gg — Granitic gneiss
- pC ag — Augen gneiss
- pC ba — Biotite aplitic gneiss
- pC pg — Biotite pencil gneiss

Contacts
Dashed where approximately located
Dotted where inferred

Probable fault

Shear zone

68 — Strike and dip of layers

75 — Strike and dip of foliation

Strike of vertical foliation

Disseminated rutile

Areas of intense alteration

Mine or quarry

Abandoned mine or quarry

Trench

Prospect pit

N
MN

Topography from U.S. Geological Survey Amherst, Lovingston and Vesuvius quadrangles

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INDEX TO THIN SECTION LOCATIONS