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DIVISION OF MINERAL RESOURCES
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PART I

# ECONOMIC GEOLOGY OF THE SPRUCE PINE PEGMATITE DISTRICT, NORTH CAROLINA

BY

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## CONTENTS

## CONTENTS—Con.



## ILLUSTRATIONS

### FIGURES



### TABLES



### PLATES

# LETTER OF TRANSMITTAL

Raleigh, North Carolina
May 25, 1944

*To His Excellency,* HON. J. M. BROUGHTON,
*Governor of North Carolina.*

SIR:

Herewith we are pleased to hand you manuscript for a publication proposed as Economic Paper No. 43, "Economic Geology of the Spruce Pine Pegmatite District, North Carolina," by J. C. Olson.

May we call attention to the fact that this is the first report on North Carolina pegmatites in which information is based on geologic mapping.

In view of the strategic position of mica in the war effort, we believe this publication is particularly timely and hope that the information contained therein will be helpful in encouraging increased production to meet war needs and for peace-time use.

It is a notable fact that North Carolina has produced some 60 per cent of all domestic sheet mica since the keeping of records was initiated. In 1940 the production of domestic mica in North Carolina accounted for 62 per cent of the nation's output. Other minerals derived from the pegmatite deposits of the State include feldspar and kaolin, which are important in non-metallic manufacturing.

Respectfully submitted,

R. BRUCE ETHERIDGE,
*Director.*

## PREFACE

This report entitled "Economic Geology the Spruce Pine Pegmatite District, North Carolina" has been prepared cooperatively by the U. S. Geological Survey and the N. C. Department of Conservation and Development. It has been prepared with a twofold purpose: (1) by geologic mapping to determine the relations of commercially valuable pegmatites to the general geologic structures of the region, and (2) by a study of pegmatite mining, to correlate, as nearly as possible, the geologic and mineralogic features of the different pegmatite bodies with their economic possibilities.

Pegmatite minerals have for many years been the basis of the State's most important mining industry. North Carolina, in addition to being an important producer of residual kaolin, has produced 60 per cent of all domestic sheet mica and has led all other states in the production of feldspar since 1917. It is hoped that the information contained in this report may be valuable in bringing about a better development and utilization of North Carolina's pegmatite minerals.

JASPER L. STUCKEY,
*State Geologist.*

# ECONOMIC GEOLOGY OF THE SPRUCE PINE PEGMATITE DISTRICT, NORTH CAROLINA

By J. C. OLSON

## ABSTRACT

The Spruce Pine district, North Carolina, is the principal producing area of both feldspar and sheet mica in North America. North Carolina has led all other states in feldspar production since 1917, and has produced 60 percent of all domestic sheet mica. At least 75 percent of North Carolina's mica, and 90 percent of its feldspar, has come from the Spruce Pine district.

The district is underlain mostly by mica and hornblende gneisses, together with kyanitic gneiss, garnet gneiss and schist, dunite, chloritic rocks, and migmatite, a rock resulting from the impregnation of schistose rocks by material of granitic composition. These rocks are interlayered with one another in various proportions. They have been intruded by a coarse white pegmatitic granite, called alaskite, and genetically related pegmatite. The small bodies of alaskite presumably represent apophyses of a larger granitic mass as yet largely unexposed. The alaskite bodies contain many parallel slab-like inclusions near their walls, and grade outward into layers of schist and gneiss containing many parallel conformable sheets of alaskite and pegmatite, from a few feet to more than 100 feet thick, near which the older rocks have been impregnated with quartz and feldspar along foliation planes.

The pegmatites, formed contemporaneously with or in the late stages of the alaskite intrusion, occur both in the alaskite and in neighboring metamorphic rocks. Pegmatites that are enclosed in alaskite have diverse attitudes, but are most commonly either parallel or nearly perpendicular to the contacts between alaskite and metamorphic rocks or inclusions. Pegmatites in metamorphic rocks are generally conformable with the foliation. The minerals of greatest commercial value, muscovite, feldspar, and quartz, are localized in certain zones called "streaks" within the pegmatite bodies.

The regional northeasterly trend of the metamorphic rocks is interrupted near alaskite intrusions, which appear to have bulged up the overlying mica and hornblende gneisses. It is inferred that the alaskite magma rose from a general southerly direction.

Certain mineralogic differences among the pegmatites are believed to be related to the distances of the pegmatite bodies from their source, and probably to have resulted from the contamination of the pegmatitic material by the country rocks through which the material passed after being expelled from the alaskite.

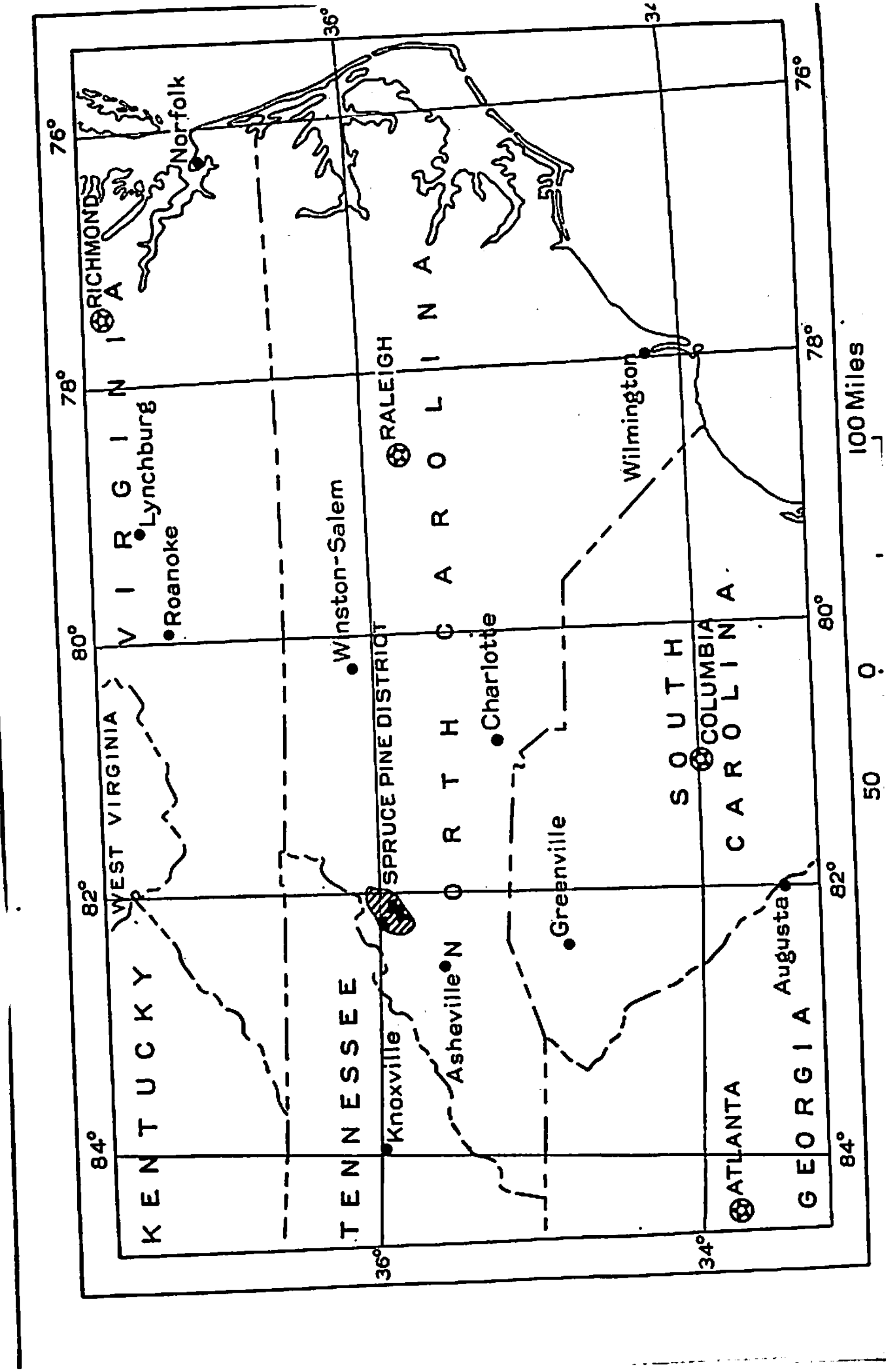
The color of muscovite, generally constant throughout a given mica streak, differs among groups of pegmatites in various parts of the district. The properties that affect the value of muscovite most are its cleavage, ease of splitting, flexibility, color, staining, and power factor. Its value is determined also by the size of the individual sheets. The quality of commercial feldspar depends upon its content of quartz and other impurities, and the ratio of potash to soda.

The success or failure of a mica mine depends upon (1) the percentage of mica in the rock mined, (2) the percentage of sheet, punch, and scrap in the total mica mined, (3) the proportions of larger sizes in the sheet and punch mica, (4) the quality of the sheet mica, (5) market conditions, and (6) other factors such as accessibility, type of mining operation, and availability of supplies and power. Similar factors determine the outcome of a feldspar operation. Mining for either feldspar or mica commonly yields the other as a byproduct, but other by-products as well should be considered in evaluating the commercial possibilities of a pegmatite body.

Any serious decline in the production of feldspar from pegmatite is more likely to be due to improved methods of beneficiation that allow the use of lower-grade material and feldspar from other sources than to depletion of the pegmatites. An increase in the production of clear, flat, easily-splitting mica of the best quality could be brought about by (1) promoting simultaneous operation of many mines to maintain average production in spite of fluctuations in the output of individual mines, and (2) concentrating attention on mines that produce the most desirable mica.

## INTRODUCTION

The Spruce Pine pegmatite district, in the Blue Ridge of western North Carolina, is the principal producing area of both feldspar and sheet mica in North America. Within its 250 square miles are hundreds of developed pegmatites. The present geologic investigation is sponsored jointly by the U. S. Geological Survey and the North Carolina Department of Conservation and Development. Its purpose is twofold: (1) by geologic mapping, to determine the disposition of commercially valuable pegmatite



in relation to the general geologic structure; (2) by a study of pegmatite mining, to correlate, insofar as possible, the geologic and mineralogic features of the different pegmatite bodies with their economic possibilities.

Spruce Pine (fig. 1), with a population of 1,968, is the mining and commercial center of the district, which includes parts of Mitchell, Avery, and Yancey counties. The three counties have a combined population of 46,743. Many of the residents earn all or part of their livelihood in the mines and in the industrial mineral plants, which include 2 feldspar-grinding mills, 3 clay refineries, 7 muscovite-grinding plants, one plant for grinding biotite, and 3 factories that cut and fabricate muscovite. The Carolina, Clinchfield, and Ohio Railroad passes through the heart of the district, and the Black Mountain Railroad joins it at Kona and serves the Burnsville area. All parts of the district are readily accessible by paved highways, good graded roads, and many temporary mining and logging roads.

Altitudes range from 2,150 feet, on the Toe River west of Bakersville, to 6,684 feet on Mt. Mitchell. Most of the region is drained by the North and South Toe Rivers, which unite near Micaville to form the Toe, a northwest-flowing tributary of the Nolichucky River. About two-thirds of the district is wooded. The rocks are deeply weathered in some places, residual kaolin having been mined to a depth of about 100 feet near Spruce Pine. The most deeply weathered rocks occur at altitudes of 2,550 to 2,750 feet; they underlie terrace levels of the Toe River. Outcrops are sparse in some of these areas because of a mantle of rounded boulders and gravel. The higher country, for the most part, is more rugged, and outcrops are rather plentiful. Hundreds of exposures of pegmatite have been prospected for mica and feldspar.

Throughout this report, the term "Spruce Pine district" will be used to designate the entire 250 square miles in which commercially valuable pegmatite occurs, including large parts of Mitchell, Avery, and Yancey Counties. The term "Spruce Pine area" applies to that part of the District shown on the geologic map Plate 1A. The geology of the Bandana area, in the western part of the Spruce Pine district is shown in Plate 1B. All Plates are in Part II of this report.

#### FIELD WORK AND ACKNOWLEDGMENTS

The field work was carried on by the writer, assisted by J. J. Page, during 5 months in the summer and fall of 1941, and for a



total of 3 months by J. M. Parker during the summers of 1940 and 1941. In addition, previous work by the writer, in which he was associated with T. L. Kesler, and assisted by F. W. Hinrichs, during 7 months in the winter of 1939-40, supplied much information of value to the present study. The 1939-40 field work, a report of which has been issued,[1] was a part of the strategic-minerals investigations of the U. S. Geological Survey; it consisted of the examination of 330 mica and feldspar mines and the compilation of statistical data on mica production. In 1941 the geology of the Spruce Pine and Bandana areas was mapped and some of the largest feldspar and mica mines were examined in detail. The writer wishes to acknowledge the hearty cooperation of Dr. J. L. Stuckey, State Geologist of North Carolina, and of the mineral producers, buyers, and miners in the district, whose assistance in the field work has been invaluable.

## MINERAL PRODUCTION

Deposits of the following minerals and rocks of economic value have been mined or prospected in the Spruce Pine district: feldspar, mica, kaolin, gem beryl, kyanite, garnet, asbestos, talc, dunite, iron ore, dolomitic marble, and biotite schist. Of these, feldspar, mica and kaolin are the most important. North Carolina has led all other states in feldspar production since 1917. More than 90 percent of the total for North Carolina has come from the Spruce Pine district whereas the State has produced 60 percent of all domestic sheet mica; in 1940 it accounted for 62 percent of the total. At least 75 percent of the sheet mica produced in North Carolina has come from the Spruce Pine district. Kaolin is the third principal product, and is derived from weathered alaskite. This investigation is directed toward the pegmatite minerals, mica and feldspar.

Mica is believed to have been mined by the Indians, presumably for ornamental purposes, several hundred years before the coming of the white man, but modern mining began in 1868. The Sinkhole, Clarissa, Cloudland, Flat Rock, and Deake mines were developed successively, followed by many others. The earliest demand was for large clear sheets suitable for stove windows, but with the advent of Edison's first electric motor in 1878 and the subsequent growth of the electrical industry, the field of uses of mica broadened, and sheets of smaller and smaller sizes were utilized. Domestic mica was used almost exclusively for these

[1] Kesler, T. L., and Olson, J. C., Muscovite in the Spruce Pine district, North Carolina: U. S. Geol. Survey, Bull. 936-A, 1942.

purposes until 1884, when importation from India began. The grinding of scrap mica, which began in 1893, further enlarged the industrial uses of domestic mica.

Kaolin also is believed to have been produced in western North Carolina by the Cherokee Indians, presumably for shipment to England. As early as 1744, an English patent was recorded for the production of porcelain from an earthy mixture produced by the Cherokee Nation in America, consisting probably of kaolin, feldspar, and quartz.[2] Modern kaolin mining in North Carolina began about 1888 near Webster, in Jackson County, and soon thereafter in the Spruce Pine district. For a number of years the production was small, but about 1900 North Carolina began to gain prominence as a kaolin-producing state. A large part of the early production came from the Webster-Dillsboro area, but in the last few years the entire output has been from the Spruce Pine district.

The first feldspar mined in the Spruce Pine district was shipped from the Deer Park mine by the Carolina Mineral Co. in 1911. By 1917, North Carolina had taken the lead in crude feldspar pro- duction, and has led all other states since that time. The crude feldspar was shipped to mills located mostly in New Jersey and Ohio until 1914, when a grinding plant was built at Erwin, Tenn. Since then, two plants have been constructed in the district, and an additional plant at Erwin. Electromagnetic separation, chemical control and blending, and flotation to use lower-grade raw material have been developed within the last two decades.

Table 1 shows the production of sheet mica, feldspar, and kaolin in North Carolina from the start of feldspar mining in 1911 to the present. Of the totals shown for the whole state, the Spruce Pine district has accounted for probably at least 75 per- cent of the sheet mica, 90 percent of the feldspar, and the greater part of the kaolin.

## GENERAL GEOLOGY

The Southern Appalachian province is underlain predominantly by interlayered mica and hornblende gneisses and schists. The interfingering of the mica and hornblende gneisses, called respectively the Carolina and Roan gneisses by Keith,[3] is indicated on his geologic map. Other rock types in the Southern Appalachians are kyanite gneiss, garnet gneiss and schist, graphitic

[2] Watts, A. S., Mining and treatment of feldspar and kaolin in the Southern Appalachian region: U. S. Bureau Mines Bull. 53, p. 10, 1913.

[3] Keith, Arthur, Mt. Mitchell Folio: U. S. Geol. Survey Geol. Atlas, No. 124, 1905.



TABLE 1. PRODUCTION OF SHEET MICA, FELDSPAR, AND KAOLIN FOR NORTH CAROLINA AND FOR THE UNITED STATES, INCLUDING NORTH CAROLINA, 1911-40*

*Derived from U. S. Geol. Survey and U. S. Bur. Mines, Mineral Res. of the U. S., and Minerals Yearbook, 1911-41.

| Year | Sheet Mica | | | | Feldspar | | | | Kaolin b | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pounds | | Value | | Tons[1] | | Value | | Tons[1] | | Value | |
| | N. C. | U. S. | N. C. | U S | N C | U S | N C | U S | N C | U S | N C | U S |
| 1911 | 454,653 | 1,887,201 | 187,501 | 310,254 | 15,032a | 28,131 | 47,391a | 88,394 | 14,822 | 27,400 | 130,554 | 221,045 |
| 1912 | 489,599 | 845,483 | 219,874 | 282,823 | 7,011a | 26,462 | 18,659a | 89,001 | 14,950 | 25,852 | 139,717 | 220,747 |
| 1913 | 803,462 | 1,700,677 | 230,674 | 353,715 | 12,166a | 45,391 | 30,931a | 148,549 | 16,332 | 28,834 | 139,629 | 235,457 |
| 1914 | 274,121 | 556,933 | 171,370 | 278,540 | 15,420 | 85,905 | 43,153 | 263,476 | 17,168 | 34,191 | 164,534 | 284,817 |
| 1915 | 281,074 | 553,821 | 266,650 | 378,259 | 20,635 | 105,118 | 55,991 | 489,223 | 15,699 | 28,031 | 143,505 | 241,520 |
| 1916 | 546,553 | 865,863 | 380,700 | 524,485 | 30,955 | 132,681 | 77,446 | 702,278 | 38,469a | 47,723 | 217,156a | 306,819 |
| 1917 | 643,476 | 1,276,533 | 543,207 | 753,874 | 42,463 | 126,715 | 131,442 | 474,767 | 31,312a | 31,885 | 297,386a | 301,378 |
| 1918 | 941,200 | 1,644,200 | 460,450 | 731,810 | 35,732 | 88,498 | 160,275 | 429,989 | 32,752a | 37,969 | 309,277a | 391,109 |
| 1919 | 1,021,306 | 1,545,709 | 331,498 | 483,567 | 22,594 | 63,441 | 116,826 | 347,992 | 18,169a | 152,828 | 230,470a | 1,475,681 |
| 1920 | 1,084,946 | 1,683,480 | 405,654 | 546,972 | 36,521 | 135,551 | 187,136 | 851,123 | 68,274a | 268,203 | 890,324a | 2,865,407 |
| 1921 | 230,532 | 741,845 | 51,851 | 118,513 | 40,712 | 91,865 | 259,603 | 617,652 | 11,681 | 162,726 | 188,825 | 1,579,163 |
| 1922 | 544,495 | 1,077,968 | 119,767 | 194,301 | 56,043 | 117,127 | 333,745 | 844,568 | 14,586 | 275,675 | 214,552 | 2,346,095 |
| 1923 | 1,130,283 | 2,063,179 | 188,317 | 311,180 | 57,622 | 145,004 | 360,636 | 1,057,595 | 23,673 | 336,803 | 369,398 | 2,926,255 |
| 1924 | 597,385 | 1,460,897 | 108,656 | 212,035 | 97,075 | 204,772 | 640,403 | 1,509,339 | 16,858 | 326,611 | 277,418 | 2,923,965 |
| 1925 | 592,478 | 1,793,865 | 105,376 | 321,962 | 76,806 | 185,706 | 496,563 | 1,315,654 | 18,799 | 367,319 | 309,833 | 3,220,719 |
| 1926 | 700,313 | 2,172,159 | 150,362 | 400,184 | 91,433 | 209,989 | 602,020 | 1,607,101 | 20,719 | 432,215 | 331,487 | 3,771,568 |
| 1927 | 665,360 | 1,512,492 | 114,514 | 212,482 | 100,756 | 202,497 | 612,214 | 1,424,755 | 20,334 | 454,245 | 327,638 | 3,809,834 |
| 1928 | 777,395 | 1,681,777 | 129,706 | 230,956 | 105,560 | 210,811 | 630,042 | 1,418,975 | 19,788 | 496,142 | 298,841 | 4,088,003 |
| 1929 | 894,200 | 2,035,128 | 150,293 | 286,321 | 103,273 | 197,699 | 598,938 | 1,276,640 | 17,678 | 518,169 | 282,672 | 4,281,301 |
| 1930 | 749,074 | 1,465,485 | 112,451 | 177,307 | 103,163 | 171,788 | 593,552 | 1,066,636 | 24,674 | 533,800 | 391,432 | 3,893,814 |
| 1931 | 389,426 | 962,953 | 51,657 | 111,830 | 86,429 | 147,119 | 505,525 | 861,059 | 12,234 | 443,300 | 195,596 | 2,946,953 |
| 1932 | 127,696 | 338,997 | 18,322 | 45,882 | 58,465 | 104,715 | 300,877 | 539,641 | 12,660 | 344,994 | 202,016 | 2,011,208 |
| 1933 | 162,672 | 364,540 | 21,107 | 53,179 | 85,962 | 150,633 | 471,312 | 778,826 | 6,878 | 411,233 | 102,714 | 2,366,339 |
| 1934 | 293,381 | 583,528 | 38,674 | 90,268 | 79,844 | 154,188 | 465,214 | 853,136 | 7,146 | 426,335 | 106,742 | 2,699,016 |
| 1935 | 512,590 | 936,633 | 77,598 | 191,150 | 82,499 | 189,550 | 482,729 | 1,005,021 | 8,162 | 523,656 | 118,972 | 3,765,268 |
| 1936 | 730,446 | 1,319,233 | 119,653 | 203,879 | 102,393 | 244,726 | 591,053 | 1,303,090 | 8,657 | 638,939 | 126,353 | 4,537,738 |
| 1937 | 1,044,328 | 1,694,538 | 218,176 | 285,244 | 94,595 | 269,532 | 538,567 | 1,383,249 | 46,840a | 732,282 | 533,817a | 5,349,936 |
| 1938 | 632,646 | 939,507 | 87,879 | 139,333 | 56,795 | 196,119 | 295,800 | 895,081 | 32,129a | 595,054 | 363,725a | 4,740,880 |
| 1939 | 401,170 | 813,708 | 69,344 | 138,963 | 76,738 | 253,466 | 397,631 | 1,112,857 | 11,308 | 780,804 | 165,896 | 6,200,606 |
| 1940 | 1,002,646 | 1,625,437 | 218,154 | 291,685 | 79,312 | 290,763 | 426,784 | 1,271,995 | 14,602 | 833,450 | 202,642 | 6,994,106 |

a–Other states included
b–Paper clay included in some years
1–Feldspar mostly in long tons, kaolin in short tons

muscovite schist, marble, soapstone, and dunite. The gneisses and schists are commonly layered, and the foliation is normally parallel with the layers.

Most of these rocks originated as sediments, but have since been deeply buried, strongly folded and recrystallized, and intruded by igneous rocks. Subsequent erosion over a long period of time has exposed these metamorphic rocks. The belt in which they occur, comprising the Blue Ridge and Piedmont physiographic provinces, is roughly 160 miles wide at the latitude of Spruce Pine, and trends about N 30° E, the average strike of the foliation of the metamorphic rocks.

Pegmatites occur in many parts of the Southern Appalachians, but their size, number, and composition varies greatly from place to place. The abundant large pegmatites of the Spruce Pine district are closely associated with an intrusive granitic rock called alaskite. Other granitic rocks mapped by Keith are the Cranberry granite to the north and east of the district, the porphyritic Henderson granite within 6 miles to the southeast, and the Whiteside granite to the east and south.

The alaskite and pegmatite, which are described on pages 22-32, have invaded the metamorphic rocks, and have in places effected changes in their mineral composition and physical appearance. These alteration effects are described, together with the normal characteristics of the metamorphic rocks, in the section that follows.

## METAMORPHIC ROCKS

### MICA GNEISS AND SCHIST

Micaceous rocks in the Spruce Pine district include muscovite-biotite gneiss, biotite gneiss and schist, mica schist, quartz-mica schist, quartzite, and kyanitic mica gneiss and schist. These rocks, which are predominantly or entirely meta-sediments, are commonly interlayered with hornblendic gneiss and schist rocks of markedly different composition.

The mica gneisses consist of abundant orthoclase and plagioclase feldspars, and various proportions of muscovite, biotite, quartz, and garnet. These minerals have a wide range in grain size. With increasing quartz content and diminishing grain size, the gneisses grade into hard quartzite containing only a few mica flakes. The quartzitic layers are interbedded with all other metamorphic rocks, but their total volume is small. By a relative decrease in the feldspars, and an increase in quartz and the micas, the gneisses grade into mica schist, some of which contains practically no feldspar. True biotite schist, consisting largely of coarse biotite flakes, was formed in some places by hydrothermal alteration of hornblendic rocks. Biotite and muscovite-biotite gneisses, on weathering, yield soils that are characterized by many individual mica flakes, whereas schist or migmatite yields soils that are characterized by many small bunches of closely-packed leaves of mica.



The mica gneisses in a belt as much as 8 miles wide in the western part of the district contain much kyanite and garnet. Weathered surfaces of these rocks are commonly rough owing to resistant knobs of kyanite or garnet crystals an inch or less long. Kyanite and by-product garnet have been concentrated from rock mined for a number of years 2½ miles southeast of Burnsville, on the north end of Celo Mountain. Kyanite makes up 5 to 40 percent of the rock mined.

### MIGMATITE

The term migmatite in this report indicates mica schist or gneiss that has been impregnated with material of alaskitic or pegmatitic composition. The introduced quartz and feldspar form lenses or streaks of uneven thickness and apparently not of great length. They are generally parallel with the foliation, but in some places they cut across it. Some lenses are entirely of feldspar and some streaks entirely of quartz, but most commonly both minerals occur together, with muscovite, garnet, or biotite. Schistose micaceous rocks were most permeable and most easily penetrated by solutions from the alaskite magma. Hornblendic gneiss and schist and some mica gneiss were less permeable, and therefore remain for the most part as unimpregnated or slightly impregnated layers in the migmatite. Rocks intermediate between the mica gneisses and migmatite and between the migmatite and alaskite in composition, texture, and structure are not uncommon. The areas of migmatite contain many pegmatite and alaskite bodies that are too small to be shown on the geologic map. The migmatite as mapped is therefore composite, consisting of layers of mica and hornblende gneiss, pegmatite, and alaskite, enclosed in the schistose layers that contain variable amounts of quartz-feldspar streaks or lenses.

The mica in migmatite is mostly muscovite, but biotite is commonly present, and is the most abundant mica near some of the hornblendic layers. Most layers of hornblende gneiss in migmatite remain relatively unaltered, although near pods of pegmatite

or alaskite, the hornblende is commonly recrystallized, coarser,
and not so well oriented. In some places the solutions reacted
with the mafic minerals, and produced rocks relatively rich in
dark glistening biotite or garnet, with occasional chlorite, actino-
lite, or epidote. An unusually pure biotite schist northeast of
Spruce Pine is mined at Hanging Rock and Tempa Mountain for
commercial purposes. It is apparently the result of extreme
hydrothermal alteration of hornblende gneiss. Other products
of this alteration in the same area are coarse, nearly pure mica
schist and with peculiar quartz-muscovite pegmatite veins that
occur on Tempa Mountain.

The biotite schist mined on Hanging Rock Mountain occurs in
irregular lenses and masses in migmatite in a zone about 15 feet
thick. Lenses and streaks of quartz, and to a lesser extent of
alaskite, are associated with the biotite schist and relic strips of
hornblende gneiss occur between the schistose lenses. Other
minerals observed in the schist are chlorite, talc, actinolite, chal-
copyrite, and one apatite crystal an inch long. Some of the
amphibole crystals are as much as 8 inches long and are embedded
in talc.

The biotite schist on Tempa Mountain is similar to that on
Hanging Rock Mountain. It occurs as a thick layer in migmatite
which in turn is overlain by mica gneiss. The biotite schist is
crumpled and wrinkled in small and large chevron folds. It con-
tains hundreds of discoids that consist mostly of actinolite or
hornblende crystals up to 4 inches in length but some are com-
posed entirely of quartz. The discoids range from 1 inch to 6
feet in diameter and ¼ to 18 inches in thickness. Most of them
are enclosed conformably in biotite schist so that the foliation
wraps around them. The contacts are usually sharp though some
of the larger discoids grade laterally outward from light-colored
hornblende gneiss to biotite schist, the leaves of biotite pene-
trating the edges of the discoid.

The biotite schist at each of these localities has evidently been
formed by recrystallization of hornblende gneiss that was per-
meated by hydrothermal solutions presumably derived from the
alaskite magma. These solutions effected the chemical changes,
chiefly through addition of potash, necessary to convert horn-
blende to biotite. Part of the original rock was converted to
light-colored biotite gneiss, part to the biotite schist containing
many discoids of quartz and actinolite, and part recrystallized to
coarse amphibole. All are cut by quartz veins.



### DOLOMITIC MARBLE

Dolomitic marble is interlayered with mica gneiss in a railroad cut northwest of Bandana (pl. 1B) and can be traced northeastward at least 2,500 feet. A mica gneiss band 10 feet thick separates the marble into two layers, 8 and 70 feet thick. Pegmatite cuts across the marble, and actinolite has developed in the marble near the pegmatite. The marble is coarse grained, individual grains measuring as much as 0.3 inch in diameter. The magnesia content of this rock is said to be relatively high, near that of the mineral dolomite.

### HORNBLENDE GNEISS AND SCHIST

Hornblendic rocks are interlayered with the micaceous rocks in
various proportions. Interlayered rocks that are dominantly
hornblendic are collectively mapped as a rock unit, but many
layers other than hornblende gneiss occur in them. The most
abundant hornblendic rocks are the following: (1) Dense black
hornblende schist composed almost entirely of hornblende needles
1/10 to ½ inch long, but containing a little quartz and feldspar.
(2) Hornblende gneiss, containing plagioclase of an intermediate
composition, quartz, and a little garnet, in addition to hornblende.
The hornblende gneiss in higher parts of the formation, on Woods
Mountain for example, consists of thin parallel sheets made up
largely of hornblende crystals that separate thicker white layers
of quartz and feldspar commonly about 1/10 inch thick. The
rock has a good cleavage, parallel to the foliation, and the
cleavage surfaces show irregular black and white splotches, be-
cause of the thinness of the hornblendic seams. (3) Fine-grained,
light-colored granulitic layers generally several inches to a foot
thick are associated with the hornblende-rich bands. They con-
sist principally of fine-grained feldspar and quartz, with sparse
hornblende crystals and small red garnets; they are nearly or
wholly free of mica and not noticeably schistose. (4) Epidote-
and actinolite-bearing rocks and some hornblende-biotite gneiss
that apparently have been formed by the hydrothermal alteration
of the above types. Much of the epidote, both in the gneisses and
in seams or veinlets cutting them, was derived through the
alteration of hornblende. Epidote of this origin is noticeable near
the Hootowl mine, ½ mile north of Crabtree Mountain, and at
many other pegmatite localities. Hornblende needles commonly
are coarser near pegmatite.

Magnetite occurs in some layers of hornblende gneiss in migmatite east of Hanging Rock Branch. Some prospecting for iron is said to have been done here.

Exposures of hornblende gneiss, notably in the highway cut west of Estatoe, along the railroad between Minpro and Little Bear Creek, and in Autrey Hollow west of Chalk Mountain, show few or no layers of other types of rocks. More commonly, the hornblendic rocks are interlayered with other types of metamorphic rocks, as is well exposed on the South Fork of Carvers Branch, near the top of Woods Knob, on Pine Mountain, on Emily Knob, and in the Hawk mine (see pl. 8). For areas underlain by interlayered rocks of different types the designation of rock types shown on the geologic map is based on the principal type present. On the average, hornblendic gneisses make up a slightly greater percentage of the rocks higher in the geologic column and are therefore more abundant in synclinal structures on the higher peaks.

Hornblende gneisses or amphibolites interlayered with diverse rocks have been described from similar metamorphic areas in many parts of the world, and generally interpreted as metamorphosed basic sills, dikes, or extrusive volcanic rocks. The abundance of the hornblendic layers in the Spruce Pine district, their variation in composition, and the lack of cross-cutting relationships, suggests an extrusive or a sedimentary rather than an intrusive origin for much of the hornblendic rock, although some may have been conformable sills.

### CHLORITIC ROCKS

Rocks whose characteristic mineral is chlorite or in some places actinolite are mapped as a separate lithologic unit. Typically, the finer-grained part of the rock, consisting of oligoclase or andesine, quartz, hornblende, biotite, and some garnet and opaque mineral, is divided by curved plume-like seams or veinlets of chlorite or actinolite into lenses of roughly ellipsoidal shape about ½ inch thick. The distinction between this and other rock types of nearly similar composition is based upon (1) the presence of the chlorite or actinolite and (2) the characteristic structure of chlorite-rich plumes wrapping around the finer-grained material. The surfaces of many outcrops are knobby owing to weathering along the curved chloritic surfaces. Cavities due to the weathering of sulfide minerals, principally pyrrhotite and pyrite, are common; weathered surfaces of the rock are stained dark gray where the sulfides are especially abundant.



The chloritic rocks are apparently the result of hydrothermal alteration of metamorphic rocks, principally of the hornblendic types. Foliation in the chloritic rocks is either obscure or lacking. The chlorite occurs in whorls, knots, or plumose aggregates. In thin-section, some of the minerals in the finer-grained parts of the rock, particularly biotite and amphibole, have parallel orientations; some of the chloritic seams approximately follow this faint pre-existing foliation, but others cut across it.

Bands in which the chloritic rocks occur are generally parallel to the adjacent layers of the other metamorphic rocks; some of the thicker bands are probably at least 250 feet thick. The areas of chloritic rocks shown on the geologic map (plate 1) contain layers of hornblende gneiss, quartz-mica gneiss, and quartzite that are too small to be mapped separately. Some of these layers show no effects of alteration, others contain some chlorite, thus suggesting that certain layers were more susceptible to chloritization than others. The full extent of the areas of chloritic rocks in the Brushy Creek section is probably not shown on the geologic map because of the absence of outcrops over large areas.

The localization of the alteration to certain relatively thin zones, generally parallel to the foliation of other rocks, is an interesting metamorphic problem. Detailed work in other parts of the district is necessary before speculation as to the cause of this localization would be justified.

### DUNITE AND SOAPSTONE, TALC-CHLORITE SCHIST

Dunite occurs in the Spruce Pine district at Mine Creek in the Bandana area (plate 1B), on Whiteoak Creek near Bakersville, near Frank in Avery County, on Mine Fork north of Bumsville, and on Mine Branch near Newdale, and is known at many other places in western North Carolina.[4] It consists principally of olivine, but serpentine is a common alteration product, and many other minerals occur in small amounts. Outcrops of dunite are not greatly weathered; the bare slopes have little soil and support very little vegetation.

The commercial use of North Carolina olivine as a refractory began about 1933, and a small quarry near Daybook, the second largest in the State, has shipped material for refractory purposes.

Small bodies of soapstone and talc-chlorite schist, commonly containing such other minerals as tremolite or actinolite, occur in the Spruce Pine and Bandana areas. They are derived through

[4] Hunter, C. E., Forsterite olivine deposits of North Carolina and Georgia: N. C. Dept. of Conservation and Development, Div. of Min. Resources, Bull. 41, 1941.

the alteration of such magnesian rocks as dunite, pyroxenite, and hornblende gneiss. The soapstone is impure, commonly containing several amphiboles; it is white or light gray. The largest bodies mapped are those on Crabtree Creek and Grassy Creek.

The dunite and soapstone bodies cut across the older gneisses and schists. The bodies of impure soapstone exposed on Grassy Creek, whose centers are dunite, appear to be inclusions in the younger alaskite.

## ALASKITE

### MINERALOGICAL AND CHEMICAL COMPOSITION

A coarse-grained pegmatitic granite that crops out near Spruce Pine (plate 1) has been called alaskite by Hess and Hunter.[5] It consists essentially of oligoclase, quartz, microline, and muscovite, in order of abundance. Ferromagnesian minerals are almost absent in most of the rock, but small amounts of garnet and biotite occur at some places especially near inclusions or contacts with country rocks, and are apparently products of contamination. Unlike pegmatites, in which irregular mineral distribution is the rule, the alaskite has a relatively uniform mineral composition. The similarity in chemical composition between alaskite and 500 tons of selected pegmatite from the Deer Park no. 5 mine, near Penland, is shown in table 2. The relatively high lime content, due to oligoclase, is not strictly in accord with other published analyses of alaskite whose plagioclase is albite, but the term alaskite is used in this report for the coarse white pegmatitic granite near Spruce Pine.

### TEXTURE AND INTERNAL STRUCTURE

The large masses of alaskite for the most part are uniform in grain size as well as mineral content. The texture is granitoid, but coarser than the average granite; the feldspar grains commonly exceed ⅛ inch in diameter. Much of the rock is sufficiently coarse grained to be called pegmatite, but its uniformity and wide extent make the term alaskite more appropriate. Near the margins of alaskite masses the grain size is notably irregular; the coarsest parts of the rock are pegmatite which occurs either as irregular masses gradational into alaskite, as single feldspar crystals, or as graphic granite masses a foot or so across enclosed in a more normal alaskite groundmass. The proportion of muscovite flakes is commonly higher in such zones of irregular grain

[5] Hunter, C. E., Residual alaskite kaolin deposits of North Carolina: Amer. Ceramic Soc. Bull., vol. 19, no. 3, pp. 98-103, March 1940.



TABLE 2.—CHEMICAL COMPOSITION OF ALASKITE AND PEGMATITE FROM THE SPRUCE PINE DISTRICT, NORTH CAROLINA

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 74.9 | 73.96 | 74.30 | 75.26 |
| $Al_2O_3$ | 14.9 | 15.77 | 15.50 | 14.92 |
| $Fe_2O_3$ | 0.33 | 0.33 | 0.30 | 0.28 |
| CaO | 1.0 | 1.30 | 0.90 | 1.10 |
| $K_2O$ | 4.7 | 3.74 | 4.56 | 4.19 |
| $Na_2O$ | 4.0 | 4.57 | 4.15 | 4.20 |
| Loss | 0.2 | 0.31 | 0.26 | 0.28 |
| Total | 100.03 | 99.98 | 99.97 | 100.23 |

1. 500 tons alaskite from Davis quarry, Minpro, N. C.
2 and 3. Alaskite. Hunter, C. E., op. cit., p. 100.
4. 500 tons selected pegmatite from Deer Park No. 5 mine, Penland, N. C.
Analyses by United Feldspar and Minerals Corp., Spruce Pine, N. C. Published by permission of B. C. Burgess.

size, and larger crystals, as much as 2 by 3 inches in size, have been observed apparently isolated in the finer-grained alaskite.

The foliation or layered appearance in some parts of the alaskite is due to the parallelism of mica flakes, streaks of quartz or feldspar, parallel trains of small mica flakes or of garnets, and parallel lenses of feldspar which developed before complete solidification. The mica flakes are white or green, in contrast to the browner muscovite of adjacent country rocks, and are generally somewhat coarser. The streakiness is better developed near the margins of the larger intrusive masses, but for the most part even this part of the rock is massive. Some of the thin sill-like bodies in schist bordering larger alaskite masses are foliated; others are not. The foliation in thin alaskite bodies, where present, is generally parallel with the walls and with the foliation of the wall rocks. In a few places, trains or whorls of fine mica flakes in alaskite appear to be remnants of schist inclusions that were partly replaced.

### DISTRIBUTION AND CONTACT RELATIONS

The small bodies of alaskite that crop out at many places in the Spruce Pine district are apophyses of an intrusive mass as yet largely unexposed at the surface. Within the Spruce Pine area (pl. 1A), alaskite occurs in three principal areas, referred to as the Spruce Pine, Penland, and Crabtree alaskite bodies (see figure

2, p. 33). The largest mass, between Spruce Pine and Chalk Mountain, has a width, unbroken by large inclusions, of 4,000 feet and a length of about 2 miles. Many parallel slabs of country rock are included in the alaskite near the margins of the masses shown on the map, but the central parts are relatively free of inclusions. Alaskite containing many inclusions grades outward into layers of schist and gneiss enclosing numerous parellel conformable sheets of alaskite and pegmatite a few feet to more than 100 feet thick, near which the older rocks have been impregnated with quartz and feldspar along foliation planes. In some places the migmatite thus formed by impregnation is difficult to distinguish from the more foliated varieties of alaskite.

Most slab-like inclusions, as well as the alaskite sills, are parallel to one another and to the foliation of adjacent metamorphic rocks. The tendency toward conformability is much more pronounced in the schistose rocks than in the hornblende and fine-grained mica gneisses, because the introduction of magma and solutions was controlled to a great extent by the schistosity. In the more competent and less permeable rocks, such as hornblende gneiss, cross-cutting relations are more common, and fragments of such rocks included in alaskite generally have irregular shapes. The contacts of the alaskite masses are extremely irregular in detail because of (1) innumerable apophyses of alaskite and related pegmatite in neighboring country rocks, especially the schistose rocks, (2) cross-cutting relations in some places, mostly in the less schistose rocks, and (3) many inclusions of various shapes within the alaskite.

#### WEATHERING

Kaolin, a product of the weathering and decomposition of alaskite in the Spruce Pine district, has been mined for about 50 years for use in the ceramic industries. The kaolin deposits are practically all between 2,550 and 2,750 feet in altitude, and were formed by the weathering of old land surfaces near the Toe River. Workable kaolin has been found to depths of about 100 feet. The kaolin grades downward through a semi-kaolinized zone to rock within which the proportion of hard feldspar is too great for profiitable operation. From 10 to 15 percent of the material mined is recoverable kaolin. The coarse potash feldspar and quartz in pegmatites do not weather as rapidly as the surrounding alaskite, and their presence detracts from the value of a kaolin deposit. Likewise, inclusions of country rock are objectionable and on weathering supply iron to stain the adjacent kaolin. With an alumina content of 37-38 percent, the washed kaolin is a potential low-grade source of aluminum.



### PEGMATITES

#### BODIES IN ALASKITE

Pegmatites occur in all the exposed alaskite, but the average size and number is greater near the margins of the alaskite bodies. Greater pegmatitic activity in the peripheral zones is indicated not only by the larger sizes of the pegmatite bodies, but also by textural irregularities due to local coarsening of the grain size of the alaskite. Some small pegmatites in this zone consist of isolated, foot-thick crystals of microcline or graphic granite, or a streak of gray quartz of coarser grain size than the enclosing rock.

The irregularity in shape of many pegmatites in alaskite is related to the sharpness of the contact between the two rocks. Pegmatite bodies whose contacts with alaskite are hazy or gradational commonly have irregular shapes. On the other hand, those whose contacts with alaskite are sharp, generally in alaskite that is faintly foliated, tend to be well-defined, tabular bodies.

Pegmatites in alaskite are oriented for the most part either parallel with, or nearly perpendicular to, the contact between the enclosing alaskite and the adjacent country rock. Many of the steeply-dipping pegmatites of the latter type are enclosed in alaskite that is faintly foliated parallel to the contacts with country rocks. The structure at the contact of some of these steeply-dipping pegmatites and the overlying gently-dipping country rocks is genetically significant. As exposed at about a dozen localities, the country rock overlying the steeply-dipping pegmatite, where it is in contact with the pegmatite, is warped downward to form a synclinal fold, the axis of which is parallel to the strike of the pegmatite. The folds are generally 10 or 15 feet across, and the sharpness of each fold diminishes upward from the contact; but the size and sharpness are not necessarily indicative of the thickness of the pegmatite beneath. Such a fold, however, indicates the presence of pegmatite and the origin of the one feature is related to the origin of the other. The fold appears to be the result, rather than the cause, of the pegmatite's position. The inference is that the pliant schist was depressed directly over the igneous body before it was completely crystallized, owing either to the difference in rigidity between the pegmatitic solutions and alaskite, or possibly to the loss in volume of the pegmatite as it crystallized.

The above features, together with the similarity in composition between alaskite and pegmatite enclosed in it (see table 2), and the distribution and sizes of pegmatite bodies relative to that of the alaskite in the Spruce Pine area, demonstrate the close genetic relation between the two rock types. Where the two are intergradational, the degree of sharpness of the contacts indicates the relative lapse of time between the crystallization of the alaskite and of the different bodies of pegmatite. The crystallization of pegmatite began before that of the alaskite was completed, but in a few places where contacts are sharp, the pegmatitic solutions were apparently driven into fractures, possibly formed by shrinkage, in alaskite already crystallized.

#### PEGMATITES IN METAMORPHIC ROCKS

The attitudes of many pegmatites in country rocks have been plotted on the map of the district (see pl. 2). Contacts with metamorphic rocks are commonly sharp, except for the impregnation of schistose country rocks by quartz and feldspar as described in the section on migmatite. Contacts with the hornblendic wall rocks show the development of biotite, chlorite, or epidote in zones of altered rock a few feet thick, and coarse biotite schist within a few inches of some contacts.

Many pegmatite bodies are tabular or sheetlike, having long surface outcrops and relatively narrow widths. Most of them occur in schistose wall rocks and conform with the foliation. Other pegmatites, such as that at the Autrey mine (fig. 5) are also conformable and lenticular in cross-section, and may be tongue-like or pipe-like in shape. The pitch of such bodies, where it can be established, is generally south or southwest at low or moderate angles, parallel to the pitch of minor structures such as fluting and drag folds in the metamorphic rocks. The pitches of pegmatite bodies as shown on plate 2 actually represent the pitches of mica or feldspar-rich zones that are followed in mining, but such mineral zones almost invariably parallel the pitch of the pegmatite body. Pegmatite bodies of very irregular shape, as though emplaced in badly distorted and fractured rock, are more common in the gneisses than the schistose rocks.

#### MINERALOGY

At least 44 different minerals have been reported from the Spruce Pine pegmatites. Those of greatest economic importance



are discussed in the following pages, with emphasis on their localization, or segregation into certain zones or streaks, and their mutual relations.

*Quartz.*—Quartz occurs in all the pegmatites in various proportions, probably averaging 25-35 percent of the total pegmatite. The most quartzose pegmatites, more than half quartz, are those near the head of the South Toe River and in the Black Mountains, and the quartz-mica veins on Tempa Mountain. Most of the quartz is of the gray pegmatitic variety, but some is white, and some smoky. The smoky quartz seems to be darker where radioactive minerals, such as autunite, uraninite, and uranophane, are abundant, for example at the Pine Mountain mine, 1 mile north of Minpro. Quartz in large quantity is a by-product in some of the mines, and is sold for $1.50-5.00 per ton, depending upon its purity. A quartz mass 1-20 feet thick in the middle of the Chestnut Flat pegmatite (pl. 7) has yielded more high-grade pegmatitic quartz than any of the others.

*Feldspar.*—Both microcline and plagioclase, commercially referred to as potash and soda spars, occur in the Spruce Pine pegmatites. The plagioclase feldspars are oligoclase and albite; studies by Maurice[6] have shown a range in composition from $Ab_{95}An_5$ to $Ab_{70}An_{30}$. The feldspar throughout any one shoot or lens within a pegmatite ordinarily has a uniform composition, but the composition varies among pegmatites in different parts of the district. Maurice has noted that potash feldspar is more abundant in pegmatites whose plagioclase is highly sodic.

Some oligoclase crystals are as much as a foot across, but more commonly the plagioclase occurs as finer-grained aggregates with garnet, muscovite, or quartz, or as tiny veinlets in potash feldspar. The coarsest crystals occur in the pegmatites that contain very little potash feldspar. Where both potash and soda feldspars are abundant in a pegmatite, the parts of the body near the walls contain the most plagioclase, together with mica and quartz. Some calcic oligoclase crystals that occur both in pegmatite and as small pods in wall rock are colorless, transparent, and have a glassy luster. In weathered pegmatite, the plagioclase is dull white and soft, and the harder, pinkish or cream-colored microcline is easily distinguished from it.

Perhaps the most interesting and significant feature of the plagioclase feldspars is their variation in composition in different pegmatites, explained by Maurice[7] as being due to differences in

[6] Maurice, C. S., The pegmatites of the Spruce Pine district, North Carolina: Econ. Geol., vol. 35, nos. 1 and 2, pp. 49-78, 158-187, 1940.

temperature of formation. From compositional data presented by Maurice, it appears to this writer that the most sodic plagioclase is found in pegmatites in or near large alaskite masses, in migmatite closely related to alaskite, or in very large pegmatites such as those of the McKinney and the Hootowl mines. The more calcic feldspars are in pegmatites that are farther from known alaskite, and, therefore, presumably farther from their source. With regard to type of country rock, pegmatites in kyanitic gneisses and schists contain on the average the most calcic plagioclase, and those in hornblende or mica gneisses contain plagioclase slightly more sodic than do those in kyanitic rocks, but not so sodic as do the pegmatites in or near alaskite.

Microline, the chief commercial feldspar, is most abundant in the central parts of pegmatites. Crystals as much as 6 feet long occur in some large quartz bodies, and masses of nearly pure microcline weighing many tons have been mined. Generally speaking, microcline occurs in larger crystals and is less intergrown with other minerals than any other constituent of the Spruce Pine pegmatites. Graphic intergrowths with quartz are common, but pegmatite containing much graphic granite is not mined for two reasons: (1) the graphic granite is of low grade as commercial feldspar owing to high silica content; (2) it is ordinarily barren as a source of commercial mica. Large quantities of both potash feldspar and mica do not ordinarily occur together in pegmatite. Both minerals have the same constituents, potash, alumina, and silica, but the molecular ratio of potash to alumina in muscovite is 1:3 and in potash feldspar, 1:1. This difference, and differences in molecular ratios between potash or alumina and silica, may have determined whether potash feldspar, graphic granite, or muscovite was the dominant potash mineral to crystallize, when varying amounts of potash, alumina, and silica were available for their formation. Other important factors were the proportions of volatiles present, principally water, and the temperature of formation.

The largest feldspar mines are in pegmatite bodies at least 25 feet thick or much larger. Thick pegmatites are most common near the margins of alaskite bodies, in either alaskite or adjacent country rock. Areas in which large feldspar deposits might occur, near or in the outer parts of alaskite bodies, cover a large part of the Spruce Pine map area (pl. 1A), but a relatively small part of the entire Spruce Pine district. In such areas, the proportion of potash feldspar to soda feldspar in the pegmatites is probably a little higher than in pegmatites farther from their source. Pegmatites with the highest average ratio of potash to soda feldspar in the district probably occur in the Big Ridge-Kona-Bee Ridge section north of Micaville.

[7] Maurice, C. S., op. cit.



*Muscovite*.—Muscovite occurs sporadically in all pegmatites in the district, with the exception of several mined for feldspar along the northwest edge. The largest crystal mined in the district, a block of A-mica from the Fannie Gouge mine, is said to have weighed 4,300 pounds. The thinner pegmatites 20 feet or less thick, many of them only 4 to 6 feet thick, have produced most of the mica of high quality in the Spruce Pine district. Although pegmatites 6 feet or less thick may be mined from wall to wall, mining in thicker bodies is confined to the part or parts richest in muscovite, called "streaks" or "shoots." Unusually rich clusters of mica crystals encountered in mining are called "pockets." The erratic distribution of muscovite in the different pegmatite bodies makes it impossible to apply any one rule universally to its localization. The following generalizations, however, apply to most of the Spruce Pine pegmatites:

(1) Sheet muscovite is most abundant in pegmatite consisting of quartz, plagioclase, and muscovite, or in quartz-plagioclase-muscovite shoots in pegmatite or alaskite of a more diverse composition, or in many small quartz-plagioclase-muscovite pegmatites collectively forming a pegmatite zone in mica schist.

(2) The best qualities of muscovite (flat ruby or rum) are associated more commonly with quartz and calcic oligoclase than with more sodic feldspar or potash feldspar.

(3) Many pegmatites tend to be richer in plagioclase feldspar and in muscovite, near their margins, and richer in potash feldspar near their centers.

(4) Muscovite is associated with quartz without exception, either (a) in quartz-plagioclase shoots as mentioned above, (b) in quartz-muscovite shoots either in pegmatite or country rock, or (c) about the margins of quartz masses, a few inches to 20 feet thick, in pegmatite or alaskite.

(5) Pegmatites or parts of pegmatites that are rich in graphic granite contain little or no commercial muscovite.

(6) The abundance of muscovite is approximately in inverse proportion to the biotite content of the pegmatite. Some biotite-rich pegmatites contain no muscovite.

(7) The color of mica is fairly constant throughout a given mica-rich zone. If several different colors of muscovite occur in the same pegmatite, they generally come from different mica streaks.

(8) In some pegmatites containing both clear and mineral-stained muscovite, there is a tendency for the stained mica to occur near the walls or inclusions.

(9) In some pegmatites that pinch and swell, mica tends to be more abundant near the constrictions.

(10) In some bodies a greater concentration of mica is found near sharp bends or "rolls" of the hanging wall, footwall, or both.

(11) Mica tends to be most abundant along the crests of some pipe-like or tongue-like bodies.

(12) "A" mica is most abundant in microcline-rich pegmatite along the southeast border of the district, in areas of alaskite. Where "A" mica occurs at the margins of quartz masses, the point of the "A" commonly projects into the feldspar, away from the quartz body. "A" mica is common near large quartz masses.

(13) Mineral-stained mica is confined almost entirely to pegmatites that contain no biotite.

(14) Muscovite is generally ruby- or rum-colored if biotite is present, never green, and very rarely stained.

(15) In pegmatites containing lithia minerals (rare in the Spruce Pine district) the muscovite is usually light yellowish-green.

(16) Garnet is associated far more commonly with green "A" mica than with flat ruby or rum mica.

A relation between the composition and the color of muscovite is indicated above by numbers 6, 13, 14, 15, and possibly 16. The quantity and state of oxidation of the iron in muscovite is believed to be the chief cause of color variations, although other elements have some effect. Some crystals of ruby mica on old mine dumps have green edges where exposed to weathering, possibly because of a change in the state of the iron. Areal distribution of micas according to color in the Spruce Pine district is shown in plate 2.

*Other minerals.*—Biotite and its alteration product vermiculite are practically absent from pegmatites in alaskite, but occur in some pegmatites in the metamorphic rocks, particularly in the Bakersville-Bandana section. Small biotite flakes, parallel to one another near the walls of some pegmatites, are remnants of



partly replaced wall rock, but most of the pegmatitic biotite is very coarse. Strips or sheets of biotite, or of biotite intergrown with muscovite, are as much as 5 feet long and an inch thick. They cut across microcline, graphic granite, and less commonly plagioclase. The coarse pegmatitic biotite is said to be less amenable to fine grinding, because of its greater toughness, than the biotite schist mined near Spruce Pine.

Garnet is typically associated with plagioclase and green mica. Four garnet samples from different parts of the district, examined by Jewell Glass of the Geological Survey, were found to have refractive indices ranging from 1.795 to 1.817, ranging in composition from spessartite to almandite-spessartite. Both flat and euhedral garnets are commonly intergrown with green "A" muscovite, less commonly with flat muscovite, and almost never with biotite.

Lime-bearing minerals, which are scarce in the pegmatites, include apatite, allanite, epidote, thulite, zoisite, and calcite. Apatite and allanite are most abundant in pegmatites that contain abundant fine-grained calcic oligoclase. Epidote, which in many places, originated from the alteration of hornblendic wall rock, is one of the last-formed minerals in the pegmatites.

Beryl occurs in about a dozen mines, mostly along the southeast edge of the district. Gem beryl has been mined from two pegmatites near Spruce Pine, and common beryl is fairly abundant at the Ray mine, 2 miles southeast of Burnsville; but it is relatively scarce in the Spruce Pine district as a whole.

Columbite occurs in small quantities at the McKinney mine, 2 miles west of Little Switzerland, and probably in other pegmatites near Spruce Pine, but is more abundant in some mines in the Green Mountain section, where it could perhaps be saved as a by-product. The Randolph mine, 1½ miles southwest of Green Mountain Post Office, is said to have supplied columbite during the first World War.

Calculations of the age of uraninite in the pegmatites, based on the lead-uranium ratio, have given figures of 251 million[8] and 358-382 million[9] years. A calculation by a different method using monazite gives an age of 600 million years.[10]

[8] Holmes, Arthur, Physics of the earth—Part 4, The age of the earth: Nat. Research Council Bull. 80, pp. 342-344, 1931.

[9] Alter, C. M., and McColley, E. S., The lead-uranium-thorium ratios of various zones of a single crystal of uraninite from Spruce Pine, N. C.: Am. Min., vol. 27, no. 3, p. 213, Mar. 1942.

[10] Bliss, A. D., Analysis and age of monazite from Deer Park no. 5 mine, Spruce Pine, N. C.: Am. Min., vol. 27, no. 3, p. 215, Mar. 1942.

## EMPLACEMENT OF THE ALASKITE AND PEGMATITE

### RELATION TO REGIONAL STRUCTURE

The regional northeasterly trend of the metamorphic foliation and of fold axes is interrupted near alaskite intrusives, as shown on the geologic map of the area (pl. 1). The alaskite appears to have bulged the overlying hornblende and mica gneisses upward. Generally speaking, the alaskite bodies occur in the cores of such bulges, and the hornblende and mica gneisses in synclinal areas between them on the higher ridges such as Sparks Ridge, Otter Knobs, The Peak, Pine Mountain, and Woods Knob. The principal structural units discussed below are shown on figure 2.

Southeast of the principal alaskite masses, the metamorphic rocks dip mostly to the east and southeast at angles less than 45 degrees. To the northwest, between Spruce Pine and Bakersville, they dip more steeply southeast. Key beds are lacking, but the wide areas of steeply-dipping interlayered mica and hornblende gneisses are best explained by close or isoclinal folding rather than great thicknesses of the original formations. The axial planes of the isoclinal folds dip southeast, toward the exposed alaskite masses. These major structures are believed to be comparable, on a larger scale, to the "hair-pin" folds seen in smaller exposures. Minor structures, such as drag folds and fluting in the metamorphic rocks, pitch to the south or southwest over most of the Spruce Pine district.

The Pine Mountain syncline and other related synclines (see fig. 2) separate the Spruce Pine and Crabtree alaskite bodies. The country rocks west and south of the Spruce Pine alaskite body form the east limb of the syncline; their strike parallels the contact with the Spruce Pine alaskite, and their dip is generally to the south or southwest. The axis of this major syncline extends from near the top of Woods Knob, where the highest stratigraphic units in the Spruce Pine map area are exposed, northward through Pine Mountain. The limbs of the syncline dip gently near Woods Knob, but steepen northward, and are overturned in many places from Pine Mountain northward.

The Spruce Pine alaskite body is a heterogeneous assemblage of alaskite, migmatite, and some mica and hornblende gneisses, in which the alaskite is dominant. The smaller masses of alaskite in this body are sill-like and occur mostly in the more schistose rocks, which commonly dip to the south or southeast. Mica gneiss and hornblende gneiss that are interlayered with the migmatite in many places may be equivalent to similar rocks in the



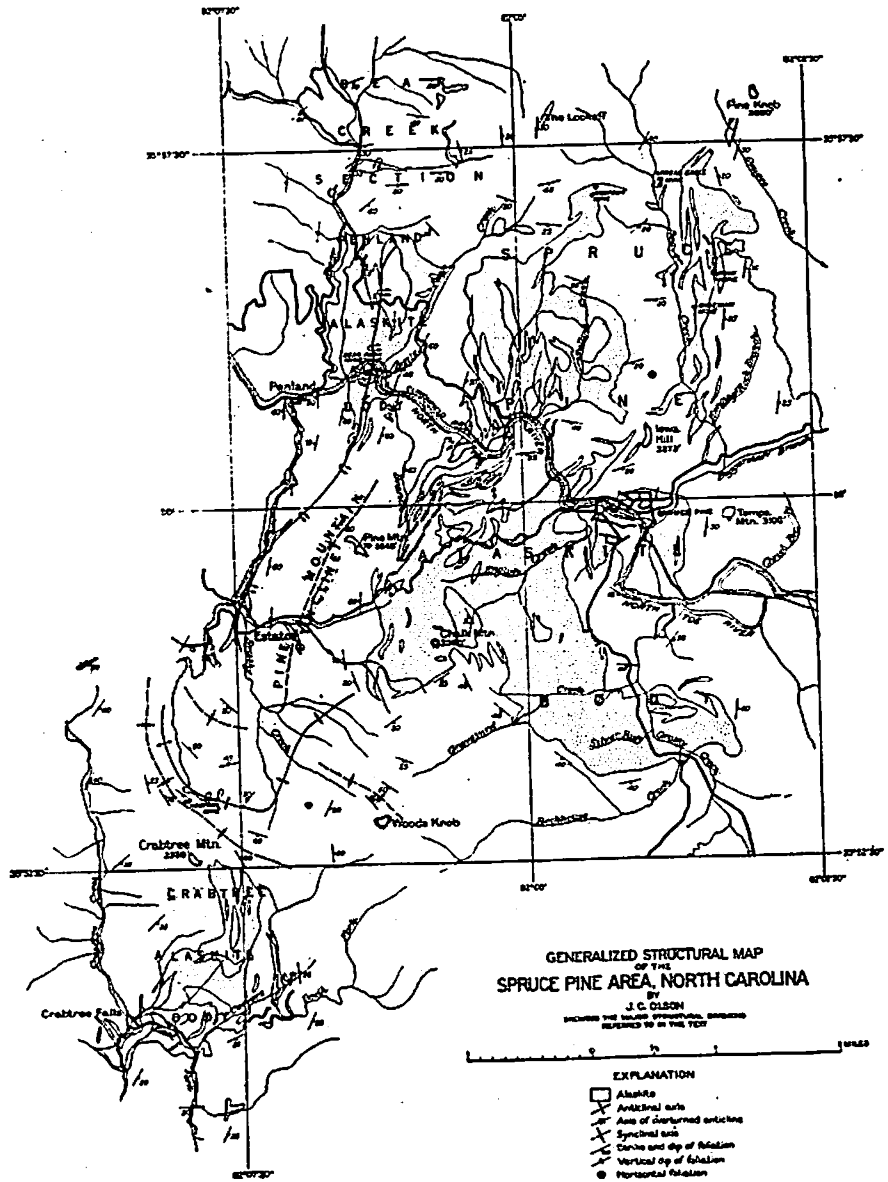



FIG. 2.—Generalized structural map of the Spruce Pine Area, North Carolina.

area between Bear Creek and The Lookoff, northwest of the Spruce Pine alaskite body. The general structure of the metamorphic rocks is obscure, however, because of the great number and irregular shapes of the inclusions in the alaskite, the inconsistency of structural attitudes, and the possibility of different degrees of overturning.

The Penland alaskite body occurs in an overturned anticline. On the east limb, the metamorphic rocks dip 40-60 degrees to the east and southeast, and on the west, or overturned limb, more steeply eastward at angles from 60 degrees to vertical. Farther west the dips range from vertical to steeply west. Hornblende gneiss overlies the south end of the alaskite body and is probably isoclinally folded. Migmatite occurs along the north and west boundaries of the alaskite, and as many inclusions in the body; only the larger inclusions can be shown on the geologic map. Smaller inclusions are well exposed in the Deer Park and Number 12 mines. These more or less tabular inclusions reflect the anticlinal structure, near the nose of which is situated the Deer Park mine (see pl. 3).

The rocks bordering the Penland alaskite body on the north, bend sharply around it and in places strike northwest. The structure in the Bear Creek section is complex, but appears to consist of several overturned folds whose axes curve to conform approximately with the northern boundary of the Penland alaskite body. Fluting and minor folds that pitch to the south or southeast are abundant in this section. Pegmatites at the Chestnut Flat mine (pl. 7) and the Emily Knob mine, as well as other pegmatites, have the same pitch as the minor structures.

The Crabtree alaskite body, like the Spruce Pine, is fringed on the south and east by gently-dipping gneisses whose strike conforms with the outline of the alaskite. The hornblende gneiss, overlying the alaskite and associated migmatite, appears to be the same lithologic unit that overlies the Penland and Spruce Pine alaskite bodies. The great sill-like pegmatites on Carvers Branch are relatively fine-grained but coarser than typical alaskite.

In the Spruce Pine area pegmatites large enough to be mined for feldspar occur in or near alaskite bodies. The average size of pegmatites diminishes away from their source. Pegmatites and alaskite tend to be more abundant in anticlinal structures where erosion has exposed lower stratigraphic units, but minable pegmatites also occur elsewhere.



Minable pegmatites are not confined to any particular part of the Penland and Crabtree alaskite bodies, except for their general occurrence near inclusions. In the larger Spruce Pine alaskite body, however, large pegmatites are uncommon along the southeast margin and in the Graveyard Creek-Silver Run area in the middle of the alaskite body. The alaskite beneath tabular inclusions commonly contains large pegmatites, and such places are favorable for prospecting.

Schistosity is the dominant structural feature controlling the location and attitudes of pegmatites in the metamorphic rock. Penetration by pegmatite-forming solutions was greater in schistose rocks than in gneisses, and much greater parallel to the schistosity than across it. A pegmatite zone in metamorphic rocks can often be traced along its strike by small lenses of pegmatite or quartz, or by altered rock, features which are useful in prospecting or mining. No structural control other than schistosity was universally effective in determining the positions of the pegmatites in the country rocks. Only a few dikes owe their attitudes to pre-pegmatite jointing and faulting.

#### RELATION TO FAULTS AND JOINTS

Large faults are uncommon in sheet mica districts. Small post-pegmatite faults occur at many places, and mica near them is commonly ruled. Large pre-pegmatite faults, if present in the Spruce Pine area, were obscured by metamorphism; no definite evidence of them was found.

Pre-pegmatite jointing may have guided the introduction of pegmatite in a very few places, for example, the two parallel cross-cutting pegmatites at the Georges Fork mine, 2 miles southeast of Burnsville. Post-pegmatite joints are more common; they strike northwest, across the regional trend of the metamorphic rocks, and are nearly vertical. Some are filled with veinlets of quartz, epidote, or zoisite, or by thin basaltic dikes.

#### POSSIBLE SOURCE OF THE ALASKITE MAGMA

The source at depth of the pegmatite and alaskite may be inferred from the following observations: (1) Over most of the Spruce Pine district, the pitch of pegmatites, where determinable, is in a direction within 30 degrees of south and generally at angles of 25-30 degrees from the horizontal. (2) Fluting and drag-folds in the metamorphic rocks commonly have this same pitch. (3) The metamorphic rocks dip gently on the south and east sides of the major alaskite bodies in the Spruce Pine area, but more steeply on the north and west sides. (4) Structures within the Penland alaskite body suggest that it pitches south. (5) Along the south margins of the principal alaskite bodies the alaskite magma penetrated the metamorphic rocks to slightly higher stratigraphic levels than in other parts. (6) The thinner sill-like sheets of alaskite commonly dip to the south or southeast. It is inferred, then, that the alaskite magma rose from a general southerly direction. As parts of the alaskite crystallized, the solutions from which the pegmatite formed were expelled upward and to the north.

Mineralogic differences among the pegmatites also conform to this interpretation of the source of the alaskite magma. They include (1) the less sodic composition of the plagioclase farther from the alaskite, and the corresponding difference in potash feldspar content of the pegmatites, which on the average is greater in pegmatites in or near alaskite, (2) the areal distribution of prevailing colors of muscovite in various pegmatites, shown in plate 2, (3) the fact that muscovite from all pegmatites observed in kyanitic wall rocks is ruby-colored and is associated with the least sodic plagioclase feldspars, and (4) the practical absence of biotite from pegmatites in alaskite, and its abundance in some that are far from it.

These mineralogic differences may be due partly to the distance of the pegmatite from its source, the alaskite. It is suggested that reaction with wall rocks probably decreased the amount of potash in the pegmatite, and that accompanying contamination of the pegmatite resulted in an increase of lime and iron. The fact that hornblendic wall rock is prevailingly biotitic near pegmatites is another evidence of such reaction.

## MICA AND FELDSPAR DEPOSITS

### MICA

#### IMPORTANCE AND USES

The modern electrical and radio industries depend heavily upon sheet mica as an insulating material. Some form of mica is used in nearly all electrical equipment, the poorer grades being used in many household appliances. Mica of highest quality is essential for radio transmitter and trimmer condensers, airplane-motor spark plugs, transformers, armatures, commutator segments and V-rings, and as bridges or spacers in radio tubes. Because of the dependence of this country on foreign sources for its supply of



such high-quality mica in the past, sheet mica and splittings are listed as strategic materials.

Splittings, films of mica about 0.001 inch thick, are bonded together with shellac or other bonding material, and baked under pressure to form a product known as built-up mica, mica-board, or micanite. Built-up mica is quantitatively by far the most important sheet mica commodity, representing a greater tonnage and a greater value than all other sheet mica products combined. Most of the splittings are made from the smaller sizes of sheet mica, averaging not more than 3 square inches. In India, the work of splitting is done generally in homes at a contract rate of pay averaging about 3 cents per pound of splittings equal to 9 or 12 cents per day, depending upon the speed of the worker and the number of hours worked.[11] The high cost of labor in the United States has in the past precluded an important domestic production of splittings.

#### PROPERTIES

The combination of certain physical properties has given mica a position unique among industrial minerals, and no artificial product has yet been found that duplicates all its valuable properties. The following are the most important properties that determine the value of sheet mica:

(1) *Perfection of cleavage.*—To be suitable for the most exacting uses, mica must split readily into perfectly flat sheets of uniform thickness throughout. The perfection and flatness of cleavage surfaces may be marred by (a) the occurrence of random fine cracks, known as haircracks, through the sheets; (b) distortion of the crystal by rock movement, resulting in curved cleavage surfaces, crushed crystals, or ruling of the mica crystal into many parallel ribbonlike strips parallel to glide cleavages; or (c) the development of "A", herringbone, or wedge structure, which originated at the time of crystallization. "A" mica is a variety that has two sets of cleavage imperfections, called reeves or ridges, that intersect at an angle near 60 degrees, forming an A. Crystals of "A" mica that are thicker at one end than at the other are called wedge mica. A variety known as herringbone mica has 3 sets of reeves, 2 of them intersecting a central spine-like set at angles of about 60 degrees. "A" mica that yields flat sheets between the reeves, called "flat A" mica, has constituted

[11] Wierum, H. F., and others, The mica industry: U. S. Tariff Commission, Rep. 130, 2 ser., pp. 11-26, 1938.

probably between 10 and 25 percent of all sheet mica from the Spruce Pine district.

(2) *Flexibility.*—Films of "cigarette mica" about 1 mil thick, for airplane spark plugs, must be rolled into a cylinder about an eighth of an inch thick without cracking. Mica that is intergrown with quartz often seems more brittle and consequently less easily split than other mica.

(3) *Intergrowths with other minerals.*—Minerals that are commonly intergrown with the muscovite include garnet, biotite, epidote, thulite, quartz, albite, apatite, and tourmaline. These intergrowths reduce the value of mica crystals by making them more difficult to split. Air or water bubbles in the cleavage planes, if few, can be removed by careful splitting, but if abundant they lower the value of the mica.

(4) *Color.*—Terms most commonly used for the color of mica in the Spruce Pine district are green, rum (light brown), ruby (also called red rum), brown or dark rum, and white (pale green or very light tint of any color). Other terms are used less commonly, and intermediate colors are numerous.

(5) *Staining* is due to substances such as iron oxide between the leaves of mica. Descriptive terms used to denote various kinds of staining are "black," "heavily-stained," "light-stained," "specked," "powder-specked," "spotted," "black-stained," "black-spotted," and "electric." Mica with infiltrated clay between the laminae in the zone of weathering is said to be clay-stained.

(6) *Power factor.*—The power factor of a substance, expressed in percent, is a measure of the loss of electrical energy in a condenser in which that substance forms the dielectric medium. It is the most important electrical property to be considered in the qualitative evaluation of sheet mica. Since excessive power loss results in the overheating and destruction of condensers, mica of low power factor, generally not greater than 0.40 per cent, is essential in their manufacture.

Power factor commonly varies in the mica throughout a single mine, or even in a single mica crystal. Most specimens that have high power factor show visual defects such as iron-oxide staining, haircracks, tiny pin-holes, or air bubbles. Mica of low power factor occurs at many places in the Spruce Pine district as shown by the results of recent tests by the National Bureau of Standards and by condenser manufacturers.[12] Manufacturers in the past have expressed a preference for ruby and rum micas, but the tests

[12] Kesler, T. L., and Olson, J. C., op. cit.



indicate that some clear green and dark brown micas also have low power factors.

High dielectric strength and a dielectric constant between 6.5 and 8.5 are properties that all muscovite possesses. They are unimportant, however, in appraising condenser sheet mica because any mica whose other properties are satisfactory always has sufficiently high dielectric strength.

## GRADING AND PRICES

Mica mined in the Spruce Pine district is generally split, trimmed, and roughly classified by the miners themselves before marketing to local buyers. The operation is known locally as "sheeting." The preliminary qualitative classification is based on the presence or absence of iron oxide inclusions in the mica which is, accordingly, classed as clear or stained. A further qualitative classification is often made by designating the mica as "no. 1," "no. 2," and "no. 3." No. 1 is clear mica of good quality, and corresponds approximately to the Indian and A. S. T. M. grades of "clear," "clear and slightly stained," "fair-stained," and some "good-stained." No. 2 is less perfect because of curved cleavage, clay-staining, minor iron oxide staining, or air bubbles, and corresponds to the Indian "stained" grades and possibly some Indian "black-stained" grades. No. 3 mica is heavily stained, and corresponds to most of the Indian "black-stained or spotted" mica.

The primary divisions of muscovite based on size are sheet, punch, and scrap. Table 3 shows the common sizes into which

TABLE 3.—PROPORTIONS AND PRICE RANGES OF SHEET MICA SIZES IN THE SPRUCE PINE DISTRICT, 1917-40

| Size | Clear | | Stained | |
|---|---|---|---|---|
| | Percent of Total Clear Sheet* | Price Range Per Pound | Percent of Total Clear Sheet* | Price Range Per Pound |
| 1½ x 2 | 34.007 | $ 0.15– .60 | 36.415 | $ 0.20–0.40 |
| 2 x 2 | 20.885 | .30– 1.00 | 30.378 | 0.35–0.60 |
| 2 x 3 | 20.495 | .45– 1.40 | 10.375 | 0.60–1.00 |
| 3 x 3 | 7.484 | .60– 2.00 | 6.872 | 0.75–1.50 |
| 3 x 4 | 4.949 | .80– 2.30 | 9.902 | 0.90–1.70 |
| 3 x 5 | 6.230 | 1.00– 2.65 | 4.018 | 1.10–2.25 |
| 4 x 6 | 3.463 | 1.75– 3.60 | 0.549 | 1.25–2.50 |
| 6 x 8 | 0.664 | 2.25– 7.00 | 0.072 | 2.00–2.75 |
| 8 x 10 | 0.225 | 3.50–11.00 | | |
| Unclassified | 1.598 | | 1.419 | |

*—Kesler, T. L., and Olson, J. C., Muscovite in the Spruce Pine district, North Carolina: U. S. Geo. Survey Bull. 936A, 1942.

domestic clear and stained sheet mica are graded, the approximate percentages of the total recorded production included in each size, and their price ranges. The range in price is due partly to fluctuating market conditions and partly to differences in quality.

Punch mica includes clear sheet mica smaller than 1½ by 2 inches but larger than a circle 1¼ inches in diameter, and stained sheet mica smaller than 2 by 2 inches but larger than a circle 1½ inches in diameter. Sizes smaller than punch are included in scrap mica.

#### SCRAP MICA

Scrap mica far exceeds sheet mica in volume produced and has exceeded it in value in most years since 1925. The 4 sources of scrap mica in the Spruce Pine district are (1) inferior by-product mica from sheet mica and feldspar mines; (2) clay-stained mica recovered from soft, weathered pegmatite, which is mined hydraulically at 4 mines and by pick-and-shovel methods at others; (3) mica recovered in the beneficiation of kaolin; (4) mica-rich parts, locally called "schist," of quartz-mica veins on Tempa Mountain. The biotite schist on Hanging Rock Mountain and Tempa Mountain has also been mined for ground mica.

Most scrap is ground by either wet or dry methods, but fine mica recovered by washing decomposed pegmatite or alaskite is sometimes sized by screening and sold without being ground. Wet-ground mica is ground in tubs by large wooden wheels rolling over wet mica, and the foreign matter is then removed by a process of settling. The wet-ground product, of better quality than dry-ground, is used principally in wall-paper, paints, as a mineral lubricant, and to some extent as filler in rubber and other plastic compounds. Dry-ground mica, pulverized by hammer-mill or attrition-mill grinding, is used mostly as a backing for rolled asphalt roofing to prevent sticking. It is also used in stucco and concrete, as Christmas tree "snow," mica axle grease, and the dusting of rubber tires. By a special process, it is possible to reduce the size of the mica particles to 2,000-mesh.

There are 7 plants for grinding muscovite and one for grinding biotite in the district. Some scrap mica is brought into the Spruce Pine district from outside sources, principally from mines in Macon, Jackson, and Haywood counties, and from South Dakota, but most of it is produced within the district. In 1940, North Carolina produced 11,595 short tons of scrap mica, valued



at $173,327, a little more than half the total United States production of 22,386 tons valued at $314,565.[13]

Prices for scrap mica range from 8 to 20 dollars per ton, averaging $12-14.00 in normal times. The price paid for scrap mica depends upon (1) freedom from impurities such as clay and quartz, and (2) depth of color; mica having very pale colors appears white when ground, and is most desirable.

### FELDSPAR

#### VARIETIES AND IMPURITIES

Commercial feldspar, except for impurities, is a mixture of microcline (potash feldspar), albite (soda feldspar), and anorthite (lime feldspar). These minerals have the following theoretical compositions:

| | $K_2O$ | $Na_2O$ | CaO | $Al_2O_3$ | $SiO_2$ |
|---|---|---|---|---|---|
| Microline | 16.9% | | | 18.4% | 64.7% |
| albite | | 11.8% | | 19.4 | 68.8 |
| anorthite | | | 20.1% | 36.6 | 43.3 |

The proportions of these three members determine the commercial classification as potash, soda, or soda-lime feldspar. Quartz is always present, together with such impurities as muscovite, biotite, garnet and kaolin. The proportions of the different minerals present in some commercial feldspars have been determined microscopically by Insley.[14] In the various samples analyzed by Insley, potash feldspar ranges from 1.9 to 95.6 percent, the plagioclase from 3.2 to 94.3 percent, the quartz from 0.8 to 26.7 percent, and the miscellaneous minerals from 0.4 to 3.4 percent.

Most commercial feldspar is the potash variety, in which $K_2O$ ranges normally from 7 to 13 percent. All commercial potash feldspar contains soda, which is either chemically combined in the potash feldspar or occurs in small streaks of albite intergrown with the microcline to form microperthite. Small separate crystals of albite or oligoclase may also be enclosed or closely associated with microcline or microperthite. If the ratio of potash to soda in the analysis is less than 2.5 to 1, or in most cases less than 3 to 1, free plagioclase crystals must be present in addition to the plagioclase in perthite, according to Knight.[15]

[13] U. S. Bur. Mines, Minerals Yearbook 1940, p. 1360.
[14] Insley, H., Microscopic analysis of feldspar: Jour. Amer. Ceramic Soc., vol. 10, no. 9, p. 651, Sept., 1927.
[15] Knight, F. P., Commercial feldspars produced in the United States: Amer. Ceramic Soc. Jour., vol. 13, no. 8, p. 548, Aug., 1930.

Batches of feldspar containing 4 percent or more soda probably always contain some blended plagioclase feldspar in addition to the perthite.

Soda-lime feldspar is less widely used than the potash variety. In the Spruce Pine district, coarse oligoclase, in crystals as much as a foot across, has been mined at the Horton Rock, Lick Ridge, Zack Young, Mossy Rock, Fannie Gouge, Gibbs, and many other mines. An aggregate analysis of all feldspar produced in the Spruce Pine district, if compared with other large feldspar districts, would probably show a higher lime content owing to the relatively abundant soda-lime feldspar, but most of the Spruce Pine product is potash feldspar.

Graphic granite, or "corduroy spar," is an intergrowth of quartz and potash feldspar containing about 25 percent free quartz. Large quantities of it have been mined in the past, but the trend in recent years toward utilization of less siliceous commercial feldspars has limited the market for graphic granite.

The total silica in commercial feldspar mixtures ranges from 65 to 74 percent. Most of it is held within the feldspar molecules, but free quartz, regarded as an impurity, constitutes 3 to 30 percent of most ground feldspar. Other impurities affecting the value of crude feldspar are garnet, muscovite, biotite, iron-oxide stains, and kaolin. Garnet is more closely associated with plagioclase than with potash feldspar, but some potash feldspar is intermixed with both plagioclase and garnet, and must be discarded.

Where garnets occur in microcline, the adjacent feldspar crystals are likely to be reddish or pink instead of the ordinary white or cream-colored variety. Pink microcline is associated also with hornblende gneiss inclusions in pegmatite at a few places, suggesting that the pink color may be due to iron. Spence,[16] however, on the basis of many analyses of Canadian feldspar, much of which is red, states that color is not a reliable index with which to gauge iron content. Iron-bearing minerals such as garnet, biotite, and muscovite, as well as iron from grinding machinery, can be removed electromagnetically.

Muscovite, if present in large crystals, is a valuable by-product of feldspar mining, but unfortunately much muscovite occurs as fine green flakes in the feldspar, rendering it valueless. The iron content of muscovite is particularly objectionable, and although traces of the mineral can be found in most ground feldspar, rock in which much mica is visible must be discarded. Biotite is objectionable both for its iron content when fresh and the staining it imparts to the pegmatite when weathered. Staining by iron or manganese oxides is most common where pegmatites are deeply weathered, fractured, or jointed.

[16] Spence, H. S., Feldspar: Canada Dept. of Mines, Mines Branch, Bull. 731, p. 10, 1932.



Kaolin is a common impurity in the Spruce Pine district, where rocks are deeply weathered. Plagioclase decomposes more readily than potash feldspar on weathering, so that the latter can be mined by pick and shovel from some weathered pegmatites.

Commercial feldspar, then, is actually a mixture of several minerals, and may be thought of as ground pegmatite. Only those parts of the pegmatite are mined that yield the most feldspar, generally the potash variety, and the least impurities. The rock thus mined is further beneficiated by cobbing and sorting, and, after grinding, by separation processes, but the finished product still contains some minerals other than feldspar.

### GRADING AND PRICES

A rough qualitative classification, based upon quartz content and impurities, divides the crude potash or soda feldspar into No. 1 or No. 2 grade. Prices vary considerably within these grades and fluctuate according to market conditions and quality. Each truckload brought to the buyers is appraised separately according to cleanness of the spar, freedom from impurities, and probable potash-soda ratio. Prices range from around $3.50 to $8.00 per ton; they were mostly between $5.50 and $6.50 at the time this survey was made.

Prices for ground feldspar also vary according to use, market conditions, and quality. Feldspar for container glass is usually priced at between 10 and 14 dollars per ton, enamel feldspar at 12 to 16 dollars, and pottery and glaze feldspar at about 16 to 21 dollars per ton.

### USES

The uses of feldspars depend largely on their chemical composition. Table 4A records an estimated average analysis of the total feldspar consumed in the United States in 1930, based on an actual average analysis of 30,000 tons. Table 4B shows the estimated distribution of the total feldspar consumed in the United States in the same year.

Most feldspar is used in the ceramic industries. Electrical porcelain contains around 35 percent feldspar; high-tension uses de-

TABLE 4.[17]—COMPOSITION (A) AND USES (B) OF COMMERCIAL FELDSPAR.

| A | | B | |
|---|---|---|---|
| $SiO_2$ | 69.2% | Whiteware | |
| $Al_2O_3$ | 17.6 | Electrical porcelain | 14.0% |
| $Fe_2O_3$ | 0.1 | General | 17 |
| CaO | 0.5 | Sanitary | 10 |
| $K_2O$ | 9.1 | Tile | 12 |
| $Na_2O$ | 3.2 | Enamel | 10 |
| Loss on ignition | 0.3 | Glass | 32 |
| | | Abrasive | 1.5 |
| | | Miscellaneous | 3.5 |

A—Estimated average analysis of the total feldspar consumed in the United States in 1930, based on actual average analysis of 30,000 tons.

B—Estimated distribution of the total feldspar consumed in the United States in 1930, based upon figures from the Feldspar Grinders Institute.

mand a product with less than 5 percent free quartz and a high potash-soda ratio.

Feldspar generally constitutes 10-35 percent of whiteware bodies. A fairly high content of free quartz is allowed, particularly in sanitary ware, and the potash-soda ratio should be greater than 2 to 1. Tile contains more feldspar, around 55 percent, than any other ceramic product, and the quality must equal that demanded for any other except high-tension electrical porcelain. Glazes in the whiteware industry contain 35 to 50 percent feldspar comparatively high in soda, the potash to soda ratio commonly being not more than 1 to 1. Feldspar makes up 20-45 percent of enamel for sheet metalware, and must have a fairly constant silica content for this purpose, whereas the proportions of alkalis are more important in whiteware manufacture.

For glass, freedom from iron is required, the maximum allowable $Fe_2O_3$ content being 0.15 percent except for green glass. Feldspar is used in glass as a source of alumina, which constitutes 15-19 percent of most commercial feldspar; at least 17 percent is desired for the glass industry. Container glass is about 10 or 15 percent feldspar. The glass industry absorbed 52.4 percent in 1940, 53.4 percent in 1939, and 54.9 percent in 1938 of the total United States feldspar sales—a big increase[18] over the previous decade. Recent expansion of nepheline syenite production in Canada and aplite in Virginia have encroached upon the market for feldspar in the glass industry. Technologic de-

[17] From Knight, F. P., Commercial feldspars produced in the United States: Amer. Ceramic Soc. Jour., vol. 13, no. 8, p. 534, Aug. 1930.
[18] U. S. Bur. Mines, Minerals yearbook, Review of 1940, p. 1317.



velopments may bring about greater consumption of these low-cost products in the ceramic industries as well.

Most feldspar used as a binder for abrasives contains 20-25 percent free quartz and less than 3 percent soda. Feldspar is also used in scouring soaps, terra cotta, roofing, concrete aggregates, non-ceramic abrasives, filler, poultry grit, and artificial teeth. All uses demand a low iron content. During the first World War some high-potash feldspar was used in Portland cement to increase the by-product potash recovery, and about the same time a few hundred tons of high-potash feldspar were shipped from North Carolina to a plant near Atlanta, Ga., for potash extraction by one of the patented processes.[19]

## MILLING AND PREPARATION

Feldspar is dry-ground according to the specifications of the consumer, the most popular sizes being 20, 100, and 200-mesh. Most glass manufacturers use the 20-mesh size. The 200-mesh size predominates in whiteware. An intermediate size around 100-mesh is ordinarily used in enamels.

Flotation is being used at the present time to separate feldspar from quartz, and magnetic separation is employed to remove iron-bearing impurities. The alaskite, quarried on Crabtree Creek and Sullins Creek, near Spruce Pine, and treated in this manner, yields an acceptable product that is relatively high in soda and lime. The quantity of alaskite available for this purpose is great, but raw material richer in potash could be more easily marketed. Perhaps run-of-mine pegmatite, selectively mined for high potash content, would respond satisfactorily to this type of treatment.

A chemical analysis is ordinarily made of each batch of ground feldspar, which then permits mixing and blending in the proper proportions to meet the great variety of specifications of the consumers.

## MINING METHODS

Most mines in the Spruce Pine district that produce either mica or feldspar also produce the other as a by-product, but the localization of these minerals into certain zones or streaks permits the classification of pegmatite mining according to the relative richness of the two minerals. The larger mines are classified on the mine map according to product (pl. 2). Small prospects for either mica or feldspar are numerous.

[19] Burgess, B. C., Feldspar, Chapter XIV of Industrial minerals and rocks: A.I.M.E., p. 267, 1937.

The size, attitude, continuity, and weathering of the pegmatite to be mined, as well as topographic and hydrologic features, determine the type of mining operation. Most feldspar mines are quarries, but rich deposits have been followed underground, for example the Chestnut Flat (pl. 7), Deer Park (pl. 3), Gusher Knob, and Adam Buchanan mines. Mica-bearing zones, thinner than those mined for feldspar, cannot be mined by large-scale open-pit methods, and are developed by tunnels, shafts, and inclines, from relatively shallow open-pit workings. Timbering to prevent caving is required in many of the mines because of deep weathering.

Many old mines were abandoned at a depth of a hundred feet or so because of lack of adequate pumping facilities. Many of them have since been reopened and operated intermittently, but mines equipped with modern mining machinery are few. The great majority of active mines are operated by 2 or 3 men each, using rather primitive methods. Large-scale methods have not been justified in most mica mines. Mining and exploration blend into one operation that must pay for itself as work progresses. The marginal economic character of many mica mines has not allowed much dead work, either in exploration or development. During the winter and spring of 1939-40, mica was being mined from about 50 mines and prospects, only 5 of these employing more than 4 men each.

In feldspar mining as well as mica mining, the margin of profit is small and except in a few deposits, large-scale operations have not been justified owing to lack of proved ground. Core-drilling has been attempted in feldspar mining to block out ore, but is not a common practice. The larger-scale feldspar operations, of which there are about a half-dozen in the district, employ about 12 to 20 men each, and are commonly operated by feldspar-grinding companies. The smaller-scale feldspar mines are operated intermittently by groups of 2, 3 or 4 independent miners or farmers. It is estimated that, in an average year, slightly less than half the total feldspar produced in the district is obtained from about half a dozen large-scale mines, the production of each amounting to at least several thousand tons annually. The remainder is obtained from dozens of smaller operations, mostly producing less than a thousand tons each.

## ECONOMIC FACTORS

The success or failure of a mine operated solely for mica will be determined by the following factors:



(1) *Proportion of mica to total rock mined.* The average mica content of the rock mined ranges from 3 to 10 percent, probably 6 or 7 percent for the average mica mine, although it may be much higher in rich "pockets." This figure includes scrap mica as well as small books and flakes that cannot be recovered economically by cobbing. The block mica recovered (including shop scrap derived from the process of sheeting) probably constitutes 1 to 2.5 percent of the rock broken in mica mining; averages about 1.6 percent.

(2) *Proportions of sheet, punch, and scrap in the total mica mined.* Although scrap mica has been the sole product of a few mines in easily-mined, weathered pegmatite, punch and sheet mica are almost always necessary to raise the value of the output to a level that will permit mining. The proportions of sheet, punch, and scrap vary considerably in the mica produced from different parts of the same mine. Scrap constitutes 65 to 95 percent of the output of most mica mines, averages 75 or 80 percent and one-fourth to one-fifth of the remainder is commonly sheet. In other words, the total mica mined in a typical example might average about 80 percent scrap, 15 or 16 percent punch, and 4 or 5 percent sheet. From these figures it is apparent that sheet mica (1½ x 2 inches and larger) constitutes only a very small part, perhaps 0.10 to 0.25 percent, of the total rock mined.

(3) *Proportion of large sizes in the sheet mica.* A breakdown of 474,625 pounds of relatively clear sheet mica from many mines in the Spruce Pine district has shown the following distribution of sheet-mica sizes:[20] 1½ x 2 inches, 34.0 percent; 2 x 2, 20.9 percent; 2 x 3, 20.5 percent, 3 x 3, 7.5 percent; 3 x 4, 4.9 percent; 3 x 5, 6.2 percent, 4 x 6, 3.5 percent; 6 x 8, 0.7 percent; and 8 x 10, 0.2 percent. Many mines yield nothing larger than 3 x 5 inches; others are noted for the large sizes they produce. Owing to the high prices paid for large sizes, a small amount of 6 x 8 or 8 x 10 greatly increases the value of the block mica.

(4) *Quality.* Prices paid for domestic clear sheet mica in the past have been 1½ to 2 times as high as those for stained sheet, and the trend is toward an even higher ratio owing to the present need for high-quality mica. Mica of such high quality occurs in many mines in the Spruce Pine district, as shown by the electrical tests cited above, but unfortunately there is no record of the uses to which much of the clear sheet mica has been put in

[20] Kesler, T. L., and Olson, J. C., Muscovite in the Spruce Pine district, North Carolina: U. S. Geol. Survey, Bull. 936-A, 1942.

the past. At the present time, the value of the output of a mine might be considerably increased by separating with greater care the clear, flat, easily-splitting mica from that of inferior quality. The best qualities, corresponding to the Indian "fair-stained or better" grades, probably constitute less than 10 percent of the total sheet mica produced by even the best mica mines.

(5) *General market conditions.* Although mica consumption over a period of many years has continually risen, corresponding to the growth of the electrical industry, the market for mica from one year to the next fluctuates considerably according to general business activity. Such fluctuations add to the uncertainty of mining, and tend to discourage large-scale development.

(6) *Other factors,* such as accessibility, availability of supplies and power, and type of mining operation also affect the development of a mica deposit. Underground mining is more expensive than quarrying. An estimate of the relative cost of the two types of operation has been made for mining in Tanganyika Territory,[21] where the amount of mica that must be recovered for a quarry operation to be successful was estimated at 60 percent of that necessary for a successful underground mine.

Production costs have been published[22] for the Fannie Gouge and Barger mines in the Spruce Pine district. Rock moved in a two-year period at the Fannie Gouge was calculated to be worth $3.93 per ton for its sheet mica, scrap mica, and by-product feldspar. The cost of mining and sheeting the mica, per ton of rock, was $2.75, distributed as follows: mining labor, $1.692 (62 percent); supplies and fuel, $0.654 (24 percent); sheeting costs, $0.405 (14 percent). Similar figures for the Barger mine show the value of rock moved to be $2.55 per ton. Cost of mining and sheeting at the Barger, per ton of rock mined, was $2.23, distributed as follows: mining labor, $1.439 (64.5 percent); supplies and fuel, $0.369 (16.5 percent); and sheeting costs, $0.424 (19 percent). Sheeting costs per pound of block mica recovered were $0.0106 at the Fannie Gouge and $0.0090 at the Barger, an average of about a cent a pound.

Feldspar is a low-priced product that does not allow high mining or transportation costs. Accessibility and haulage facilities are more important than in mica mining. Other factors that affect successful feldspar mining are the following:

[21] Williams and Skerl, Mica in Tanganyika Territory: Tanganyika Territory, Dept. of Lands and Mines, Geol. Div., Bull. 14, p. 42, 1940.

[22] Urban, H. M., Mica-mining methods, costs, and recoveries at the No. 10 and No. 21 mines of the Spruce Pine Mica Co., Spruce Pine, N. C.: U. S. Bur. Mines, Inf. Circ. 6610, 1932.



(1) Proportion of feldspar recovered from the rock mined, which at most large mines averages 20 to 30 percent. Assuming a value of $6.00 per ton for the feldspar, minable pegmatite containing 30 percent recoverable feldspar would be worth $1.80 per ton; containing 20 percent, $1.20 per ton. The value of the pegmatite per ton is often increased by marketing by-product minerals.

(2) The amount of cobbing necessary. Cobbing, to separate the 20 to 30 percent recoverable feldspar from the remaining mixture of finer-grained feldspar, quartz, and other pegmatite minerals, is one of the costliest operations in the handling of feldspar. The extent to which it is practical is limited by the low unit value of the feldspar.

(3) Quality of the feldspar.

(4) Market conditions. Feldspar consumption parallels the demand for pottery and container-glass, fluctuating according to general business activity. Other influences on the feldspar market are freight rates and the replacement of pegmatite feldspar for some uses by aplite from Virginia and nepheline syenite from Canada. Greater utilization of lower-grade raw material through beneficiation methods would adversely affect the mining of pegmatite.

(5) Type of mining operation, depending partly on the size of the feldspar body. All large feldspar mines in the Spruce Pine district are in pegmatite bodies at least 25 feet thick, and the largest are in pegmatites 50 to more than 150 feet thick.

(6) Cost of labor. Labor averages about 50 percent of the cost of producing crude feldspar. Generally speaking, it takes two man-hours to handle a ton of rock in feldspar mining. Therefore, if the feldspar recovery is 20 percent of the rock broken, and the wage rate 30 cents per hour, the average cost of crude should be $6.00 per ton.[23]

Pegmatite mines whose operation depends upon the aggregate production of two or more minerals combine the economic factors of both feldspar and mica mining, and possibly those of other commercial products that may be present. The value of the rock will be determined by the abundance, distribution, and quality of each mineral. A pegmatite body might not be minable if the value of the rock for its mica alone is only $1.25 per ton, but mining might be feasible if, in addition, recoverable feldspar adds

[23] Burgess, B. C. Feldspar, Chapter XIV of Industrial Minerals and Rocks: A.I.M.E., p. 277, 1937.

$1.00 or more per ton to the value of rock mined. One-half percent beryl, if recoverable, would add $0.175 per ton to the value of the rock, if priced at $35.00 per ton, or $0.40 if the price were $80.00. By-product quartz, sold for $1.50 to $5.00 per ton, helps to defray mining costs at some feldspar mines.

### FUTURE POSSIBILITIES

The erratic distribution of mica and feldspar does not warrant the estimation of reserves from the appearance of single working faces or outcrops. Mining and prospecting merge into one uncertain venture, and the specific value of a deposit is determined only by results. Mining is begun only on promising outcrops, and is discontinued as soon as it becomes unprofitable. Core-drilling has been used in feldspar mining to determine the approximate grade of rock to be mined, but the low unit value of feldspar does not permit extensive prospecting. Drilling might be done also, to locate pegmatite, in a few places where it is thought that thin pegmatite, if present, might contain commercial mica, but it would not necessarily disclose the size or abundance of mica blocks. Prices sufficiently high to allow the moving of some barren rock would encourage full-time operation of a mine in place of the present practice of abandonment as soon as a rich "pocket" is depleted.

In most years, large-scale mines yielding 3,000 tons or more of feldspar have contributed slightly less than half the total for the district. These mines are in thick pegmatite bodies in which masses of coarse feldspar are segregated from the other constituents. The number of such large pegmatites is relatively small, but mines in them are long-lived, some having been operated at least 20 years. The small-scale mines, which annually supply slightly more than half the total for the district, are very numerous. It is estimated that the many small deposits, some of which may become large producers, combined with the large-scale mines, should be able to supply feldspar for many years at about the same rate as in the past, or to increase it by increasing the number of operating mines. Concentration of feldspar from alaskite by the current flotation process yields a product that has relatively high soda-potash ratio and run-of-mine potash-rich pegmatite could presumably be given similar treatment.

It has been estimated that the approximate average annual production of 45,253 pounds of clear sheet mica over the 17-year period 1924-40 could be doubled or trebled by (1) promoting



simultaneous operation of many mines to maintain average total production in spite of fluctuations in the output of individual mines, and (2) concentrating on mines that produce the most desirable mica.[24] The resulting figure of 90,000 to 135,000 pounds includes only domestic clear sheet mica of good quality, and by combining punch mica would be between 4 and 5 times this amount. There is little market for heavily stained mica at the present time, but the great demand for clear, flat, free-splitting mica of strategic grades should encourage the selective mining of this type of mica.

## SELECTED MINES

### THE DEER PARK MINES

The Deer Park mines, in a horseshoe bend on the North Toe River near Penland, have produced large quantities of both feldspar and sheet mica. The first feldspar shipped from the Spruce Pine district was mined from the Deer Park mine by the Carolina Mineral Company in 1911. Prior to that, mining near the surface had been carried on for many years for sheet mica. The shallow mica workings have been greatly deepened since feldspar mining began, particularly from 1922 to 1939 when the mine was operated almost continuously by Tennessee Mineral Corporation and by United Feldspar and Minerals Corporation. After being abandoned in 1939, the mine was reopened in May, 1942, with sheet mica as the principal product sought.

The Deer Park feldspar-mica mines are on several pegmatites located near the crest of an anticlinal fold in a mass of alaskite almost one-half mile wide. The crest of this fold, reflected in the attitude of inclusions in the alaskite and of the surrounding country rocks, is probably near the No. 5 and No. 3 mines (see plate 3). The parallel, southward dipping, tabular inclusions are composed of mica gneiss and schist, migmatite, and hornblende gneiss.

The pegmatites on the property are of two types, according to the character of their contacts with alaskite: (1) pegmatites that are commonly thin, with sharp walls, apparently formed in fractures in the alaskite, and (2) pegmatites that may be thick or thin, having irregular, gradational contacts with the enclosing alaskite.

The thick productive pegmatites are localized in the upper part of the alaskite mass, directly beneath the inclusions. These peg-

[24] Kesler, T. L., and Olson, J. C., Op. cit.

matites have approximately the same strikes, dips, and pitches, and are spaced at nearly equal intervals across the Deer Park property. They strike northeast, dip steeply southeast, and pitch southwest at angles of 30 to 40 degrees; they are lenticular in cross-section and elongate in the direction of pitch. These steeply-dipping pegmatite bodies intersect the tabular inclusions at high angles, and at the No. 5, No. 3, and No. 2 mines this intersection is marked by the trough of a sharp synclinal fold in the overlying inclusion. Two factors that perhaps bear on the large size of the Deer Park pegmatites are (1) their location near the crest of an anticlinal fold and (2) their location directly beneath the tabular inclusions.

The largest pegmatite on the Deer Park property has been mined at the No. 5 mine. It has a maximum exposed thickness of 120 feet and has been mined down the pitch for more than 600 feet. The No. 5 pegmatite strikes N50°E, dips about 65° to the southeast, and pitches about 35° to the southwest (see plates 3 A and 4). An offshoot 10 feet thick from the main pegmatite mass extends westward into the alaskite footwall and is exposed in the footwall stope. The walls are alaskite, and well-defined shear contacts between the two rock types contrast with the gradational contacts found elsewhere in the mine, indicating that the structure of this offshoot was controlled by a gently-curving fracture in the alaskite footwall.

Inclusions of mica schist, migmatite, and hornblende gneiss have been encountered in several parts of the mine. Many of them strike approximately parallel to the No. 5 pegmatite, but commonly dip at lower angles to the southeast. Other inclusions have random orientations. An inclusion of hornblende gneiss about halfway down the incline has been partly altered to biotite gneiss near its borders. Microcline near this inclusion is pink in contrast to the cream or light-gray color found elsewhere in the mine.

The central part of the No. 5 pegmatite is composed of very coarse-grained microcline-perthite. Pillars left in the mine indicate that this zone was nearly pure potash feldspar, although small amounts of plagioclase, milky to dark-gray quartz, and occasional books of muscovite (usually green wedge "A") are present. The walls of the coarse-grained potash feldspar zone are irregular and poorly-defined except in the footwall stope. The zone grades outward into the medium-grained zone of plagioclase-and-microcline pegmatite that commonly surrounds the potash feldspar zone. The abundance of plagioclase increases toward the alaskite walls, and the grain size correspondingly decreases.



Most of the flat, greenish-rum mica obtained appears to have come from four widely-separated sections of the mine, although three of these apparently are on one discontinuous mica streak. The mica occurs in the central potash feldspar zone, relatively near the footwall of the pegmatite, and is associated with gray quartz commonly only a few feet or less thick. West of the 2330-foot level, flat mica is also reported to have been very abundant and to have occurred mostly on the hanging-wall side of the largest quartz mass found, most of which has been removed. Good mica also has been found at the bottom of the mine, particularly in the South Heading, where lens-shaped alaskite inclusions were observed near the mica-rich zone. These inclusions are as much as 15 feet long and 5 feet wide and have their long axes parallel to the strike of the mica streak.

The No. 2 pegmatite has been mined from an open cut 270 feet long and by underground workings which pitch southwestward. The pegmatite is probably as much as 30 or 40 feet thick, but thins to only a few feet at the east end of the workings. The curve in strike and the steepening of dip westward in this pegmatite is similar to the one in the footwall stope of the No. 5 mine. This curve in strike is an uncommon feature of pegmatites in alaskite. The floor of the No. 2 cut is partly filled with waste rock, and mineralogic zones are not readily defined. Sterrett[23] reports that feldspar occurred in a rich streak 10 to 25 feet thick, but this streak is not exposed at the present time. Most of the pegmatite exposed is composed of plagioclase and microcline, the latter being more abundant in the central portion of the dike. A central gray quartz mass, which is apparently fairly continuous, is exposed in the rock stull near the middle of the open cut. The contacts between pegmatite and alaskite are gradational.

The No. 3 pegmatite contains an unusually large amount of quartz. The alaskite mass in which it is situated overlies that in which the other Deer Park pegmatites occur and is separated from it by a tabular inclusion of country rock. At the No. 3, a quartzose pegmatite 15 feet thick was followed nearly due south down its pitch, directly beneath the trough of a synclinal fold in the overlying schist. The flexure was gentle at the surface, but at the bottom of the stope 150 feet deep the limbs of the fold formed an angle of 90 degrees with each other. High quartz

[23] Sterrett, D. B., Mica deposits of the United States. U. S. Geo. Survey, Bull. 740, p. 253.

content is often a favorable indication in feldspar or mica mining, but in this mine the disproportionate amount of quartz caused abandonment of the No. 3 mine.

The No. 4 mine is in the upper part of the same alaskite mass as the No. 5, and has a parallel pitch. The inclined stope is about 150 feet long, but most of it was flooded at the time of examination.

A pegmatite 8 to 10 feet thick has been mined at the No. 1 mine. It strikes N40°E and dips 60-70°SE, cutting across the faint foliation of the alaskite, which strikes N80°E and dips 40°S. Many other small workings, both for mica and for feldspar, dot the hillside south of the river.

### SINKHOLE

The general geology of the Bandana area, in which the Sinkhole mine is located, is shown in Plate 1B. Most of the area is underlain by interlayered mica and hornblende gneisses that trend northeast. Other rock types in the area are (1) mica schist containing many pods and stringers of pegmatitic feldspar and quartz, resembling the migmatite of the Spruce Pine map area, (2) kyanitic mica schist, (3) dunite, in a mass 1300 feet long and 500 feet wide on Mine Creek, (4) soapstone and talc-chlorite schist, and (5) dolomitic marble, occurring in two layers 70 feet and 8 feet thick, separated by a mica gneiss band 10 feet thick and cut by pegmatite. Actinolite has been formed at the contact of pegmatite with the dolomitic marble.

The gneisses and schists are sharply folded, and axial planes of the folds dip to the southeast. All varieties of the country rocks are cut by many pegmatites, but the most valuable pegmatites occur in kyanitic gneisses and schists. These include the Randall, Flukens Hill, Waterhole, Sinkhole, and Abernathy mines, and the Chestnut branch mine just west of the North Toe River. The mica in all these mines is the ruby variety. Many of the pegmatites in other rock types in the Bandana area have been prospected, but have not been so productive. Of the mines in the belt of kyanitic gneisses and schists, the best-known is the Sinkhole, near Bandana, the oldest mica mine in North Carolina.

There are at least 31 old shafts at the Sinkhole mine, a plan of which is shown in Plate 5. The group trends N. 50° E. for 1100 feet, and there is said to be a total of 2000 to 3000 feet of drifts and stopes. Small prospects are situated along the strike northeast of the mine. A series of caved shafts, called the Banner Mine, lies 300 feet southeast of the Sinkhole; small openings on the hill west of the area shown on Plate 5, are known as the Oven-lifter, the "A", and the George mines. The following information concerning the Sinkhole was obtained largely from Will Silvers, part owner, from the scanty outcrops in the vicinity of the mine, and from examination of two shafts being sunk in May 1941.



The complex pegmatite, or zone of closely connected pegmatites, is enclosed conformably in kyanitic mica schist that strikes N. 50° E. and dips 45-60° SE. Workings at the extreme northeast end of the mine encountered a pegmatite 9 feet thick. Near the middle of the series of workings, for a distance of 275 feet northeast of the Mack Young shaft (pl. 5), 3 pegmatites separated by mica gneiss have been mined. Each is 4 to 8 feet thick, and each yielded mica; the total width of pegmatite and intervening country rock in this interval is 40 to 50 feet. Southwest of the Mack Young shaft, a pegmatite 8 to 10 feet thick was mined from the Rorison and Abernathy shafts; at depths of 80 feet it is reported to be rich in mica at each contact. The "Mud-cut tunnel" extends from a point just below the road at the southwest end of the mine for 900 feet N. 50° E., and intersects the bases of other shafts for drainage. Adits were also driven from the northwest side of the ridge to intersect the pegmatites. The approximate position of the Backus Young pegmatite, which is a branch of the main pegmatite zone, is shown on the map. Its thickness was 4 feet at the surface, and about 8 feet at depth.

At the end of May 1941, two new shafts were being sunk southwest of the original Clingman shaft. One of these is vertical for 40 feet to the pegmatite, with a 60-foot incline, down the dip, from its base. At the bottom, the pegmatite ranges in thickness from 6 to 12 feet, strikes N. 40° E., and dips 65° SE. It is coarse-grained, containing much microcline. Blocks of mica are present, though not abundant, and are not confined to any one part of the pegmatite. At a depth of 60 feet, a drift had been driven 102 feet northeast to older workings, where an air shaft was raised to the surface. At 85 feet from the surface, another drift had been driven 75 feet northeast, where the pegmatite pinched out locally. The other new shaft, actually a steep incline, had been sunk about 75 feet down the dip of a pegmatite having the same general thickness, attitude, and mineralogic character. The Sinkhole mica is ruby, and the mine is reported to have been a large producer of the highest grade of flat stove mica many years ago.

### MEADOW

The Meadow mine, 1 mile north of Plumtree, is one of the largest mica mines in the United States, and the largest source of stained mica. Mining began about 1875,[26] but stopes made prior to 1929 are largely inaccessible, and underlie the south portion of the mine as developed since that date (see pl. 6). All mining has been underground.

The pegmatite in the accessible part of the mine ranges from 1 to 40 feet in thickness, and is generally conformable with biotite-garnet gneiss that strikes N. 15° W. and dips northeast at angles from nearly flat to vertical. Sterrett[27] describes a local arched structure of the pegmatite exposed in the lower, now inaccessible workings at the south end of the mine. The pegmatite examined by Sterrett, and that developed since 1929, were connected by an incline, now filled by waste, about 100 feet west of the portal of the lower tunnel (see pl. 6). The overall length of workings is about 900 feet.

Plagioclase is the dominant feldspar in the pegmatite, and some of the masses are as much as 10 inches across, but microcline also occurs. Some of the plagioclase is glassy in appearance, particularly that developed in inclusions or wall rocks. The mica is of rum color, about 80 percent heavily stained, and is most abundant in quartz and plagioclase within 3 feet of the hanging wall. Parts of the pegmatite were removed from wall to wall, but in most places the footwall is not exposed. Most of the small production of clear mica was obtained near the middle of the pegmatite, farthest from the walls. Garnet, thulite, epidote, apatite, allanite, and calcite are minor accessory minerals, and biotite is rare. No graphic granite was observed.

Vertical post-pegmatite faults of small displacement cut the pegmatite at several places, and mica near them is ruled. Inclusions of biotite gneiss in the pegmatite have been partly replaced by pegmatite quartz and feldspar, and their boundaries are gradational and indistinct.

### HOOTOWL

The Hootowl mine, ½ mile north of Crabtree Mountain, has supplied large quantities of both feldspar and green-stained mica, most of which is flat. The large irregular pegmatite body (fig. 3) is exposed in an open cut from which stopes have been driven

[26] Sterrett, D. B., op. cit., p. 177.
[27] Sterrett, D. B., op. cit., p. 178.



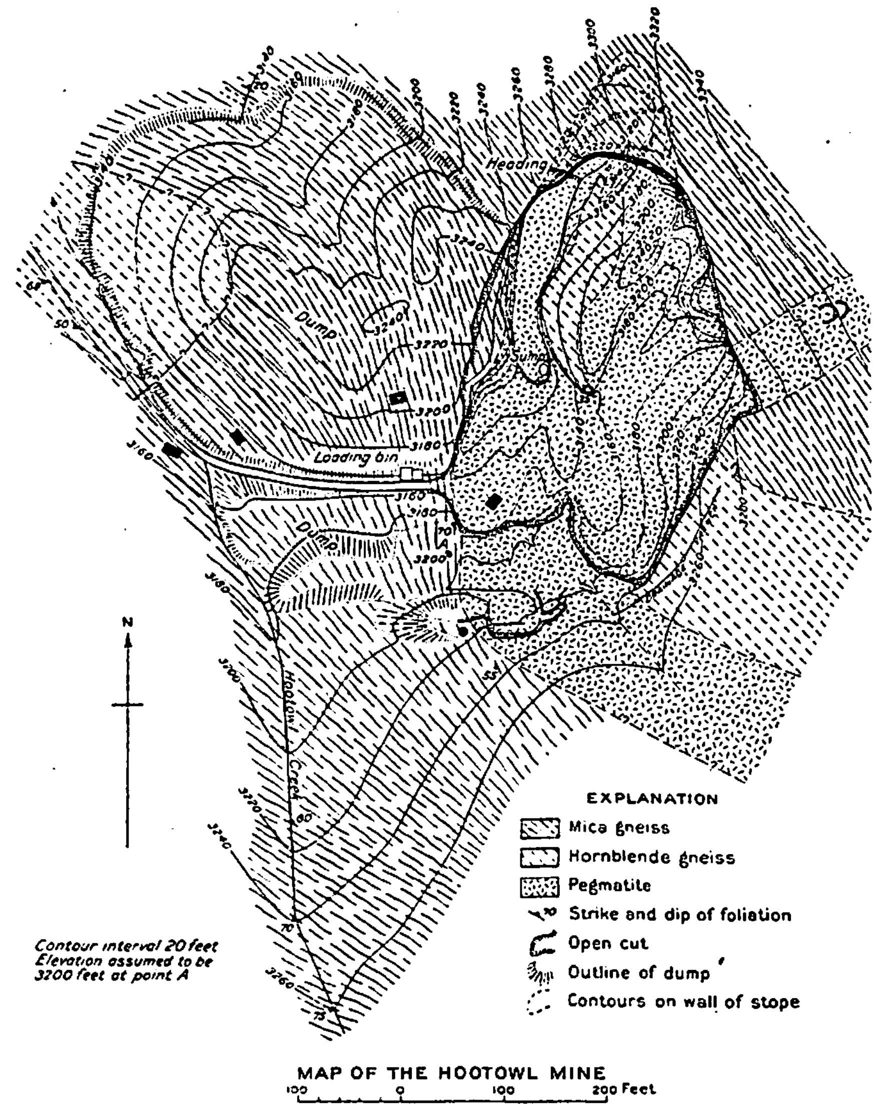



FIG. 3—Map of Hootowl Mine, Mitchell County, N. C.

northward to a total length of 500 feet, a width of 250 feet, and a depth of about 150 feet. The open cut is located in the thickest part of the pegmatite.

The wall rock was distorted by the intrusion of the pegmatite, and a variety of attitudes may be seen in the walls of the cut. Areal geologic mapping in the vicinity of the mine (see pl. 1) indicates that the hornblende gneiss and overlying mica gneiss have been folded, forming an anticline whose axis trends about N. 60° W. The Hootowl pegmatite occurs at the crest of this anticline. It strikes slightly east of north and probably dips westward, cutting across the foliation of the metamorphic rocks. A large inclusion of hornblende gneiss exposed in the middle of the open cut strikes east of north and dips 35° NW., roughly parallel to the pegmatite as a whole but at an angle with the wall-rock foliation. The mica-bearing zones in the pegmatite are said to strike parallel to the length of the open cut and to dip westward.

Two smaller pegmatites extend eastward from the main body, and several pegmatite outcrops east of the south end of the open cut indicate that a branch of the Hootowl pegmatite may connect with the pegmatite at the Gopher mine, 600 feet to the east on the crest of the ridge. Pegmatite float is abundant on the hillside for several hundred feet northeast of the open cut, indicating an extension of the main pegmatite in that direction.

The hornblendic wall rocks and inclusion contain much fine-grained epidote, presumably formed as a result of alteration by the pegmatitic solutions. Biotite is a prominent constituent of the inclusion, and a selvage of biotite schist occurs along its edges. Microcline is the dominant feldspar in the pegmatite, occurring in large crystals and masses where mined, and graphic granite is abundant. Large mica crystals are associated generally with quartz and plagioclase, rather than microcline, although some occur near microcline. Most of the mica occurs near the hornblende gneiss inclusion, in zones that dip about 75° W. Several parallel quartz veins 2 or 3 inches thick, of late origin, cut the pegmatite.

### CHESTNUT FLAT

The Chestnut Flat mine, ¾ mile east of Bear Creek Post Office, has been one of the largest feldspar mines in the United States. It has been operated about 24 years, and a production of 1,800 tons of feldspar per month is said to have been attained at one time.



A map and cross-section of the Chestnut Flat pegmatite are shown in Plate 7. The body is tongue-shaped, is 25-80 feet thick, pitches S22°E, and has been mined from an inclined stope 180 feet wide and 750 feet long. For most of this distance, a mass of quartz 1 to 20 feet thick occurred near the center of the pegmatite. The edges of this quartz mass are gray, the center white. Some of the purest quartz was used for the mirror of the 200-inch telescope for the Mt. Palomar observatory in California. The quartz body lensed out at a distance of 675 feet down the incline, and below this point minable feldspar was less abundant.

Most of the minable feldspar occurred adjacent to the quartz body, but crystals of microcline at least 6 feet long also were enclosed in it. Zones a few feet thick near the walls that contained high proportions of plagioclase, quartz, and fine mica were not mined for most of the length of the incline, but drill holes penetrated to the wall rock at several places. Crystals of wedge mica several feet long occur adjacent to the quartz body, but are entirely of scrap grade owing to the absence of flat cleavage surfaces. Mica beneath the quartz body is said to be more stained than that above it.

The stope is divided into 3 sections 30-72 feet high, which are separated by 2 rows of elongate pillars 10-20 feet thick; the sections extend 750, 680, and 650 feet respectively down the dip of the pegmatite. The lenticular quartz mass is thickest in the middle section. Forking of the pegmatite into several thin branches limited the mining westward from the west wall of the incline. The pegmatite thins rapidly eastward from the stope, as indicated by the steep dip of the footwall at the base of the east side of the stope. Outcrops along the strike of the pegmatite in both directions from the mouth of the stope indicate a considerable lateral extent of the body beyond the thickest mass, but it is doubtful whether great feldspar masses such as those near the main quartz body will be found in the extensions.

Pegmatites parallel to the Chestnut Flat occur both above and below it. A thick pegmatite above it (see Plate 7) has been mined at several points, and two of the cuts were being reopened in 1941. At the time of examination, 6 men were said to be mining about 10 tons per day of No. 2 feldspar from these openings. This pegmatite is probably continuous with that exposed at the "Fall Rock," a ledge about 50 feet thick of relatively fine-grained pegmatite consisting of quartz, microcline, plagioclase, and small flakes of muscovite. The mineral grains in the "Fall

Rock" are mostly less than an inch across, although some microcline crystals are as much as 3 inches across. A streakiness of the rock at some places is due to oriented mica flakes and small lenticular masses of feldspar. A layer of coarse-grained pegmatite perhaps 3 to 5 feet thick forms the top of the ledge. Wherever prospected, this coarse-grained zone is found to be thin, and is underlain by fine-grained material that makes up the greater part of the pegmatite.

The several parallel pegmatites on the Chestnut Flat property occur at the crest of a gentle anticlinal fold whose axis pitches S22°E at an angle of about 15 degrees, the orientation of the Chestnut Flat incline. Abundant drag folds and fluting in the country rocks nearby pitch approximately parallel to the main incline. Both the anticline and the smaller related folds were probably effective in determining the shape and position of the pegmatites.

## PINE MOUNTAIN

The Pine Mountain mine, 1 mile north of Minpro, is an example of the localization of pegmatites near the margin of a large alaskite body. As shown in the sketch map ( Fig. 4), all mine openings and prospects are near the west edge of an alaskite body hundreds of feet across. West of the alaskite, mica gneiss, mica schist, and migmatite probably extend for at least 1,000 feet, although outcrops are scarce. Many pegmatites occur in the alaskite. The inclusions are most numerous near the contact; the massive alaskite to the east contains few inclusions. Mining and prospecting have followed the contact closely, particularly in the vicinity of country rock inclusions in the alaskite.

The largest open cut, near the northeast end of the series is 200 feet long, as much as 100 feet wide, and 80 feet deep. A coarse-grained pegmatite that strikes N10°E, dips 75°E, and pitches southward was mined in this open cut, principally for feldspar. The by-product mica is of green "A" type, and at least 80 percent of it is stained. Much of the quartz is smoky. Garnet, allanite, and gahnite are among the accessory minerals, and autunite and torbernite occur with the smoky quartz.

## HAWK

The Hawk mine is 1 mile northwest of the village of Hawk. All the workings are underground, and their aggregate length is about 800 feet. The mine was opened in 1870, and was worked

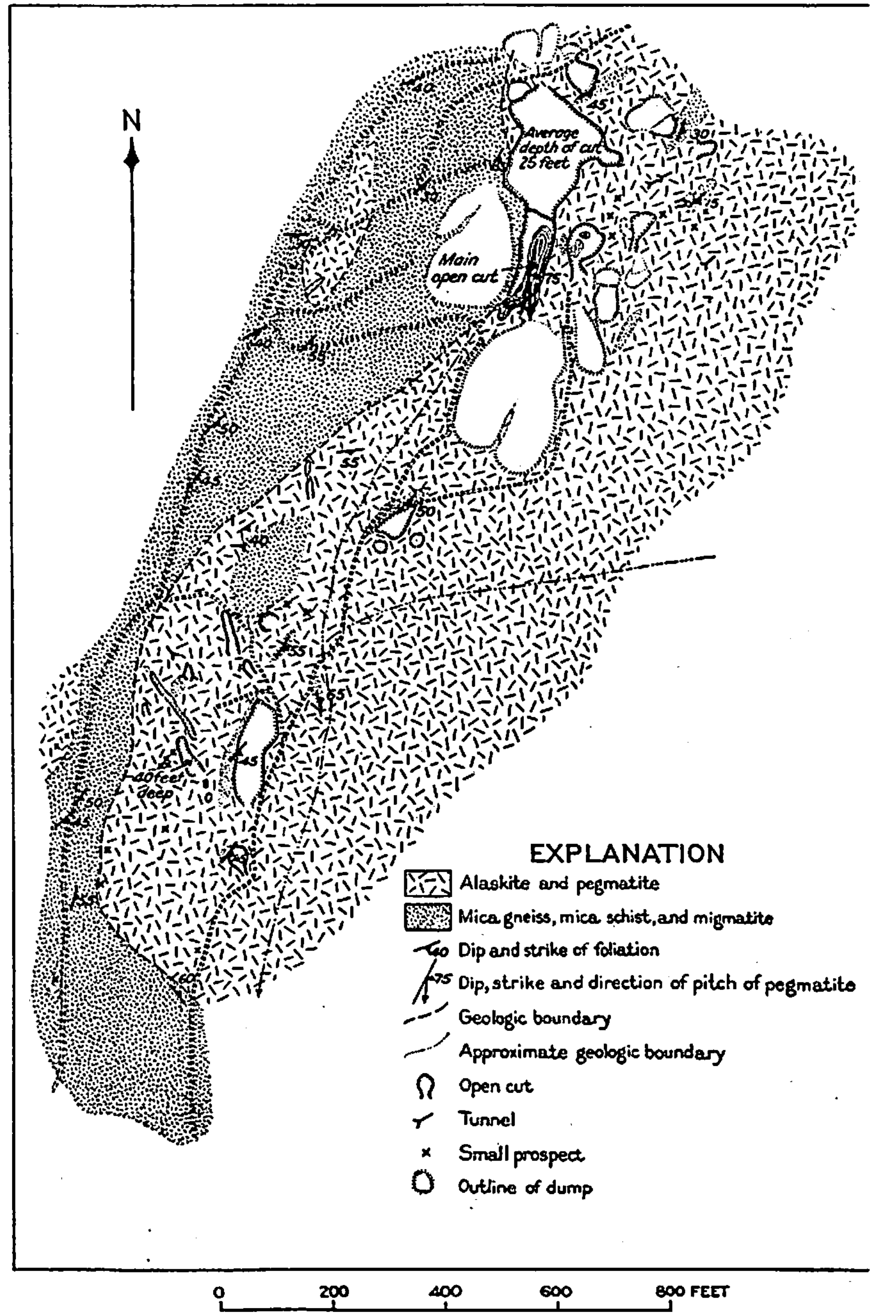



FIG. 4.—Geologic sketch map of the Pine Mountain Mine, Mitchell County.

intermittently to a depth of about 250 feet until 1893.[28] The first work of consequence since that time was undertaken in 1937 at the south end of the old workings. Mining is still in progress under the supervision of J. R. McKinney. The present work follows a narrow, complex zone of imbricate pegmatite lenses, and bodies of more irregular form, enclosed conformably in interlayered hornblende and biotite gneisses that have an average strike of N. 20°E., and an average dip of 70°SE. (pl. 8). Hornblende gneiss is the dominant country rock in the vicinity of the mine, but biotite schist is more abundant near the pegmatite zone. A thin alteration zone of biotite schist occurs at many places adjacent to pegmatite contacts.

The larger bodies of pegmatite have a maximum thickness of 10 feet, and average about 6 feet, but some parts of the pegmatite zone, which are left as pillars, contain only a few pods of pegmatite. The banding of the wall rocks bends around the pegmatite lenses, and variations in dip are referred to by the miners as "rolls." In an extreme instance, at the southwest end of the second level, the dip of the hanging wall changes from 40 degrees east to vertical in a vertical distance of 6 feet.

Occasional crystals of plagioclase in the southern part of the mine are as much as one foot across. Most of the pegmatite, however, is medium- to fine-grained and consists of oligoclase, quartz, and muscovite, but minor amounts of garnet, apatite, epidote, thulite, allanite, pyrite, and black tourmaline are present. Veinlets of green epidote cut plagioclase, and finely disseminated epidote, thulite and muscovite have been developed in the adjacent feldspar whose color is thus changed to light olive or pale pink. Some of the oligoclase crystals adjacent to biotite schist walls and inclusions are transparent and colorless, and others are intermediate between the usual milky-white and the transparent varieties. The composition of two milky-white crystals was determined as Ab 83, and of one transparent crystal as Ab 80. Isolated, undistorted crystals of oligoclase, both the milky-white and colorless varieties, have formed in the wall rocks near contacts. Some are oval, others subhedral, and the maximum dimension observed is 3.6 inches.

A plan and sections of the portion of the mine now active are shown in Plates 9 and 10. An adit 465 feet in length, extending generally northward from the southwest nose of the ridge, exposes a thickness of about 175 feet of interlayered biotitic and

[28] Sterrett, D. B., op. cit., p. 245.



hornblendic gneisses. Lenticular bodies of pegmatite are exposed in the roof of the first level, which has been widened to accommodate the hoist used for mining in the lower levels.

A ruled crystal of flat rum muscovite 860 pounds in weight, which was mined in April 1940 from the footwall side of the fourth level, occurred in medium- to fine-grained pegmatite 5 feet thick, similar mineralogically to that elsewhere in the mine. The block had an irregular outline, was 10 inches thick, and was approximately 3 feet long and 2 feet wide, parallel to the cleavage. It occurred about one foot from the footwall, and was oriented at about 45 degrees to the contact.

At the southeast ends of the second and third levels, a fault of apparently small displacement cuts the pegmatite zone. The fault strikes N. 20°W. and dips 65°NE. Little of its footwall is exposed, but feldspar in the hanging wall is fractured and the mica is more ruled than that in other portions of the mine. Epidote veinlets are relatively abundant near the fault, and hydrous iron oxide, transported by descending ground water, stains feldspar as much as 8 feet from the fault.

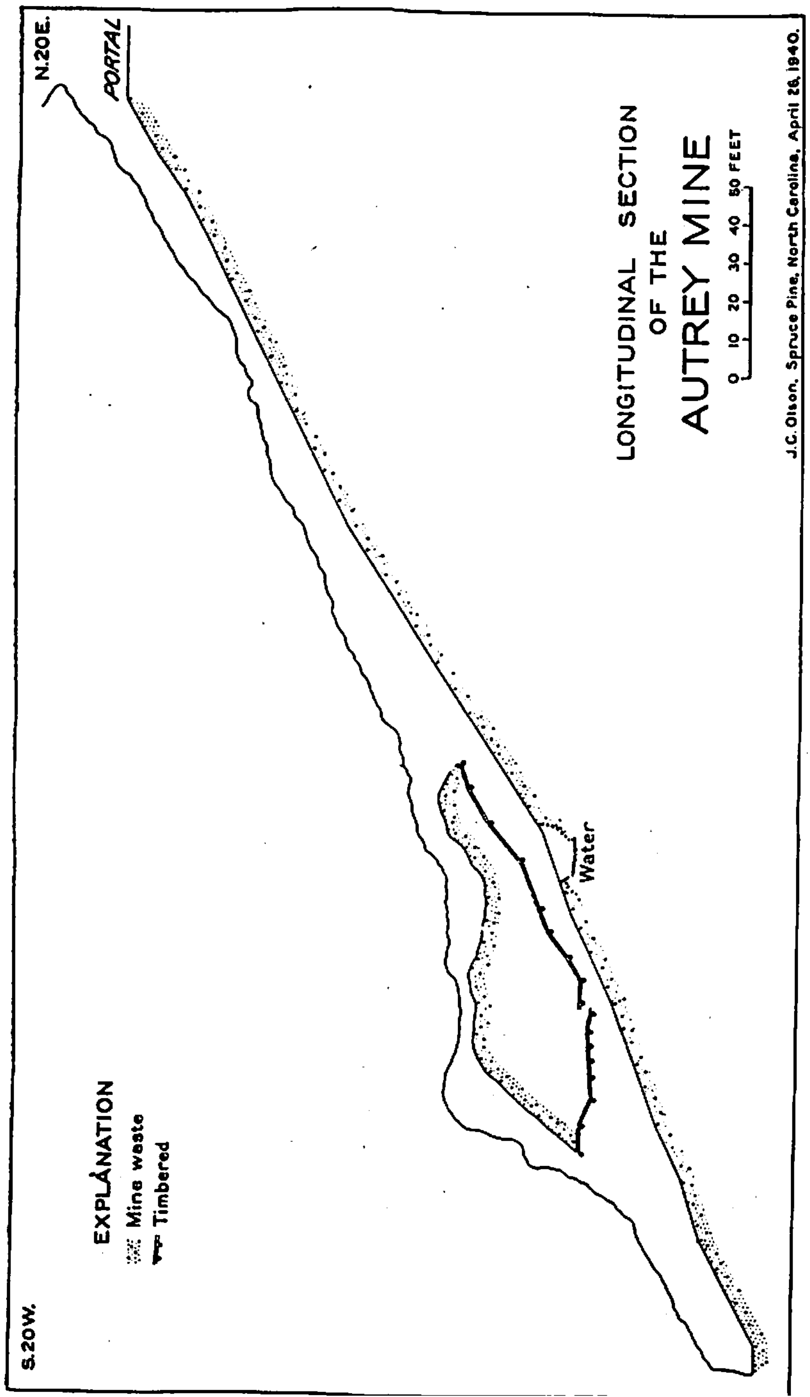
Where the adit cuts across the southwest extension of the pegmatite, 260 feet from the mouth, only minor pods of pegmatite and quartz are exposed in biotite schist, indicating that the southwest limit for mining on the first level has been reached. The southernmost lens of pegmatite mined from the second level (see pl. 8) was 4 feet thick at the heading. The southwest headings of the two lowest levels are in pegmatite that is about 10 feet thick.

The mica of the Hawk mine is light rum, clear, and of good quality though some of it is moderately ruled. Trimmed sheets as large as 18 by 20 inches in size were produced prior to 1893.[29] Holmes[30] states that much of the smaller mica was fairly well crystallized (euhedral), and this is true of crystals as large as 6 inches across mined in May 1941.

## AUTREY

Much clear ruby mica of unusually large size was produced from the Autrey mine, on Celo Mountain, between 1935 and 1938. The pegmatite is a pipe-like or tongue-like body of lenticular cross-section, conformable with the foliation of the enclosing kyanitic biotite-garnet gneiss, which strikes N. 20°E and dips 80°SE. The pegmatite pitches S. 27°W into the mountainside

[29] Sterrett, D. B., op. cite., p. 245.
[30] Holmes, J. A., U. S. Geol. Survey 20th Ann. Rept., Pt. 6, p. 694, 1899.





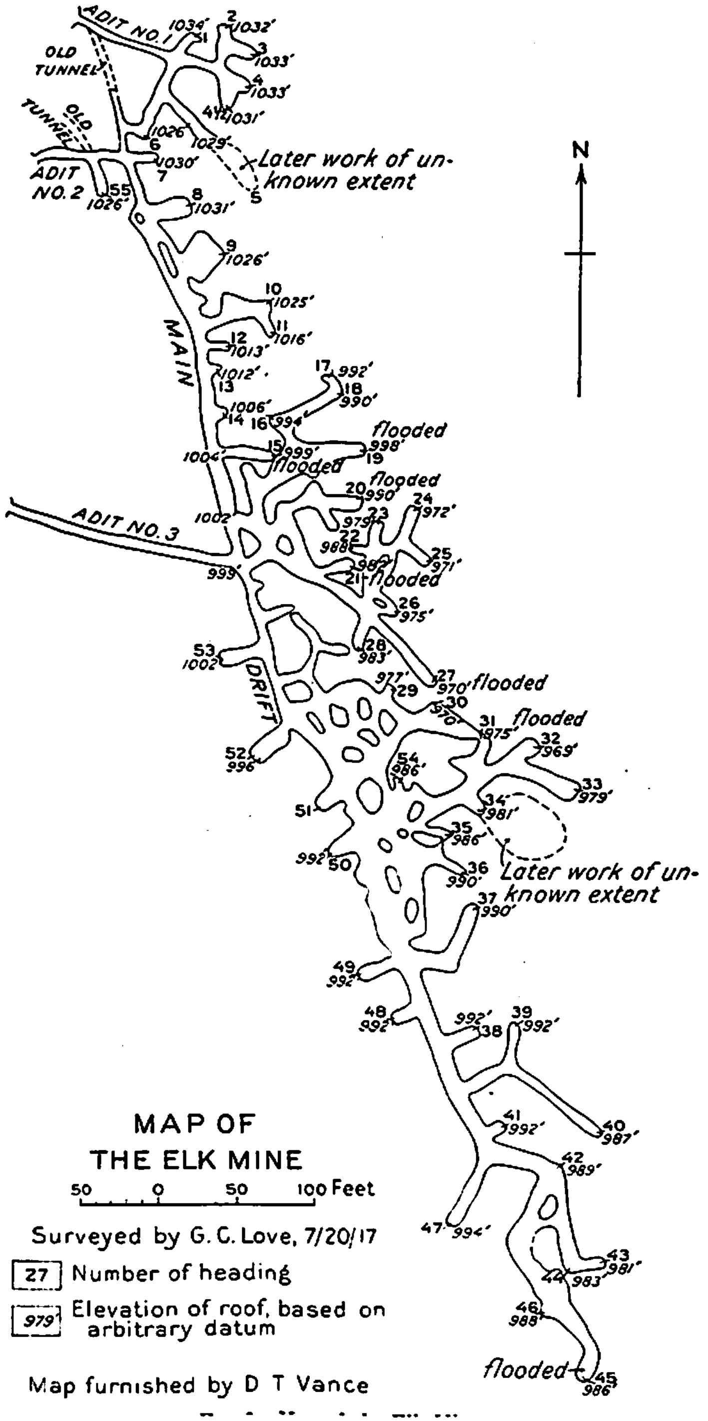

at an angle of 27 degrees, and has been mined from an incline having an average width of 6 feet, a height ranging from 5 to 50 feet, and a total length of 380 feet (see Fig. 5). The thickness ranges from 18 inches to 8 feet, and averages 4 feet. With the exception of one 8-foot barren zone, the pegmatite was very rich in mica almost to the bottom of the incline; there it thickened, the proportion of feldspar increased, that of mica decreased, and the mine was abandoned.

The Autrey pegmatite is vein-like in that it is high in quartz and contains a relatively large amount of sulphide minerals, chiefly pyrrhotite with some pyrite and chalcopyrite. Contacts with wall rocks are gradational, and the pegmatite contains thin shreds of the biotite gneiss. Most of the pegmatite consists of blue-gray quartz, oligoclase, and muscovite. The gradual change in mineral composition noted above occurs about 300 feet from the mouth of the incline, where the pegmatite thickens considerably. It is reported that under the waste that now covers the floor of the incline the pegmatite consists mainly of quartz barren of mica.

About 5 percent of the mica produced was specked or lightly stained, and was more abundant near the margins of the pegmatite and associated with shreds of biotite gneiss. The mica from the central part of the pegmatite was clear. It is reported that mica in the crest of the pegmatite, near the portal of the incline, was very abundant, but the crystals were intergrown to such an extent that the usual yield of large sizes was lowered considerably. Kyanite was found at one place 150 feet from the mouth in a quartzose remanant of the pegmatite on the west wall. The pegmatite also contains biotite, vermiculite, and apatite.

## ELK

The Elk mine is 1½ miles northeast of Plumtree, and northeast of the area shown in Plate 1A. The pegmatite occurs in biotite gneiss that is gently arched in an anticline whose axis is oriented about N20°W. The pegmatite is actually a group or conformable zone of pegmatite lenses connected by thinner tabular bodies. Where removed in earlier mining, this zone was mostly less than 8 feet thick, the pegmatite lenses ranging from 6 inches to 6 feet in maximum thickness, connected by stringers or tabular bodies that in some places were only thin films of pegmatite or quartz. The main drift (see Fig. 6), opened originally from the north end, extends nearly level S20°E for 950






feet, slightly east of, and parallel to, the crest of the fold. Drifts not over 35 feet long, west of the main drift are nearly horizontal, and those to the east dip eastward. Maximum dip of the wall rocks and pegmatite zone is 25°E in headings about 100 feet east of the main drift.

The pegmatite consists of quartz, plagioclase, and muscovite, with little or no microcline. The mica is light-ruby, clear, and flat, and is said to have been scarce in headings west of the main drift. Sterrett[31] states that mica crystals 5 or 6 inches in diameter were mined from pegmatite lenses only 10 inches thick. Quartz and mica are generally more abundant near the contacts of the lenses, most of which are sharply defined.

Some of the mica crystals are perpendicular to the contacts. Accessory minerals of the pegmatite are pink garnets, apatite, pyrite, and pyrrhotite. Thin seams filled with epidote cut the other minerals.

Near the mouth of adit No. 3, a basalt dike 4 feet thick passes from the hanging wall through the pegmatite into the footwall. The dike is exposed beneath the pegmatite eastward for about 125 feet, where it passes upward through the pegmatite into the hanging wall. The rock contains laths of plagioclase (An 70), mostly oriented parallel to the contacts, and euhedral olivine phenocrysts which are altered to serpentine within 1/4 inch of the contacts.

[31] Sterrett, D. B., op. cit., p. 161.

## PART II

ECONOMIC GEOLOGY OF THE SPRUCE PINE PEGMATITE DISTRICT, NORTH CAROLINA

Bulletin #43 of the North Carolina Department of Conservation and Development

## ERRATA

### Part I

Page 16. 10th line from bottom. Comma should be inserted between schist and rocks.

Page 18. 10th line from top. The third word should be the, instead of with.

Page 21. 3rd line in 4th paragraph. The last word should be Burnsville, instead of "Bumsville."

Page 24. 7th line from top. "Parellel" should be parallel.

Page 28. 1st word of 2nd paragraph. "Microline" should be Microcline.

Page 31. 5th line in third paragraph. There should be no comma between places and originated.

Page 34. There should be no period after north at end of first line in paragraph in middle of page.

Page 38. 7th line in paragraph on power factor (2nd paragraph from bottom). Should be 0.04 percent instead of 0.40.

Page 47. 8th line from top. Substitute comma for semicolon, and averaging for "agerages."

8th line in 2nd paragraph: "averages" should be averaging. There should be a comma after percent.

Page 56. 3rd line from bottom. There should be a comma between green and stained, instead of a hyphen.

Page 65. 14th line from bottom: "remanant" should be remnant.

Page 67. 2nd line from top. There should be a comma after drift.

### Part II

Plate 8: In the scale, the word miles should be feet.

In the explanation, the words "strike, dip, and pitch of foliation" should be changed to "strike and dip of foliation, and pitch of axis of minor fold, respectively."

Plate 10: "Verticail" in the title should be Vertical.

In the scale, the word miles should be changed to feet.