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Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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T. L. KESLER, W. H. MONROE, DAVID GALLAGHER
and others

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MUSCOVITE IN THE SPRUCE PINE DISTRICT NORTH CAROLINA

BY

T. L. KESLER AND J. C. OLSON

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MUSCOVITE IN THE SPRUCE PINE DISTRICT, NORTH CAROLINA

By T. L. Kesler and J. C. Olson

ABSTRACT

The recorded production of sheet and punch mica from North Carolina since 1868 is 25,563,341 pounds, of which the Spruce Pine district has produced 16,600,000 pounds or more. The district's production of relatively clear sheet mica, larger than punch, has averaged about 45,000 pounds a year since 1924. Some of this, although the proportion cannot be determined, is apparently as good as the higher grades of imported mica used in the manufacture of radio equipment, airplane spark plugs, transformers, and generators. Sheet mica of highest quality is indispensable for these purposes, and is classed as a strategic mineral.

The Spruce Pine mica is mined from pegmatite bodies that range from a few inches to more than a hundred feet in thickness. Their source is a coarse-grained granite, termed alaskite, which crops out principally north and west of Spruce Pine. About 225 mines have been operated for mica, with feldspar a prominent byproduct. About 289 mines have been operated for feldspar, with mica commonly a byproduct.

This report describes the occurrence of the mica and its physical properties among which is an unusually wide range of colors. A table is presented showing the results of power-factor measurements made by the National Bureau of Standards on 196 samples of sheet mica from 109 mica mines and 15 feldspar mines. Samples from 71 of the mines have power factors within the limits allowed for use in radio-transmitter condensers. Other tables show the results of fabrication and electrical tests of samples from 10 mica mines in North Carolina, 6 of them in the Spruce Pine district, as determined by two commercial users of mica, who concluded that the mica in 8 of the 10 samples is suitable for use in condensers.

It is concluded that more systematic planning of mica mining, for the district as a whole, would result in an average yearly production of at least 90,000 pounds of relatively clear sheet and possibly much more. Tables analyzing the recorded production of many mines, both individually and in the aggregate, are included for use in anticipating future production.

INTRODUCTION

Sheet mica of the highest quality is used as the dielectric in condensers for radio and long-distance telephone, for the manufacture of airplane motor spark plugs, as bridges and spacers in radio tubes, as insulation in transformers, for commutator segments and V-rings, and for armature insulation in motors and generators.[1] Only a small part of the world's total production of mica is flat, clear, and flawless enough, and of such low power factor, as to be usable for these purposes; and the United States has depended very largely on foreign sources for its supply.

The Spruce Pine district was selected for investigation because it is the principal mica-producing area of the United States. What proportion of the clear sheet mica produced from the district has been of the quality now of strategic value is not known, for the final test of such quality is industrial use, and, unfortunately, it is impossible to trace all the uses to which Spruce Pine sheet mica has been put, much less the amounts involved in each use.

The district, which is in the Blue Ridge physiographic province, centers in the town of Spruce Pine (population 1,968), and includes parts of Yancey, Mitchell, and Avery Counties, in western North Carolina (see fig. 1). The three counties have a combined population of 46,743, a large proportion of which has taken some part in the mining and manufacturing of mica. The industrial mineral plants in the district comprise three feldspar grinding mills, two clay refineries, seven plants for grinding muscovite, one plant for grinding biotite, and three factories that cut and fabricate muscovite. The Carolina, Clinchfield, and Ohio Railroad passes through Spruce Pine, and the district is also served by 65 miles of paved highways, 125 miles of relatively good graded roads, and numerous temporary mining and logging roads.

1/ Weirum, H. F., and others, The mica industry: U. S. Tariff Commission Rept. 130, 2d ser., pp. 14-23, 1938.

The area of the district is 250 square miles, and its longest dimension, from northeast to southwest, is 25 miles. Altitudes range from 2,150 feet on the Toe River, west of Bakersville, to 6,684 feet on Mount Mitchell, southeast of Burnsville. Most of the region is drained by the North Toe and South Toe Rivers, which unite near Micaville to form the Toe, a northwest-flowing tributary of the Nolichucky River.

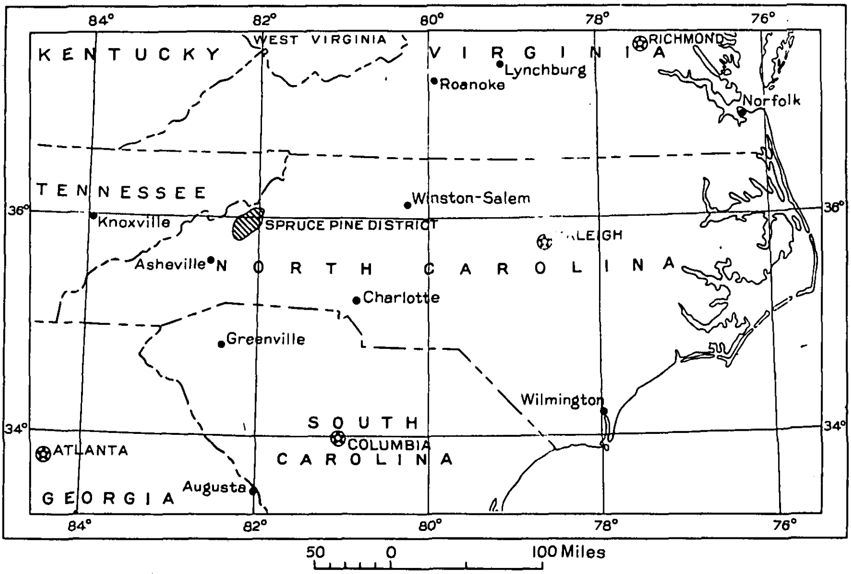

Figure 1.- Index map showing location of the Spruce Pine district, North Carolina.

The geology of the region has been described by Keith,[2/] and some of the pegmatite bodies that have been mined have been described by Sterrett [3/] and Maurice.[4/]

The authors' field work in the district began in November 1939 and continued until the end of May 1940; later developments were examined in July 1940 and May 1941. The field work was carried on largely by Olson, assisted by F. W. Hinrichs, but

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2/ Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), 1903; Mount Mitchell folio (No. 124), 1905; Roan Mountain folio (No. 151), 1907.

3/ Sterrett, D. B., Mica deposits of the United States: U. S. Geol. Survey Bull. 740, pp. 177-184, 245-261, 273-279, 1923.

4/ Maurice, C. S., The pegmatites of the Spruce Pine district, North Carolina: Econ. Geology, vol. 35, pp. 49-78, 158-187, 1940.

Kesler was in the field for 2 months. Examinations of 219 mica mines and 110 feldspar mines were made. The locations of these mines, and also of those not examined in detail, are shown on plate 1, a topographic map of the district.

Operators, miners, and buyers without exception cooperated heartily throughout the course of the work. Thanks are due to Mr. E. L. Hall, of the National Bureau of Standards, for determining power factors of 196 specimens of mica from 109 mines, and to the Bureau for permission to publish the results. The laboratories of the Scintilla Magneto Division of the Bendix Aviation Corporation and of the R. C. A. Manufacturing Corporation, Inc., fabricated and tested, in order to determine its suitability for commercial use in condensers, mica collected from six mines in the district and from four mines elsewhere in North Carolina. The writers are indebted to these companies for permission to publish the results of their tests, and particularly for the cooperation of Mr. Tullio Tognola, of the Scintilla Magneto Division, and of Mr. R. Howell, of the R. C. A. Manufacturing Corporation.

GEOLOGIC SETTING

Schists and gneisses

Interlayered mica schists and gneisses and hornblende gneisses underlie most of the district; less abundant metamorphic rocks are kyanite-garnet gneiss, graphitic muscovite schist, marble, and soapstone. Keith [5/] considered these rocks to be of pre-Cambrian age. In general they strike northeast and dip southeast, but other attitudes prevail over considerable areas. Dips in the western and southwestern parts of the district mostly exceed 45°; those elsewhere are generally less, approaching the horizontal in the northeast part.

5/ Keith, Arthur, op. cit.

Alaskite

A medium- to coarse-grained granite, in part pegmatitic, crops out in the central part of the district. The rock consists of potash feldspar, sodic plagioclase, quartz, a very little muscovite, and mere traces of dark minerals. It has been termed alaskite by Hess and Hunter.[6] The composition of typical material, quarried a fourth of a mile east of Minpro, is shown in table 1. The alaskite probably is late Paleozoic in age.

The structural relations of alaskite to the schists and gneisses can be observed best in open-cut mines at localities where the alaskite has been weathered to clay. In these exposures, the alaskite appears to be intrusive into the metamorphic rocks, mostly as irregular, sill-like bodies that extend along the strike of the wall rocks but do not everywhere conform to them in detail. The alaskite bodies contain slablike inclusions, mostly oriented parallel to the foliation of the wall rocks. The alaskite bodies range in length from a few hundred feet to perhaps a mile or more. Their contacts are commonly sharp, but muscovite schists marginal to some alaskite bodies have been impregnated with feldspars and quartz.

Pegmatite

The pegmatite bodies of the Spruce Pine district range in size from podlike bodies less than an inch across, developed in wall rocks near larger bodies of pegmatite and alaskite, to bodies a hundred feet or more in thickness. Forty-four minerals have been found in them, but their principal constituents are oligoclase, microcline, quartz, albite, and muscovite. The relative proportions of these minerals vary greatly in different parts of some individual bodies, and sharp contrasts in the bulk

6/ Hunter, C. E., Residual alaskite kaolin deposits of North Carolina: Am. Ceramic Soc. Bull., vol. 19, p. 98, 1940.

compositions of adjacent bodies are common. Differences in composition, together with other mineralogic, economic, and textural features, have been used by Maurice 7/ in an elaborate classification of Spruce Pine pegmatite and a theory of its origin. Holmes 8/ has computed the age of uraninite from the Flat Rock mine (147) 9/ as 251 million years--late Carboniferous or early Permian.

Origin.--Every well-exposed body of alaskite in the district contains irregularly shaped masses of pegmatite which range in maximum dimensions from a few inches to several hundred feet. These pegmatite masses characteristically have transitional contacts with the alaskite and consist of the same essential minerals, the only apparent differences between the two rock types being in grain size and muscovite content, which generally is higher in pegmatite. Their similarity in chemical composition is shown in table 1.

Table 1.--Average composition of alaskite from the Davis quarry and of pegmatite from the Deer Park No. 5 mine (155) 1/

	Average from 500 tons alaskite (percent)	Weighted average from 47,992 tons pegmatite (percent)
SiO_2	74.9	75.26
Al_2O_3	14.9	14.92
Fe_2O_3	.33	.28
CaO	1.0	1.10
K_2O	4.7	4.19
Na_2O	4.0	4.20
Loss	.2	.28
Total	100.03	100.23

1/ Analyses by United Feldspar & Minerals Corporation, Minpro, N. C. Published by permission of Mr. B. C. Burgess.

These pegmatite masses are neither inclusions of rock older than alaskite nor intrusive bodies younger than alaskite. The

7/ Maurice, C. S., op. cit.
8/ Holmes, Arthur, Physics of the earth, part IV, the age of the earth: Nat. Research Council Bull. 80, pp. 342-344, 1931.
9/ Numbers in parentheses refer to the mine numbers used in plate 1 and the accompanying lists of mines.

intergradation of textures and similarity of compositions of the two establish their genetic relationship, the pegmatite apparently having been formed while the alaskite crystallized, through the medium of solutions expelled into openings that formed contemporaneously by shrinkage.

Emanations from the crystallizing alaskite were also driven into zones of weakness in the schists and gneisses, forming pegmatite bodies at various distances from the alaskite. Some of these bodies contain alaskitic rock that intergrades with the coarser pegmatitic rock. This condition is similar to that in alaskite bodies that contain pegmatite masses, except that the relative proportions of the two rock types are reversed. Pegmatite bodies in the metamorphic rocks have been the principal sources of mica, but many of them have yielded much feldspar.

Relations to wall rocks.--The 62 commercially developed pegmatite masses in alaskite that were examined have random and unpredictable attitudes, and no consistent structural relations between pegmatite masses and enclosing alaskite could be established.

Pegmatite bodies in the schists and gneisses are mostly tabular, but some are lenticular in cross section. Of those examined, 195 are generally conformable in attitude with the layers of their wall rocks, 22 are crosscutting, and the attitudes of 50 could not be determined because of inadequate exposures. Conformable lenticular bodies commonly occur in closely spaced imbricate arrangement, and a group of such bodies may be mined as a unit. The operation is simplified where the lenticular bodies are connected by thin, tabular extensions of pegmatite, forming composite bodies known locally as "pinch-and-swell" or "peanut veins".

Contacts with hornblendic wall rocks are relatively sharp, but the hornblende commonly is altered to biotite in a contact zone ranging from a few inches to several feet in thickness.

Contacts with mica schists are frequently gradational owing to impregnation of the wall rocks by pegmatitic feldspar and quartz, which is well shown at the Googrock (255) and Bailey Mountain (307) mines. Many pegmatite bodies contain inclusions of wall rocks, mostly tabular or slablike and generally oriented parallel to the walls. The contacts between inclusions and pegmatite are commonly indistinct as a result of partial replacement of the inclusions by pegmatitic feldspar and quartz.

Near Plumtree and Ingalls most of the pegmatite bodies in the schists and gneisses are nearly horizontal (see pl. 1), and few of them dip more steeply than 30°. From the vicinity of Spruce Pine southwestward to Celo, most of these bodies strike northeast and dip 30°-45° SE. Alaskite bodies in this area have similar attitudes, but, as already stated, pegmatitic masses in the alaskite bodies have random attitudes. Bodies in the northwestern part of the district, from the head of Henson Creek southwestward to Micaville and Burnsville, strike more or less uniformly northeastward and dip 60°-80° SE. Most of the bodies south of Celo and in the northern part of the Black Mountains strike northwest to north and dip southwest. A few are definitely pipelike and pitch southwestward.

Groups of adjacent pegmatite bodies that are similar in composition and contain muscovite of the same color almost invariably lie parallel to the structural trend of the country rocks. This suggests that the composition of wall rocks influenced the composition of pegmatite. A result, from the practical standpoint, is a general correlation between the quality of mica and the character of wall rocks; for example, pegmatite having kyanitic wall rock yields mica of ruby color almost exclusively, and that in alaskite contains mostly green and greenish-rum mica.

There has been some relatively minor deformation of the pegmatite, reflected by faults of slight displacement, by fractured feldspar crystals, and by ruled and bent mica crystals.

Basalt

A few dikes of fine-grained basalt, mostly less than 5 feet in thickness, cut the other rocks in the district, including pegmatite. Dikes of the basalt are exposed at the Peru (6), Puncheon Camp (11), and Elk (24) mines. Keith 10/ has correlated these dikes with the Triassic diabase of the Piedmont.

Occurrence of muscovite

Muscovite is distributed sporadically in pegmatite throughout the district. Commercially valuable mica, however, is localized in shoots called "streaks" in which mica generally constitutes 2 to 6 percent of the rock, or even as much as 40 percent in exceptionally rich "pockets". In mica mining, pegmatite bodies 6 feet or less in thickness are generally mined from wall to wall, but only the mica-bearing shoots are removed from thicker bodies.

The color of the mica is fairly uniform throughout any one shoot, but where two or more shoots occur in the same pegmatite body, the mica of one may differ in color from that of the other. The distribution of the mica is irregular, which adds to the uncertainty of mining and to the difficulty of estimating reserves. In geologic relations, each mica shoot differs in detail from most others, so that a rigid geologic classification of the mica deposits would be complex if not impossible.

Shoots of commercially valuable mica occur (1) near contacts with metamorphic wall rocks and inclusions (along hanging walls more commonly than along footwalls); (2) near constrictions and sharp bends ("rolls") in thin pinch-and-swell pegmatite bodies;

10/ Keith, Arthur, U. S. Geol. Survey Geologic Atlas, Mount Mitchell folio (No. 124), pp. 5-6, 1905.

(3) near the crests of pipelike or tonguelike bodies; (4) in or adjacent to the massive bodies of blue-gray quartz which commonly occur near the centers of pegmatite bodies; and, (5) more rarely, in micaceous wall rocks and inclusions partly replaced by pegmatite, notably at the Clarissa (87) and Poll Hill (298) mines.

The best mica in the Spruce Pine district (flat and of ruby or rum color) is found most abundantly in pegmatite composed principally of plagioclase and quartz, or in those parts of more heterogeneous bodies that consist mainly of quartz and plagioclase. The mica is associated more consistently with quartz than with plagioclase. Pegmatite containing abundant microcline and graphic granite rarely contains much muscovite of good quality, except (1) in the few bodies in which lathlike intergrowths of muscovite and biotite transect graphic granite, and (2) in the many bodies in which mica occurs with quartz and plagioclase adjacent to, but not intercrystallized with, potash feldspar. Pegmatite comparatively rich in biotite is not, in general, rich in muscovite. Biotite occurs more commonly in pegmatite enclosed in hornblendic wall rocks. In pegmatites containing flat mica that is mostly clear, the small proportion of mineral-stained mica seems to occur principally near walls and inclusions.

The pegmatite bodies examined in the present study are identified by numbers on plate 1. The outstanding characteristics of these bodies, particularly the color of the mica that they contain, are summarized in table 2.

In the alphabetical list of mines on plate 1, three symbols are used to indicate mines whose production is considered likely to contain an appreciable proportion of clear sheet possibly suitable for strategic uses. These mines have been selected on the composite basis of field examination, value of product, reputation among operators and buyers, and, if known, power factor. The symbol I indicates mines most of which produce ruby or white mica of high quality. Mines marked II also produce some mica of high quality, though mostly with different shades of rum color. Mines marked III produce mica that apparently is of good quality but is green or has a pronounced greenish cast. There is some prejudice against clear green mica, but the investigations incidental to this report have not shown that the prejudice is well founded. The economic classification implied by these symbols cannot of course be infallible or final, and further developments will doubtless necessitate some revision.

PROPERTIES AFFECTING THE VALUE OF MUSCOVITE

Muscovite has the approximate formula $K(Al,Fe)_2(Al,Si)_4O_{10}(OH,F)_2$, and crystallizes in the monoclinic system. Its principal physical properties have been described and illustrated by Sterrett.[11/] Only those that serve most to determine its commercial value as well as specific uses [12/] are described below.

Cleavage.--The outstanding characteristic of muscovite is perfect cleavage parallel to the basal pinacoid. Normal, fully developed (euhedral) crystals have six faces at right angles to the cleavage, but a common variety, known as "A" mica, is incompletely developed. Some faces may fail to develop in a crystal of either type. A mica crystal is called a block [13/] by miners and buyers.

Undeformed crystals of the normal variety of muscovite can be split along the basal cleavage into sheets that have equal thicknesses throughout and whose surfaces are essentially plane. Hence the normal variety is designated as flat mica. The size of a block, and the continuity of the cleavage planes in it,

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11/ Sterrett, D. B., op. cit., pp. 11-18, pls. 3-8.

12/ For uses of muscovite, see Wierum, H. F., and others, op. cit., pp. 11-26.

13/ The term "book" is synonymous with "block", but is not used extensively in the southern Appalachians.

Table 2.--Summary of the occurrence of mica in the Spruce Pine district

Mine numbers	Predominant type of mica 1/	Subordinate types of mica	Associated minerals and rocks	Relative economic importance of feldspar	Strike of pegmatite bodies	Dip of pegmatite bodies	General character of country rocks
1-61	Dark rum...	Ruby, green "A", white, light rum.	Quartz and plagioclase; pegmatite bodies relatively thin.	Minor........	Diverse.	Mostly less than 30°.	Principally hornblende gneiss with interbedded mica gneiss.
62-109	Ruby and rum.	Dark rum, white.	Biotite and microcline common in 100-108; otherwise mostly quartz and plagioclase.	Minor........	NE.....	Mostly 60°-70° SE.	Mica gneiss, hornblende gneiss, kyanitic mica gneiss.
110-136	Green, stained.	Mostly shades of green and brown.	Mica, relatively scarce, associated with plagioclase; microcline and graphic granite abundant.	Moderate.....	NE.....	60° SE....	Interbedded mica and hornblende gneisses.
137-157	Green and rum.	Dark rum, ruby.	Mostly quartz and plagioclase; microcline abundant.	Major........	N. to NE.	Generally SE.	Alaskite and interbedded hornblende and mica gneisses.
158-166	Green "A"; some stained.	White........	Mostly quartz.......	Moderate.....	Diverse.	Very shallow.	Alaskite.
167-223	Green and rum, some stained.	Light rum....	Mostly quartz and plagioclase; microcline common.	Moderate.....	Irregular, generally NE.	Irregular.	Mostly alaskite.

224-234	Green, stained.	Rum, ruby....	Mostly quartz and plagioclase; microcline abundant.	Major........	Irregular.	Irregular.	Interbedded hornblende and biotite gneisses.
235-256	Greenish rum.	Green "A", rum, ruby.	Variable...........	Moderate.....	NE.....	50°-80° SE.	Interbedded mica and hornblende gneisses.
257-272	Light rum, some stained and ruled.	White, stained, ruby.	Mica occurs in or near massive quartz; pegmatite bodies relatively thin.	Minor........	NE.....	40°-80° SE.	Interbedded mica and hornblende gneisses.
273-288	Ruby; some stained.	Green "A"....	Quartz and plagioclase; pegmatite bodies less than 15 feet thick.	Moderate.....	NE.....	40°-85° SE.	Interbedded mica and hornblende gneisses.
289-314	Rum, green; some stained.	Dark rum, ruby, white; some heavily stained.	Quartz and plagioclase in relatively thin pegmatite bodies, or rarely in inclusions and walls partly replaced by pegmatite.	Minor........	NE to NW.	Diverse.	Interbedded hornblende and mica gneisses and mica schist.
315-345	Green "A"; commonly stained.	Ruby.........	Mostly quartz and plagioclase; microcline abundant.	Moderate.....	Irregular, generally NE.	Moderate, SE.	Alaskite.
346-360	Ruby.......	Green "A", brown.	Mostly quartz and plagioclase.	Minor........	NE to NW.	Steep, some E., some W.	Mica gneiss, some kyanitic.
361-375	Ruby; mostly "A".	Green "A"....	Much quartz.........	Minor........	NW.....	SW........	Mica gneiss, some kyanitic.

1/ The mica is predominantly flat unless "A" mica is specified.

determine the sizes of sheets that it will yield; and value increases with size (see table 9). Mica that splits imperfectly because the cleavage planes are not continuous through the block is termed tanglesheet or gummy. The sheets are trimmed to eliminate marginal imperfections, are split further to specific thicknesses, and are die-stamped or cut to shapes required in the manufacture of electrical and other apparatus. Thin films known as splittings, which are split almost entirely in India, are bonded together to form mica board, which may be stamped and molded to required forms.

In contrast to the smooth cleavage surfaces of the more valuable flat mica, the cleavage surfaces of "A" mica are uneven because of the presence of fine cleavage imperfections, called reeves. The relation of "A" mica to the flat, euhedral variety was observed at the Marie mine (16) where a complete six-sided crystal, 2.5 inches in diameter, was divided at intervals of 60° by typical "A" reeves into six parts like the pieces of a pie, the reeves diverging from the center, and each set bisecting a face of the mica crystal. Almost invariably an "A" mica unit develops separately and corresponds to a sixth of a perfect crystal of flat mica. The reeves parallel the long sides, and there is no structural feature to form the cross bar of the "A". Field evidence indicates that "A" mica is formed later than most flat mica.

The extent to which reeves have developed in a crystal of "A" mica is the principal measure of its value. If the reeves are confined to the margins, "flat A" mica may be trimmed from the area between them. Much "A" mica, however, is reeved throughout. Mica in which reeving is pronounced occurs commonly in crystals that are thinner at the point of the "A" than at the blunt end. Such mica is called wedge and is classed as scrap, which is ground by wet or dry processes.

Flexibility and elasticity.--Sheet muscovite, if free from flaws, may be distorted without breaking and returns to its normal planar condition when released. Flexibility is essential for some uses, notably in the manufacture of spark plugs for airplane engines. For making these, films of "cigarette" mica, not exceeding twelve ten-thousandths of an inch in thickness,[14/] are wrapped around a rodlike spindle a little more than an eighth of an inch in diameter. The elasticity of muscovite is important where the mineral forms supports for other units in an apparatus such as an electric toaster or a radio tube. Common flaws affecting these properties are extremely fine cracks having random orientation. Mica with this imperfection is termed haircracked, and the term brittle is used to describe mica that breaks readily when distorted.

Color.--Color usually can be detected in sheets of muscovite a tenth of an inch thick or even less, although thin films appear to be colorless. The pegmatite bodies of the Spruce Pine district contain commercial muscovite of many colors. So far as the writers are aware, there has been no systematic study of the relation between color and chemical composition, but the differences in hue and intensity of color must reflect some differences of composition. Such a correlation has been found for biotite,[15/] whose color is dependent on the relative contents of iron, magnesia, and titania.

Color terms that are standard in the Spruce Pine district are listed below in the order of desirability, and the approximate number of mines whose production of mica is more than 50 percent unstained is given for each color:

14/ Wierum, H. F., and others, op. cit., p. 19.
15/ Hall, A. Jean, The relation between colour and chemical composition in the biotites: Am. Mineralogist, vol. 26, pp. 29-33, 1941.

	Mines
Ruby, light pink to light brownish red	59
Rum, light brown	30
White, very pale tone of any color	5
Greenish rum, light greenish brown	9
Water-colored, deep greenish brown	19
Green, pale to deep bottle green	14

Slight color variations within crystals are fairly common. While some are caused by finely disseminated iron oxide and may be classed as staining (see below), many apparently express variations in the composition of the mica. Color bands are commonly parallel to the prism faces of the crystal and constitute true crystallographic zoning; less commonly, the color varies irregularly giving the mica a mottled appearance.

Staining and inclusions.--The value of sheet mica is impaired by stains, mostly of primary origin, on the cleavage surfaces. Secondary organic stains (called vegetable stains) are uncommon in the Spruce Pine district, but secondary mineral stains, mostly due to infiltrated clay, are common in weathered pegmatite.

The primary stains are more serious than the secondary, for they persist indefinitely downward. They consist of tiny spots of iron oxide, arranged either according to the crystal structure of the mica or at random. The frequency of the spots, or "specks", determines whether the mica shall be graded as lightly stained, stained, or heavily stained. Heavily stained sheet mica is used for insulation in the commoner electrical appliances, and is frequently called black-stained, black-spotted, or electric mica.

The iron-oxide stains are composed of magnetite, hematite, and limonite. Magnetite apparently crystallized as inclusions during crystallization of the muscovite, and is converted into hematite and limonite by weathering. Other inclusions, thicker than the iron-oxide films, include crystals of garnet, epidote, thulite, zoisite, quartz, apatite, plagioclase, and tourmaline.

The crystals of these minerals grew most readily parallel to the cleavage of the mica, so that they are commonly flat. Inclusions interfere with splitting of the mica and must be eliminated in trimming, thus reducing the size of marketable sheets. Mica that is intimately intergrown with quartz tends to be brittle.

A little flat mica is intergrown with biotite and its alteration product vermiculite. Muscovite intergrown with the dark micas is generally of the desirable ruby color, but it splits unevenly; it occurs in many places but not in great quantity. Intergrowths of "A" mica and biotite are rare.

The cleavage of mica that has been deformed even slightly, or that has been exposed to weathering, may be opened sufficiently to admit air or water. Both are objectionable, but water can be removed by drying, and air bubbles can be eliminated to some extent in splitting the mica.

Natural distortion.--The principal effects of distortion of mica, resulting from rock movements, are bending and ruling. These are most pronounced near faults of minor displacement that cut the pegmatite bodies. Such faults are common throughout the Spruce Pine district, but are more numerous in the Green Mountain section, north of Burnsville, than elsewhere.

Bent mica has curved cleavage and generally has to be ground as scrap. Ruled mica has a parting, or secondary cleavage, induced in one or more of three directions 60° apart on the basal cleavage. According to Sterrett,[16/] these directions parallel the rays of the pressure figure of muscovite and the reeves of "A" mica, and the plane of parting makes an angle of nearly 67° with the basal cleavage. Intensity of ruling in flat mica determines the sizes of sheets that may be trimmed from it, and mica that is otherwise of highest quality may be ruled to such an extent that it must be classed as scrap.

16/ Sterrett, D. B., op. cit., pp. 15-16.

Power factor.--The loss of electrical energy in films of sheet mica used as the dielectric in condensers is known as the power factor, and is expressed in percent. A low power factor, generally 0.04 percent or less, is essential in any mica used for transmitter condensers. Results 17/ of tests of muscovite obtained from domestic mines and from foreign sources have shown that the power factor of some domestic mica is comparable with that of the best imported material.

TESTS OF SPRUCE PINE MUSCOVITE

The lack of specific information concerning the purposes for which sheet mica from the Spruce Pine district has been used makes it difficult to evaluate resources with respect to strategic uses and needs. The results, presented in detail on pp. 19-30, of some tests conducted by the National Bureau of Standards and by two industrial organizations will serve in some degree to supply this lack.

Measurements of power factor

To determine whether mica having a low power factor is common or uncommon in the Spruce Pine district, the Geological Survey submitted to the National Bureau of Standards samples from 109 of the district's mica mines and from 15 mines whose principal product is feldspar. Most of these mines have produced mica of relatively high value on the local market, but a good many of the samples tested were of borderline or inferior quality. The results of the tests are presented in table 3. They indicate a close correlation between power factor and physical appearance, which therefore provides the geologist and engineer with the simplest possible basis for preliminary appraisal of quality. Many of the specimens submitted were collected from

17/ Horton, F. W., Mica: U. S. Bur. Mines Inf. Circ. 6822, pp. 43-45, 1935.

dumps where they had been exposed to weathering for many years. The tests indicate that weathering does not affect the power factor so long as the muscovite remains free from haircracks and secondary stains.

Mica from 71 of the 109 mica mines has power factors not exceeding 0.04 percent. The specific results given in the table are not to be counted on as applying throughout the respective pegmatite bodies, but they indicate approximately the values to be expected in the better mica from the mines represented.

The explanatory section of the report of the Bureau of Standards on power factors of Spruce Pine mica is quoted in full:

> This report is submitted in compliance with the request of July 10 of Mr. Howard C. Sykes, Consultant on Mica, National Defense Commission, and the request of August 3 of the Director of the Geological Survey. The samples were submitted on August 3, 1940.
>
> The majority of the samples were submitted in the form of "books", from which sheets 1 to 4 mils thick were split. The best-looking pieces were selected, free from cracks, pin holes or rock inclusions. Where possible the specimens selected were free of visible stains and air bubbles, and the surfaces were formed by single cleavage planes. If a specimen about 1 inch square could not be obtained, no specimen was prepared; this was the case for 18 samples.
>
> The power factor was measured at room temperature for each sample at a frequency of 1000 kilocycles per second. A small electrical condenser was prepared from each sample using two small pieces of lead foil attached on opposite sides of the mica specimen. The lead foil pieces were of two sizes, 7/8-inch square and $1\frac{1}{4}$-inch square. The smaller piece did not have to be accurately centered above the larger piece. The lead foil pieces were attached to the mica using either white petroleum jelly or linseed oil. A small amount of the adhesive was rubbed on the mica, and then rubbed off with a piece of chamois, thus insuring an extremely small amount of foreign matter. The foil was carefully smoothed into place endeavoring to remove all air bubbles. The capacitance of the condensers thus prepared ranged from about 170 to 800 micromicrofarads. There were only two or three samples under 200 $\mu\mu$f, the majority being in the range from 300 to 500 $\mu\mu$f.
>
> A few experiments were made to determine changes in power factor readings as caused by different methods of applying the lead foil to the mica specimen. If linseed oil was used without care in removing excess oil, the power factor was increased about five in the third decimal place. If a minimum amount of linseed oil or petroleum jelly was used, the difference in power factor was two or three in the third decimal place, depending on the adhesive used.

Specimens were made up in which small air bubbles were left under the electrodes and the power factor measured. It was observed on three samples that if the air bubbles were removed, the power factor was reduced by two to five in the third decimal place. It is therefore apparent that the results are not significant to more than ±1 in the second decimal place. The results have accordingly been rounded off at this point.

The power factor tests were made using a type 513-C radio-frequency bridge made by General Radio Company, Cambridge, Mass. The standard in terms of which the measurements were made was a General Radio type 722-N precision variable air condenser. Measurements on three samples were also made using the resistance variation method employed in tests reported in this Bureau's Research Paper No. 347, "Some Electrical Properties of Foreign and Domestic Micas and the Effect of Elevated Temperatures on Mica". Results of tests by the two methods were in close agreement.

Tests were made on 18 samples to see if there was any relation between the relative clarity of the mica as indicated by its transmission of light and its electrical power factor. A red filter was used to differentiate more sharply between ruby and green micas. The results indicated no relation between the clarity of the mica and its power factor. The clarity data are therefore not included in this report.

Table 3.--Power factors of muscovite from the Spruce Pine district, North Carolina
[Tests made by the National Bureau of Standards]

Mine No.	Name of mine	Character of specimen	Power factor (percent)
1	Cowcamp (South)	Ruby	0.05
4	Bluff	Rum, lightly stained	.04
15	Lincoln Rock	Dark rum	.03
19	Meadow	Rum, stained	.10
	....do	Rum, lightly stained	.04
20	"A" (on Little Elk Ridge).	Rum, stained	.15
22	Plumtree	....do	.04
24	Elk	Ruby	.04
	....do	....do	.03
25	White Rock	....do	.01
28	Slippery Elm	Greenish rum	.03
35	Hoppey	Ruby	.04
40	Tom Carpenter	Dark rum, lightly stained.	.06
43	Honey Waits Wiseman	....do	.01
45	Aldrich	Rum	.08
46	Alfred	Dark rum	.03
47	Doublehead	....do	.04
	....do	....do	.07
50	Houston Rock	Light rum, lightly stained.	.02
51	Charlies Ridge	White	.04
	....do	....do	.03
52	Justice	Light green	.04
54	Branch (on Little Henson Creek).	Rum, heavily stained	.19
55	Wolf Ridge	Ruby	.01

Table 3.--Power factors of muscovite--Continued

Mine No.	Name of mine	Character of specimen	Power factor (percent)
59	Charley Burleson	Ruby	0.04
62	Four Foot Square	Dark rum, stained	.08
66	Landers	Rum	.03
68	Birch	Light rum	.01
71	Little Hawk (head of Henson Creek).	Ruby	.03
	....do	....do	.02
81	Hawk	Light rum	.04
	....do	....do	.04
	....do	....do	.04
83	Haw flat	"Water-colored", stained.	.47
84	Mossy Rock	Rum	.02
	....do	....do	.02
85	Bardon	Ruby	.02
88	Zach Young	Rum	.01
89	Lick Ridge	Dark rum	.02
90	Joe Stevenson	Ruby	.02
	....do	....do	.02
92	Horton Rock	....do	.01
94	Cloudland	....do	.08
	....do	....do	.03
95	Ben Cox	....do	.03
96	Milt Wilson	....do	.01
	....do	....do	.04
	....do	....do	.01
98	Buckeye	White	.02
99	Pannel	Rum	.02
100	Randall	Ruby	.06
102	Waterhole	....do	.01
105	Sinkhole	....do	.01
	....do	....do	.01
107	Abernathy	....do	.03
	....do	....do	.02
	....do	....do	.06
108	Chestnut Branch	....do	.01
	....do	....do	.04
121	Jeff Howell	Rum	.02
	....do	....do	.04
	....do	....do	.03
	....do	Rum, lightly stained	.04
134	Murphy Rock (on Rebels Creek).	Ruby, lightly stained.	.02
139	Gimbel	Ruby, clay-stained	.30
145	Putman	Rum	.01
	....do	....do	.01
146	Jase	....do	.02
147	Flat Rock	Greenish rum	.09
150	Miller	Rum	.03
151	Pegram	....do	.01
	....do	....do	.02
	....do	Green	.01
153	Davis	Rum	.03
155	Deer Park No. 2	....do	.02
	....do	....do	.03
162	"A" (or Brushy Creek)	Light greenish rum	.02
164	Mill Race	Light green, clay stained.	.11
166	Gusher Knob	Green, lightly stained.	.01

Table 3.--Power factors of muscovite--Continued

Mine No.	Name of mine	Character of specimen	Power factor (percent)
166	Gusher Knob	Green, lightly stained.	0.02
174	Wiseman	Green, heavily stained.	2.00
192	Pine Mountain	Rum	.02
	....do	Rum, lightly stained	.16
198	Lissie Smith	Dark green, heavily stained.	1.70
199	Deake	Rum, clay-stained	.12
208	Miller	Rum	.02
210	Guy	Greenish rum	.03
211	Drawbar	....do	.09
214	Poteat	Light greenish rum	.02
230	Hootowl	Green, heavily stained.	.20
235	Barger	Rum	.01
	....do	....do	.04
236	Buckeye (west of Boonford).	....do	.09
	....do	....do	.01
237	Branch (west of Boonford).	....do	.02
239	Hector	Light green	.04
240	Charles Robinson	....do	.05
247	Tolley Bend	Greenish rum	.01
249	Presley	Ruby	.01
250	Anglin	Light green	.02
255	Googrock	Rum, lightly stained	.01
273	Andy Hall	Ruby	.01
276	Bee Ridge (North)	....do	.05
277	Bee Ridge (South)	Rum	.02
282	Charley Young	Ruby	.02
283	Laws	....do	.01
285	Bittner	....do	.02
287	Griffin	....do	.10
288	Charley Young (east of Shoal Creek).	....do	.02
	....do	....do	.02
	....do	....do	.02
	....do	....do	.03
	....do	....do	.03
	....do	....do	.03
	....do	....do	.02
289	Little Zeph Young	White	.02
291	Boomer Tom Young	Rum	.02
	....do	....do	.01
292	Flukens Ridge (at Newdale).	....do	.07
296	Fannie Gouge	Light green, stained	.31
298	Poll Hill	Rum	.02
	....do	....do	.03
	....do	Rum, stained	.02
	....do	....do	.01
	....do	Rum	.02
	....do	....do	.03
299	Gibbs	Rum, lightly stained	.09
	....do	....do	.06
300	Hilliard	Ruby	.02
302	Red (on South Toe River).	Green, stained	.07

Table 3.--Power factors of muscovite--Continued

Mine No.	Name of mine	Character of specimen	Power factor (percent)
303	Edge	Rum	0.04
304	Wilt Young	Rum, stained	.06
307	Bailey Mountain (group).	Rum, from Black Dixie.	.02
	....do	....do	.06
	....do	....do	.05
	....do	Rum, stained; from Shakerig.	.09
	....do	Rum, from Sleepy Hollow.	.03
	....do	Rum, from Irby Cut	.01
	....do	Rum, from Old Owlie	.02
	....do	Rum, specific opening unknown.	.01
311	Myra Gibbs	Dark rum, stained	.10
313	Big Gibbs	Ruby	.03
314	Gaston McDowell	Rum	.02
321	Carolina Mineral Co. No. 6.	Greenish rum	.02
327	George Young	....do	.01
330	Wildcat	Green	.01
336	Josh Young	Rum	.01
	....do	Nearly white	.03
339	James	Light rum, heavily stained.	2.00+
	....do	Light rum	.04
340	Commissary Ridge	Green	.06
344	Sally Knob	Rum	.01
345	Murphy Rock	Ruby	.02
	....do	....do	.05
346	Georges Fork	....do	.07
348	Ray	....do	.02
	....do	....do	.01
350	Willies Shanty	Ruby, stained	.01
354	Ayles Creek	Ruby	.02
355	Autrey	....do	.05
356	Balsam	....do	.02
357	S. W. Presley	....do	.01
	....do	....do	.03
	....do	....do	.03
358	Flem McPeters	....do	.01
359	Cattail	....do	.02
369	Westall (on Colbert Ridge).	....do	.02
374	Carson Rock	....do	.03
Prospects not shown on map	Brown (1.5 mi. NW. of Mt. Mitchell).	....do	.02
	Blevins (0.2 mi. N. of Zach Young mine).	Rum	.03
	Buck Hill Rock (S. slope Buck Hill Mtn.).	Rum, lightly stained	.08
	Chet McKinney (S. of Carson Rock mine).	Ruby	.03
	....do	....do	.04
	McKinney (E. of Cattail mine).	....do	.01
	Aaron Buchanan (N. of Dugger mine).	Rum	.02

Table 3.--Power factors of muscovite--Continued

Mine No.	Name of mine	Character of specimen	Power factor (percent)
Prospects not shown on map	Ledford (on Cane Creek).	Rum	0.02
	....do	....do	.03
	Edwards scrap-mica mine (near Newdale).	....do	.06
	Sheehan (1 mi. N. of Micaville).	Ruby	.01
	....do	....do	.01

Results of the tests of Spruce Pine muscovite, shown in table 3, are summarized by Mr. Hall in table 4, to show the distribution of the power-factor values.

Table 4.--Distribution of power-factor values of Spruce Pine muscovite, summarized from table 3

Range of power factor (percent)	Number of specimens tested
0 - 0.01$_4$	39
.01$_5$ - .02$_5$	48
.02$_6$ - .03$_4$	31
.03$_5$ - .04$_5$	21
.04$_6$ - .05$_4$	21
.05$_5$ - .08$_5$	17
.08$_6$ - .11$_4$	9
.11$_5$ and higher	10
Total	196

The measurements of power factor listed in table 4 were made in August 1940. Mr. Hall remeasured 10 of the specimens in December 1940, and he found a decrease in power factor in each sample except one. He attributed the decrease to the drying out of the specimens from August to December. Comparative results are shown in table 5.

Table 5.--Comparative results of power-factor measurements made in August and December 1940

Mine No.	Name of mine	Power factor (percent)		Change in power factor (percent)
		August	December	
24	Elk	0.04	0.03	-0.01
45	Aldrich	.08	.03	-.05
94	Cloudland	.08	.06	-.02
100	Randall	.06	.03	-.03
199	Deake	.12	.10	-.02
236	Buckeye (west of Boonford)	.09	.08	-.01

Table 5.--Comparative results of power-factor measurements made in August and December 1940--Continued

Mine No.	Name of mine	Power factor (percent)		Change in power factor (percent)
		August	December	
299	Gibbs.................	0.06	0.04	-0.02
307	Bailey Mountain.......	.02	.01	-.01
	....do................	.05	.02	-.03
...	Brown.................	.02	.02	0

<u>Tests to determine utility in condensers</u>

The results obtained from the tests conducted by the National Bureau of Standards indicate that sheet mica of sufficiently low power factor for use in condensers probably occurs, though in unknown quantity, in many of the mines in the Spruce Pine district. In order to obtain more definite information regarding utility, relatively small samples were collected from six mines that were being operated in May 1941, and from four mines also in operation at that time in North Carolina but outside the Spruce Pine district. The 10 samples had to be taken from the limited stocks of mica then available, and at least 4 of them were considered to be slightly inferior in quality to the best mica obtainable from the respective mines. The power factors of mica from the six mines in the Spruce Pine district, as determined by the Bureau of Standards, ranged from 0.01 to 0.08 percent.

Under an arrangement made by Mr. Paul M. Tyler of the Bureau of Mines, United States Department of the Interior, five of the samples were sent to the Scintilla Magneto Division of the Bendix Aviation Corporation, at Sidney, New York, and five to the R. C. A. Manufacturing Co., Inc., at Camden, New Jersey. The laboratory staffs of these companies processed the mica of each sample separately, with the results given below. It will be noted that the inadequacy of the samples for exhaustive tests is emphasized in the report of each company. The unfavorable results obtained on mica from 2 out of the 10 mines might possibly be due to the unsatisfactory way in which the samples were taken. In order, therefore, to avert the possibly unjust inference that these two mines cannot become sources of condenser mica, it was considered inadvisable to identify the individual mines further than by indicating whether they are within or outside of the Spruce Pine district.

Tests made by the Scintilla Magneto Division, Bendix Aviation Corporation, Sidney, N. Y.

Fabrication of mica.--

Table 6.--Table showing relation by weight of finished condenser films to raw mica

Mine	Weight of raw mica in sample	Weight of finished condenser films 1/	Relation of film weight to raw weight (percent)
A 2/........	1 lb. 10.0 oz.	2.75 oz.	10
B 2/........	1 lb. 12.0 oz.	3.50 oz.	12
C 2/........	11.5 oz.	2.25 oz.	19
D...........	1 lb. 5.5 oz.	3.00 oz.	14
E...........	1 lb. 1.0 oz.	3.25 oz.	19
Approximate average for India mica............			25

1/ Dimensions of the films in inches: 1.370 ± 0.010 by 1.370 ± 0.010 by 0.0009 to 0.0014.
2/ Spruce Pine district.

Comments by Scintilla.--

(1) The dielectric strength, power factor, and dielectric constant of the various samples are acceptable for condenser splittings.

(2) All samples were free splitting, and no particular difficulty was encountered during the process of manufacturing.

(3) The percentage net weight is only partly indicative of the suitability of the various samples, owing to the fact that the size of the sheets was not uniform.

(4) The variation in color of the various samples submitted was not indicative of the suitability of the various micas for the intended purpose.

(5) From all indications obtained during the processing of the above samples, the various micas can be used for condenser films, although the small quantity of raw mica submitted limited us somewhat in our investigation.

Tests made by the R. C. A. Manufacturing Co., Inc., Camden, N.J.

Descriptions and fabrication of mica.--

Mine F (Spruce Pine district)

Description of sample: Color very light green. Very soft. Many air inclusions and a few foreign inclusions. Very scaly in splitting. Only occasional pieces flat.

Weights:

Sample	2 lbs. 9.00 oz.
Scrap from splitting	3.75 oz.
Scrap from cutting	1 lb. 4.30 oz.
Reject films	7.75 oz.
Good films	9.25 oz.
Relation of film weight to raw weight (percent)	22.5

Mine G (Spruce Pine district)

Description of sample: Color a great deal like ruby but darker and somewhat more brownish. Poorly trimmed blocks split poorly. Well trimmed blocks split very well, and are reasonably flat and clear. Cracks often run in far enough from the edges to ruin otherwise good blocks. Harder than India ruby.

Weights:

Sample	1 lb. 15.80 oz.
Scrap from splitting	1.90 oz.
Scrap from cutting	20.00 oz.
Reject films	1.3 oz.
Good films	8.60 oz.
Relation of film weight to raw weight (percent)	27.0

Mine H (Spruce Pine district)

Description of sample: Color same as G. Many quartz inclusions. Splits fairly well when well trimmed, but most of sample poorly trimmed. Much air. Many cracks. Hard.

This sample showed such a high power factor at 1000 kc., by preliminary bridge measurement, that no further work was done on it.

Mine I

Description of sample: Color greyish brown with slight ruby tinge. Very poorly trimmed. Many quartz and other inclusions and holes. Surfaces fairly flat, splits well. Very hard.

Weights:

Sample	1 lb. 8.50 oz.
Scrap from splitting	1.50 oz.
Scrap from cutting	14.00 oz.
Reject films	1.50 oz.
Good films	7.50 oz.
Relation of film weight to raw weight (percent)	30.6

Mine J

Description of sample: Color similar to I but with yellowish shade in place of ruby, giving lighter brown. Very irregular surface, very scaly and splits poorly. Numerous air and mineral inclusions. Very poor mica in appearance.

Weights:

Sample	10.70 oz.
Scrap from splitting	.70 oz.
Scrap from cutting	5.80 oz.
Reject films	.40 oz.
Good films	3.80 oz.
Relation of film weight to raw weight (percent)	35.0

Results of electrical tests.--Silvered mica test capacitors (condensers) were built from the mica of each sample using the film thickness of which there was the greatest quantity in all samples. The samples were prepared by vaporizing silver on cleaned pieces, with a one-eighth inch margin. In some samples there was enough mica for only one capacitor, and the tests on these samples cannot be given much weight. Some India ruby mica was tested at the same time for comparison.

The electrical characteristics of each capacitor were determined, and they are listed below. Whenever there was a question about the results of a measurement, the tests were repeated on one or two extra pieces of mica. For load tests, each capacitor was run at its standard current rating at 1,000 and at 3,000 kc. until temperature stability was reached, as indicated by a spirit thermometer attached to the clamp. The results are tabulated in degrees Centigrade rise per KVA input, averaged over all capacitors tested from each sample.

Comments by R.C.A.--

(1) The preparation of the mica in these samples is considerably below the standard set by suppliers of India ruby mica. The physical quality of the mica is also below that of India ruby.

(2) The yield of finished films is not much more than half that of India mica, which is about 50 percent. Much of this loss is due to poor trimming by the supplier, leaving much waste material that should not reach the fabricator.

Table 7.--Results of electrical tests by R. C. A.

Mine	Quantity of mica tested (pieces)	Average capacity (Mmfd.)	Area (sq. cm.)	Thickness (cm.)	Power factors at 1,000 kc. (percent)			Dielectric constant	Load tests (degrees Centigrade/KVA)		Conclusion regarding suitability for receiver capacitors
					Highest	Lowest	Average		at 1,000 kc.	at 3,000 kc.	
F 1/.	3	520.4	8.46	0.01023	0.019	0.0142	0.0165	7.11	5.1	7.2	Satisfactory for plain and silvered capacitors. P.F. comparable to India mica.
G 1/.	6	532.1	9.31	.0111	.035	.00602	.0160	7.17	5.1	7.1	Unsatisfactory because of wide range of power factor.
H 1/.	6	537.8	8.27	.0098	.0467	.0043	.0311	7.19	Not tested because of unsatisfactory power factor.		Decidedly unsatisfactory because of wide range of power factor.
I....	3	533.4	8.70	.00998	.0241	.0172	.0203	6.89	5.2	8.3	Satisfactory for plain and silvered capacitors.
J....	5	531.5	9.36	.01075	.0261	.005	.0159	6.87	8.1	9.7	Satisfactory for plain mica capacitors only.
India ruby.	3	532.0	7.93	.00971	.0141	.00612	.0106	7.34	4.4	6.5	....

1/ Spruce Pine district

Flashover test: All samples were tested on D.C., and flashed over the edges at 6,000-8,600 volts, but the mica dielectric was not punctured in any sample.

(3) Of the samples tested, that from mine J indicates the highest loss under load tests--nearly twice that of India mica. The other three appear to be low enough to be reasonable substitutes for India mica.

(4) The dielectric strength of all samples is apparently equivalent to that of India mica.

MINING AND MARKETING

History of mining

The early history of muscovite mining in the Spruce Pine district has been summarized by Sterrett.[18] Weathered surficial portions of several pegmatite bodies were mined by American Indians before the region was settled by white men, but modern mining began in 1868. There was demand only for sheet mica, used principally as stove windows, until about 1893, when the grinding of scrap mica was begun. This provided an outlet for mica whose irregular cleavage makes it unfit for punch or sheet, and the demand for ground mica increased steadily until some mines were operated for scrap mica alone.

Sheet mica was first mined in weathered, easily excavated pegmatite, where large blocks were found at the surface. When hard rock was encountered, mining was continued by hand drilling until the inadequate pumping facilities could no longer handle the water. Improvement of equipment and growing demand for all grades of mica caused some of the better mines to become relatively large. The largest mines in the district are feldspar mines, most of which produce mica as a byproduct. The following are among the largest of the mica mines:

19	Meadow	Series of stopes 900 feet long.
24	Elk	Series of stopes 900 feet long.
51	Charlies Ridge	500-foot incline.
81	Hawk	Tunnel and stopes 800 feet long.
87	Clarissa	Series of shafts 450 feet long, maximum depth 475 feet.
105	Sinkhole	Series of interconnecting shafts, 1,100 feet long.
296	Fannie Gouge	850-foot incline.
298	Poll Hill	850-foot incline.
299	Gibbs	500-foot incline.

18/ Sterrett, D. B., op. cit., pp. 167-168.

Of 219 mica mines examined, 50 were being worked on a small scale during the period from November 1939 to the end of May 1940. Five of these mines employed more than 4 men each; the other 45 were operated intermittently by 2 or 3 men each. The remaining 169 mines were in various stages of inaccessibility because of flooding and caving. By May 1941, there had been considerable revival of mining, and some of the largest of the mines had been reopened.

One of the principal difficulties encountered in the study of domestic mica mining is that of intermittent operation, which can be caused by fluctuating prices, by legal difficulties, and by the erratic distribution of the mica. Table 8 shows, as examples, the intermittency of operation in five mines during periods for which records of production are available. The table indicates that the known or estimated output of a mine over a long period of years is commonly the result of actual mining during a small fraction of that time, and this fraction usually is the sum of still smaller fractions. Such frequent alternations of mining and abandonment must of course add considerably to mining costs.

Table 8.--Table showing intermittent operation of mica mines in the Spruce Pine district

Mine No.	Name of mine	Period of recorded production	Approximate percentage of full-time operation	Calculated actual working time (years)
214	Poteat.............	1917-33	27	4.4
249	Presley............	1922-40	26	4.5
289	Little Zeph Young...	1926-38	20	2.5
298	Poll Hill..........	1917-38	39	8.2
345	Murphy Rock (on Crabtree Creek)...	1930-38	24	2.1

Grading and prices

Domestic raw mica is divided commercially into three classes: sheet, punch, and scrap. Sheet and punch consist of flat and "flat A" mica that can be stamped, trimmed, or fabricated. In the Spruce Pine district, the terms "No. 1", "No. 2", and "No. 3" are used to designate general quality. "No. 1" is domestic clear mica, free of mineral inclusions, and corresponds approximately to the Indian and A.S.T.M. grades "clear", "clear and slightly stained", "fair-stained", and some "good-stained". "No. 2" is less perfect because of waviness, clay staining, or minor iron-oxide staining, and corresponds to the Indian "stained" and possibly some Indian "black-stained". "No. 3" is heavily stained with magnetite or hematite and corresponds to most of the Indian "black-stained or spotted" mica.

According to common usage, therefore, clear domestic mica includes not only sheet that is clear according to the Indian classification, but "fair-stained" and "good-stained" as well, and the term "clear" is used in this report in the same broad sense.

Sheet mica is graded according to size as well as quality. The general range of prices of mica locally classed as clear trimmed sheet, from 1917 to 1940, is shown in table 9. Prices fluctuate according to demand, and are currently at the maximum level. Sizes larger than 8 by 10 inches are rare.

Table 9.--Price range of clear sheet mica in the Spruce Pine district, 1917-40

Size (inches)	Price range (per pound)	Size (inches)	Price range (per pound)
$1\frac{1}{2}$ x 2	$0.15 - 0.60	3 x 5	$1.00 - 2.65
2 x 2	.30 - 1.00	4 x 6	1.75 - 3.60
2 x 3	.45 - 1.40	6 x 8	2.25 - 7.00
3 x 3	.60 - 2.00	8 x 10	3.50 - 11.00
3 x 4	.80 - 2.30		

Small sheet mica is classed as punch mica. Specifically, punch includes stained mica smaller than 2 inches square, but more than $1\frac{1}{2}$ inches in diameter, and clear mica smaller than $1\frac{1}{2}$ x 2 inches, but of greater diameter than $1\frac{1}{4}$ inches. Its value has ranged from 3 to $12\frac{1}{2}$ cents per pound over a long period of years.

Scrap mica, which is suitable only to be ground, comprises strongly reeved "A" mica, ruled and bent flat mica, trimmings from the manufacture of sheet and punch, and relatively fine-grained muscovite recovered from decomposed pegmatite and mica schist. Prices for scrap mica have ranged mostly from $10 to $20 per ton.

Production

The Spruce Pine district has been more or less consistently the principal producing area not only of North Carolina but of the United States. During 1929 and 1930, it is reported to have produced more than 85 percent of the State's total production of sheet mica.[19] This probably is higher than the all-time average, which may be estimated conservatively at about 65 percent. The recorded production of clear and stained sheet mica, including punch, from North Carolina is shown in table 10. The production of scrap mica is not listed because the amount obtained from mica-bearing pegmatite has been obscured during recent years by scrap derived from mines in clay, decomposed pegmatite, and mica schist.[20] The total production of scrap mica from North Carolina far exceeds in volume that of sheet and punch combined, and it has exceeded sheet and punch in value in most years since 1925.

Table 10.--Recorded production of sheet and punch mica from North Carolina, compared with total for the United States, including North Carolina 1/

Period	Amount (pounds)		Value	
	North Carolina	United States	North Carolina	United States
1868-81	400,000	Unrecorded	$800,000	Unrecorded
1880	Unrecorded	81,669	Unrecorded	$127,825
1881	....do....	100,000	....do....	250,000

1/ Figures from U. S. Geol. Survey Ann. Repts. 18-21, 1897-1901; Mineral Resources U. S., 1885-1931; and Minerals Yearbook, 1932-41.

19/ 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. 6616, p. 2, 1932.

20/ Tyler, P. M., and Warner, K. G., Mica: Minerals Yearbook, pp. 1360-1361, 1941.

Table 10.--Recorded production of sheet and punch mica--Continued

Period	Amount (pounds)		Value	
	North Carolina	United States	North Carolina	United States
1882	60,000	100,000	$150,000	$250,000
1883	68,400	114,000	171,000	285,000
1884	100,000	147,410	253,000	368,525
1885	60,000	92,000	105,000	161,000
1886	24,000	40,000	42,000	70,000
1887	50,000	70,500	87,500	142,250
1888	20,000	48,000	Unrecorded	70,000
1889	Unrecorded	49,500	....do....	50,000
1890	....do....	60,000	....do....	75,000
1891	....do....	75,000	....do....	100,000
1892	....do....	75,000	....do....	100,000
1893	....do....	66,971	....do....	88,929
1894	....do....	35,943	....do....	Unrecorded
1895	....do....	84,408	....do....	50,381
1896	....do....	Unrecorded	56,802	65,441
1897	65,225	82,676	Unrecorded	80,774
1898	84,687	129,520	....do....	103,534
1899	85,707	108,570	....do....	70,587
1900	107,255	456,283	....do....	92,758
1901	266,160	360,060	....do....	98,859
1902	303,816	373,266	65,419	83,843
1903	Unrecorded	619,600	Unrecorded	118,088
1904	610,121	668,358	100,724	109,462
1905	742,875	924,875	117,732	160,732
1906	800,440	1,423,100	205,756	252,248
1907	645,221	1,060,182	209,956	349,311
1908	599,234	972,964	114,540	234,021
1909	1,296,274	1,809,582	122,246	234,482
1910	455,020	2,476,190	193,223	283,832
1911	454,653	1,887,201	187,501	310,254
1912	489,599	845,483	219,874	282,823
1913	803,462	1,700,677	230,674	353,517
1914	274,121	556,933	171,370	278,540
1915	281,074	553,821	266,650	378,259
1916	546,553	865,863	380,700	524,485
1917	643,476	1,276,533	543,207	753,874
1918	941,200	1,644,200	460,450	731,810
1919	1,021,306	1,545,709	331,498	483,567
1920	1,084,946	1,683,480	405,654	546,972
1921	230,532	741,845	51,851	118,513
1922	544,495	1,077,968	119,767	194,301
1923	1,130,283	2,063,179	188,317	311,180
1924	597,385	1,460,897	108,656	212,035
1925	592,478	1,793,865	105,376	321,962
1926	700,313	2,172,159	150,362	400,184
1927	665,360	1,512,492	114,514	212,482
1928	777,395	1,681,777	129,706	230,956
1929	894,200	2,035,128	150,293	286,321
1930	749,074	1,465,485	112,451	177,307
1931	389,426	962,953	51,657	111,830
1932	127,696	338,997	18,322	45,882
1933	162,672	364,540	21,107	53,179
1934	293,381	583,528	38,674	90,268
1935	512,590	936,633	77,598	191,150
1936	730,446	1,319,233	119,653	203,879
1937	1,044,328	1,694,538	218,176	285,244
1938	632,646	939,507	87,879	139,333
1939	401,170	813,708	69,344	138,963
1940	1,002,646	1,625,437	218,154	291,685

Most of the mica mined in the district is sold to local buyers. Fairly complete records of production for the year 1938 show that 528 producers made 1,380 sales of mica, or an average of 2.6 sales each during the year. Eighty percent of these sales were of small lots, each less than $25 in value, obtained from part-time mining by hand methods, but these small lots accounted for only 14 percent of the year's total production of sheet mica (both clear and stained). The bulk of the sheet mica, therefore, was produced from a few relatively large mines.

Complete records of production could be obtained for only 3 out of a total of approximately 225 mica mines. As these have been opened since 1935, the difficulty of reconstructing production histories is obvious. Incomplete records, extending as far back as 1917, have been obtained also for 100 mica mines, and for the mica output of 27 feldspar mines. The recorded production of each of these 130 mines has been analyzed, and some of the results are shown in table 11. In assembling production data, attention was focused on relatively clear sheet mica, which has been the main product of most of the mines listed in the table. No special attempt was made to obtain complete figures for large producers of stained mica, such as the Meadow and Hootowl mines, and records pertaining to the output of scrap mica from individual mines are too fragmentary to be included. Scrap generally constitutes 65 to 90 percent, by volume, of the output of a mine.

Recorded production of clear sheet from the mines listed in table 11 has been combined to determine the size range of aggregate production, and the results are shown in table 12, together with values. The percentages of the different sizes of clear sheet are based on nearly half a million pounds of mica, most of which is classed as among the best produced in the district, and should be of considerable value in estimating the size range of future production of sheet mica from Spruce Pine.

Table 12.--Analysis of aggregate recorded production of sheet mica from 130 mines in the Spruce Pine district, 1917-40

	Quantity (pounds)	Percent of total quantity	Value	Percent of total value	Average value per pound
Sheet mica......	605,880	25.2	$483,552	82.2	$0.789
Punch mica......	1,797,774	74.8	105,013	17.8	.058
Sheet and punch.	2,403,574	100.0	588,565	100.0	.245

Sheet mica

Size	Clear		Stained	
	Pounds	Percent of total	Pounds	Percent of total
8 x 10..................	1,070	0.225	95	0.072
6 x 8..................	3,155	.664	720	.549
4 x 6..................	16,434	3.463	5,271	4.018
3 x 5..................	29,572	6.230	12,992	9.902
3 x 4..................	23,489	4.949	9,015	6.872
3 x 3..................	35,524	7.484	13,605	10.375
2 x 3..................	97,273	20.495	39,853	30.378
2 x 2..................	99,117	20.885	47,772	36.415
1½ x 2..................	161,418	34.007	......	......
Unclassified............	7,573	1.598	1,852	1.419
Totals................	474,625	100.000	131,175	100.000

FUTURE POSSIBILITIES

The erratic distribution of mica in pegmatite bodies of the Spruce Pine district makes it impossible to judge the economic possibilities of any single working face or outcrop, and it precludes specific estimates of reserves. It is possible to sample qualitatively, but not quantitatively. Theoretically, any pegmatite body proved by previous mining to contain mica of profitable quantity and quality may be regarded as a potential source of further production. Practically, however, this generalization is inapplicable for several reasons, chief among which is the lack of any known method of prospecting to block out valuable parts of the body. Diamond drilling might locate mica-bearing pegmatite, but is unlikely to provide any assurance that the mica crystals would be of commercial size and quality. Prospecting of this type might, in a few places where thin pegmatite bodies have been productive, find minable parallel bodies

Renewal of activity in abandoned mines, therefore, depends almost entirely on stimulation provided by market conditions, with the result that prospecting and mining merge into a single, economically hazardous undertaking. Operators will not invest in the machinery necessary to develop mines adequately without some assurance that prices will remain at a level that will justify the risk.

Production of sheet mica from North Carolina from 1924 through 1940, was 2,051,478 pounds, excluding 8,221,728 pounds of punch mica. At least 75 percent of the sheet, or 1,538,609 pounds, came from the Spruce Pine district, and about half of this amount was stained. The remainder, 769,305 pounds, is approximately the Spruce Pine district's production of clear sheet, larger than punch, during the 17-year period. The resulting average of 45,253 pounds per year includes the effects of variable market conditions, and may represent a rough average to be expected in the future if market conditions fluctuate in the same way. The results of the tests by the Bureau of Standards, listed above, indicate that much of the Spruce Pine mica has power factors as low as the best imported mica.

The computed average yearly production during the period 1924-40 was attained without coordinated planning and, in many cases, without proper equipment. It is known from the past history of the Spruce Pine district that rise in prices will not, of itself, affect production capacity quickly, nor permit attainment of approximate full capacity before a succeeding decline. There is little doubt that production of relatively clear sheet mica can be stimulated to an average figure possibly two to three times that of the years 1924-40, by (1) concentrating principally on mines that produce the most desirable mica, of which there are 70 or more, and by (2) promoting simultaneous operation in order to keep total production fairly uniform even though the output of individual mines may fluctuate. The data presented in table 11 provide a preliminary basis for estimating the individual production of most of the mines that would be involved in a systematic program, and those presented in table 12 may be used to estimate aggregate production.

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