MICA DEPOSITS OF THE BLUE RIDGE IN NORTH CAROLINA

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ABSTRACT

Pegmatites in the Blue Ridge of North Carolina are important sources of sheet and scrap mica, feldspar, kaolin, and quartz. Small amounts of beryl, columbite-tantalite, monazite, samarskite, and uranium minerals also have been produced. The mica-bearing pegmatites occur in mica and hornblende gneiss and schist throughout the Blue Ridge province but are concentrated in the Spruce Pine and Franklin-Sylva districts.

The Blue Ridge is geologically complex; the rocks are mainly polymetamorphic orthogneisses and paragneisses and schists that are part of a large thrust sheet that has moved at least 30 miles to the northwest in the northern part of the area. This thrust sheet is bounded on the east by the Brevard fault zone and on the west by the Unaka Mountain belt which consists of metamorphosed and nonmetamorphosed late Precambrain and Cambrian sedimentary rocks in various complex folds and thrust-faulted blocks.

During an early Precambrian metamorphic period a thick sequence of sedimentary and volcanic rocks was altered to gneiss and schist. Parts of the sequence were migmatized to layered granitic gneiss and intruded by masses of granite and granodiorite. In the early or middle Paleozoic a second period of regional metamorphism resulted in the widespread intrusion of pegmatite associated in some areas with large masses of finer grained granodiorite. The pegmatites are in areas where the metamorphic intensity in the second period of metamorphism reached at least the kyanite-muscovite subfacies of the almandine amphibolite facies. Some deformation of the pegmatites occurred after crystallization, and later faulting in the pegmatites is probably related to a late Paleozoic deformation that culminated in widespread thrust faulting.

The pegmatites have a simple mineralogy and structure and range in composition from granite to granodiorite. The principal minerals are oligoclase, perthitic microcline, quartz, and muscovite. Biotite and garnet are the main accessory minerals, but a wide variety of other minerals has been found in minor amounts.

Two-thirds of the pegmatite bodies are tabular, a quarter of them are lenticular, and the remainder are of irregular shape. About half the bodies are discordant with the foliation of the enclosing country rock. Simple zoning has been reported in about 40 percent of the deposits but may have been overlooked in some others. The most common type of zoned pegmatite has a plagioclase-quartz-muscovite wall zone and a quartz or quartz-perthite core. A few deposits have perthite intermediate zones or cores. More than half the deposits are deeply weathered, and for many of these the geology is incompletely known.

Sheet mica generally is scattered throughout unzoned deposits or is concentrated in wall zones. In some deposits, mica is concentrated in shoots within a zone. The size and quality of the mica vary widely between districts, within districts, and even within a single deposit. About 50 percent of the deposits contain some stained mica, about 15 percent contain mica with mineral intergrowths, and about 30 percent contain mica that has been deformed after crystallization.

Descriptive data are available on 1,350 mines and prospects. About 100 mines have an individual production greater than 10,000 pounds of sheet mica, but more than half of the deposits have produced less than 500 pounds each. Total production of sheet mica for the region is unknown. Production in recent years has been 25–50 percent of the total weight and 45–85 percent of the value of United States production. About half of the scrap mica and half or more of the feldspar produced in the country have come from the Blue Ridge area.

Reserves of sheet mica cannot be calculated but probably as much mica remains in the ground as has been mined. A few new deposits have been found in the last 20 years, but most of the recent production has been from old mines. Reserves of scrap mica, feldspar, and clay are extensive.

INTRODUCTION

Since 1868 the pegmatites of the Blue Ridge in North Carolina have been among the principal sources of sheet muscovite in the United States. Production of feldspar, kaolin, quartz, and scrap mica has also been large; minor amounts of beryl, columbite-tantalite, monazite, samarskite, uranium minerals, vermiculite, zircon, and other minerals have been produced as byproducts. The production of sheet muscovite has not been continuous since mining began; the principal periods of production include 1867–85, 1896–1913, 1916–20, 1922–30, 1935–46, and 1952–62.

Since 1961 the Blue Ridge province has produced annually one-quarter to one-half of the sheet mica mined in the United States. This production represents 45–85 percent of the total value of sheet-mica production. Most of this mica has come from two districts in North Carolina: the Spruce Pine district in Avery, Mitchell, and Yancey Counties and the Franklin-Sylva district in Haywood, Jackson, and Macon Counties. The other districts in the Blue Ridge (fig. 1) have produced only small amounts of mica during recent years and have never been important producers.

The pegmatite districts of the Piedmont province (fig. 1), which have also been important sources of muscovite, are described by Jahns and others (1952–53).

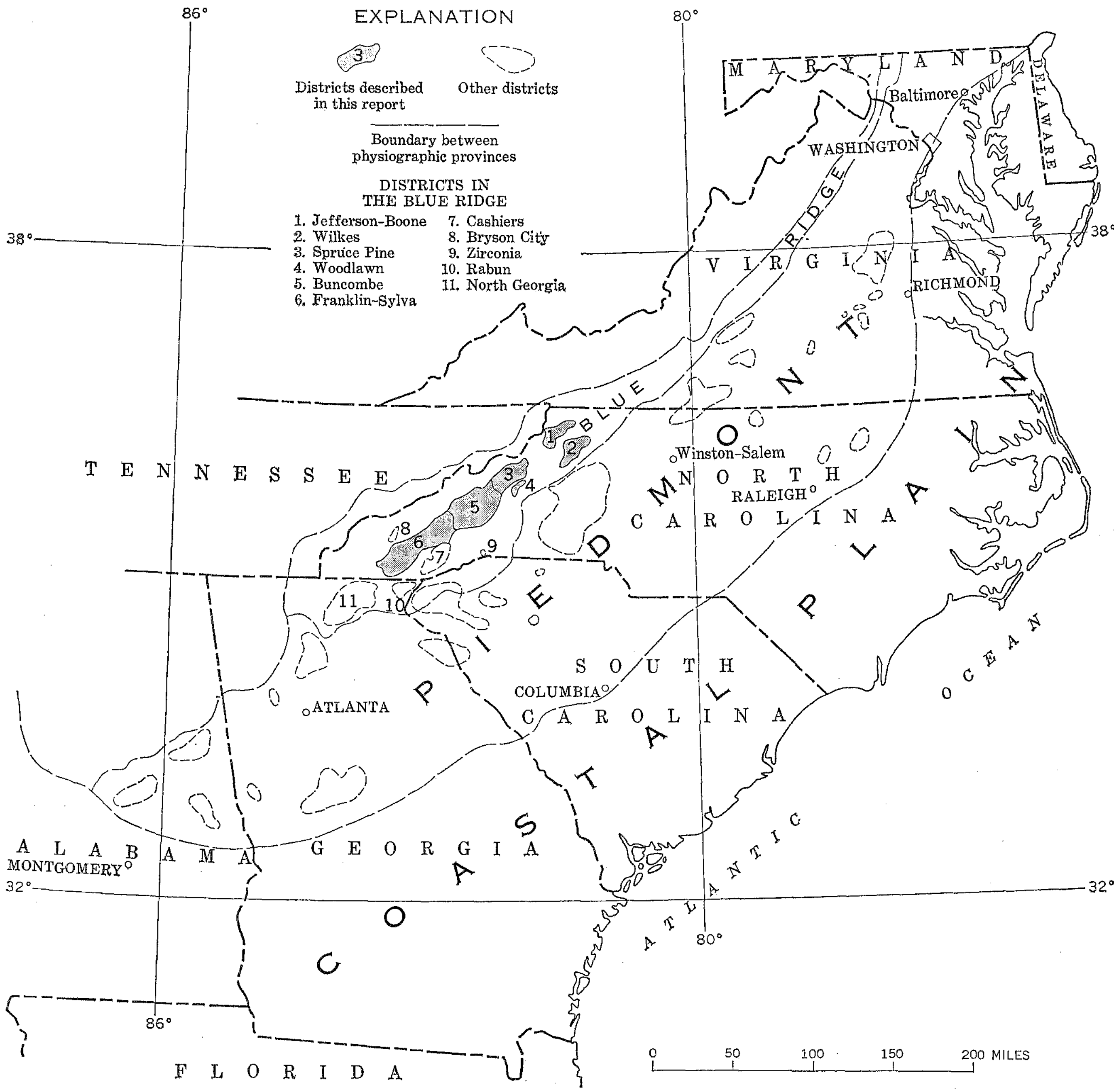

FIGURE 1. Map showing location of pegmatite districts in the southeastern United States.

INVESTIGATIONS

This report is based on studies of the mica deposits in the Blue Ridge of North Carolina made between 1939 and 1962 by geologists of the U.S. Geological Survey. From 1939 to 1945, 25 geologists and assistants mapped more than 200 mica deposits and examined nearly 800 others as part of the Survey's strategic minerals investigations (Kesler and Olson, 1942; Olson, 1944; Olson and others, 1946). The following men mapped in one or more of the principal districts in the Blue Ridge for periods ranging from 2 weeks to several years: V.C. Fryklund, Jr. (1943–44), L. W. Goldthwait (1944), W. R. Griffitts (1943–45), J. B. Hadley (1944), E. W. Heinrich (1944–45), J. E. Husted (1944–45), W. P. Irwin (1944–45), R. H. Jahns (1944–46), T. L. Kesler (1939–41), M. R. Klepper (1943–44), D. M. Larrabee (1943–44), R. W. Lemke (1943–45), Roswell Miller III (1944), J. J. Norton (1943), J. C. Olson (1939–45), J. J. Page (1941–43), J. M. Parker III (1940–46), L. C. Pray (1944), W. C. Stoll (1943), and R. A. Swanson (1945). Field assistants working for periods of 3–20 weeks included W. B. Allen (1943), Edward Ellingwood III (1944), P. W. Gates (1943), F. W. Hinrichs (1939–40), and L. W. Seegers (1943). The studies were under the supervision of T. L. Kesler (1939–41), J. C. Olson (1941–44), and R. H. Jahns (1944–46). During the period 1941–45 the work was done in cooperation with the North Carolina Department of Conservation and Development, and was integrated with the activities of the Colonial Mica Corp., an agent for the Metals Reserve Co.

Between 1945 and 1953, emphasis was placed on areal geologic mapping in the Spruce Pine district (Parker, 1952; Kulp and Brobst, 1956; Brobst, 1962), study of the feldspar deposits in the Bryson City district (Cameron, 1951), and examination of the pegmatites of the Cashiers and Zirconia districts (Olson, 1952). These studies were also done in cooperation with the North Carolina Department of Conservation and Development.

From 1951 to 1959 the Defense Minerals Exploration Administration (DMEA) and its successor, the Office of Minerals Exploration (OME), aided in the exploration for sheet muscovite by granting loans to individual operators. The exploration work was guided by the joint efforts of geologists from the U.S. Geological Survey and of mining engineers from the U.S. Bureau of Mines. The field examinations for the Geological Survey were made by D. H. Amos (1953–55), S. A. Bergman (1955–58), E. L. Boudette (1957), R. A. Laurence (1951–62), F. G. Lesure (1957–62), A. R. Taylor (1955–56), K. H. Teague (1951–55), and Helmuth Wedow (1958) and for the Bureau of Mines by W. A. Beck (1951–59), S. A. Feitler (1957–58), A. L. Peyton (1951–57), and L. E. Shirley (1952–58). More than 500 deposits were examined, some of which were mines mapped during World War II. The DMEA program in the southeast was under the direction of R. A. Laurence, regional geologist for the U.S. Geological Survey and Executive Officer of District V of DMEA, and V. J. Lynch, of the U.S. Bureau of Mines, who was Acting Executive Officer of District V of DMEA.

Notes, maps, and written descriptions from all the investigations during the 25 years before 1963 have been used in preparing this report. No maps of individual deposits accompany this report, but maps of most of the important deposits are available either in reports by Olson (1944) and Olson and others (1946) or from U.S. Geological Survey open-file depositories, as indicated in table 4.

GEOGRAPHY

The Blue Ridge province, which forms the mountainous backbone of the Appalachian Highlands in the southeastern United States, extends southwest from south-central Pennsylvania to northern Georgia for a total distance of 570 miles (fig. 1). The province is roughly wedge shaped. The northern half from Pennsylvania to Roanoke, Va., is less than 14 miles wide; summit altitudes rarely exceed 4,000 feet. The southern half of the province widens to a maximum of 70 miles in southwestern North Carolina and ends abruptly in northern Georgia. Many peaks and divides are above altitudes of 6,000 feet.

The Blue Ridge province is bounded on the southeast and around the southern end by the Piedmont province (fig. 1) and on the northwestern side by the Valley and Ridge province. The borders of the Blue Ridge are clearly defined in most places at the base of an abrupt slope, but, locally, the transition is too gradational to fix the boundary accurately.

In North Carolina the term "Blue Ridge" in its topographic sense is applied only to the main divide which lies near the southeastern edge of the province. The steep slope from the Piedmont to this divide is termed the "Blue Ridge front." The high linear mountain ridges along the northwestern edge of the province are called the Unaka Mountains. The mountain groups, ranges, and peaks between the Blue Ridge front and the Unakas generally lack a systematic orientation. The major valley bottoms are broad, but the slopes steepen rapidly along smaller streams. Slopes of 20°–45° are common in the headwater areas. Slopes inclined less than 10° form a minor part of the total area.

Much of the Blue Ridge province in North Carolina is drained by tributaries of the Tennessee and New Rivers, both of which flow into the Ohio River. The major rivers draining eastward to the Atlantic head along the Blue Ridge front. The area has a humid climate, and surface and ground water are generally abundant.

The mountains are heavily wooded. Rock exposures are generally limited to a few steep slopes, streambeds, and roadcuts. The depth of weathered rock ranges from a few feet to more than 100 feet.

GEOLOGY

The Blue Ridge province in North Carolina contains old sedimentary and igneous rocks that have a complex metamorphic and structural history. The area was mapped in reconnaissance by Arthur Keith and his associates from 1892 to 1906 (Keith, 1903; 1904; 1905a, b; 1907a–c). Recently, more detailed mapping has been completed in the Spruce Pine area (Olson, 1944; Parker, 1952; Kulp and Brobst, 1956; Brobst, 1962), the Hot Springs area (Oriel, 1950), northeastern Tennessee (Ordway, 1959; King and Ferguson, 1960), the Grandfather Mountain window area (Bryant, 1962, 1963; Bryant and Reed, 1962; Reed, 1964a, b; Reed and Bryant, 1964), the Great Smoky Mountains (Hamilton, 1961; Hadley and Goldsmith, 1963; King, 1964; Neuman and Nelson, 1965), and the Bryson City area (Cameron, 1951). On plate 1 the geology of the Blue Ridge has been generalized from Keith's folio maps and the more recent mapping.

The Blue Ridge geologic province, which does not coincide exactly with the physiographic province, has been divided into three major geologic belts by King (1955, p. 338): A narrow Brevard belt on the east, a wide Blue Ridge belt in the center, and the Unaka belt on the west. These belts differ in rock type, grade of metamorphism, and structure. More than half of the province is formed by the Blue Ridge belt, which contains a basement complex of older Precambrian mica gneiss and schist, hornblende gneiss and schist, migmatite, and granite gneiss, and locally extensive areas of younger Precambrian metasedimentary rocks. Intruded into these rocks are small stocks and dikes of younger Precambrian and Paleozoic granite, granodiorite, pegmatite, and ultramafic rocks. The presence of younger Precambrian and Cambrian metasedimentary rocks below rocks of the basement complex in the Grandfather Mountain window indicates that much of the Blue Ridge belt is an overthrust sheet that has moved to the northwest at least 30 miles (Bryant and Reed, 1962, p. 162). Several periods of regional metamorphism and deformation have obscured the stratigraphic relations of the various metamorphic and igneous rocks (Long and others, 1959; Bryant and Reed, 1962; Hadley and Goldsmith, 1963, p. B96–B107).

Mica-rich pegmatites are found only in the Blue Ridge belt and are restricted in general to the broad areas of mica and hornblende gneiss and schist. The only pegmatite district not in these rocks is around Bryson City where feldspar-rich mica-poor pegmatites cut metasedimentary rocks of the Ocoee Series near the edge of the Unaka belt (Cameron, 1951). The areas of granite gneiss in the Blue Ridge belt contain a few feldspar-rich pegmatites north of the Spruce Pine district and possibly a few mica-rich pegmatites southeast of Spruce Pine near the Grandfather Mountain window. Other pegmatites mentioned by Keith (1903, p. 3) in his description of the Cranberry Gneiss were not shown on the folio maps and are not shown on plate 1 of the present report.

The Brevard belt contains low-rank metamorphic rocks and may be a major fault zone along which high-rank rocks have been retrogressively metamorphosed (Jonas, 1932, p. 238; Reed and Bryant, 1960). Keith (1905b, 1907b) mapped the belt as Brevard Schist and interpreted it to be a downfolded mass of Cambrian rock. More recent reconnaissance and detailed studies have indicated that the rocks are phyllonites and blastomylonites derived by cataclastic retrogressive metamorphism of the rocks on either side of a fault zone (Reed and Bryant, 1960; Reed and others, 1961; Cazeau and Brown, 1963, p. 33), but the direction and amount of faulting are not known. A few intensely sheared pegmatite pods are present in the less intensely retrograded rock (Reed and others, 1961, p. C67).

The Unaka belt contains less metamorphosed sedimentary and volcanic rocks of late Precambrian and early Paleozoic ages (King, 1955, p. 364) and a few small areas of the basement complex exposed in various thrust sheets. The large thrust fault along which the Blue Ridge belt has moved is probably represented in the numerous thrust faults exposed in the Unaka belt (pl. 1).

LOWER PRECAMBRIAN BASEMENT COMPLEX

MICA AND HORNBLENDE GNEISS AND SCHIST

Most of the Blue Ridge belt is composed of a thick sequence of interlayered mica gneiss and schist and hornblende gneiss and schist. The mica-rich rocks comprise Keith's Carolina Gneiss, and the hornblende-rich rocks, his Roan Gneiss. Keith (1904, p. 2) described the Carolina Gneiss (of former usage) as "an immense series of interbedded mica-schists, garnet-schists, mica-gneiss, garnet-gneiss, and fine-grained granitoid layers." The Roan Gneiss (of former usage) he described as "a great series of beds of hornblende-gneiss, hornblende-schist, and diorite, with some interbedded mica-schist and mica-gneiss (Keith, 1904, p. 3). Recent workers in the Spruce Pine district, however, did not use Keith's terminology; instead, they mapped areas of predominately mica schist, mica gneiss, or hornblende gneiss (Olson, 1944; Parker, 1952; Brobst, 1962). The different rock types are not shown separtely on plate 1.

The mica-rich rocks are the more abundant of the two groups, and mica gneiss is probably more abundant than mica schist. The gneiss and schist are interlayered and grade from one to the other. Both are light to dark gray and fine to coarse grained. Both are composed of various amounts of feldspar, quartz, muscovite, and biotite. The feldspar is chiefly oligoclase or sodic andesine (Parker, 1952, p. 6; Bryant, 1962, p. D12). In the gneiss, feldspar and quartz layers alternate with layers of biotite and muscovite. Biotite tends to be more common in the gneiss; muscovite more common in the schist. Garnet may be abundant in either gneiss or schist. Graphite, apatite, epidote, staurolite, kyanite, sillimanite, and orthoclase are present in some layers. Biotite and garnet generally are more abundant near layers of hornblende-rich rock, but large belts of garnet gneiss are found in areas where hornblende gneiss is scarce (Keith, 1904, p. 2).

Kyanite-rich gneiss and schist are abundant in certain linear belts 3–8 miles wide and 20–40 miles long. Such belts are fouud in the Black and the Great Craggy Mountains (Keith, 1905b), in the region northwest of Asheville (Keith, 1904), in the Balsam and Pisgah Mountains (Keith, 1907b), and in the Nantahala and Cowee Mountains (Keith, 1907a). An extensive belt of sillimanite gneiss has been traced from Warne in Clay County to Sylva in Jackson County (Hash and Van Horn, 1951). A few lenses of marble occur locally (Keith, 1904, 1905b; Brobst, 1962, p. A8; Conrad, 1960).

Hornblende schist and gneiss are interlayered in various proportions with the mica-rich rocks throughout the Blue Ridge belt. The hornblende schist is dark green to black and consists mostly of hornblende, oligoclase-andesine, quartz, garnet, epidote, and monoclinic pyroxene (Bryant, 1962, p. D12). Minor amounts of actinolite, anthophyllite, biotite, chlorite, and zoisite are also present locally (Brobst, 1962, p. A8). The hornblende gneiss contains layers of hornblende alternating with layers of quartz or layers of feldspar, quartz, and garnet. Some hornblende-rich rocks are more massive and resemble diorite gneiss or metagabbro (Kieth, 1904, p. 3.).

The hornblende gneiss and schist are more abundant in the northeastern parts of the Blue Ridge belt. Kieth (1903, 1904, 1905b, 1907c) mapped a broad area of Roan Gneiss in Ashe and Watauga Counties, another in Avery, Mitchell, and Yancey Counties, and a third in Buncombe and Madison Counties. South of Asheville, however, in the Pisgah (Keith, 1907b) and Nantahala (Kieth, 1907a) quadrangles the hornblende gneiss and schist occur only as scattered narrow belts within a broad area predominantly of mica gneiss. In the northeastern areas the hornblende and mica gneisses are commonly interlayered. Layers of each range in thickness from a few inches to many feet and are parallel. Many of the mica mines are in areas of such interlayered rock. To the southwest this small-scale interlayering is not so common. Near Franklin most of the hornblende gneiss is restricted to lenses and tabular bodies of massive gneiss. Some of these units cut the layering and foliation of the mica gneiss.

Metamorphism and deformation have so obscured the original character of the interlayered mica and hornblende gneiss and schist units that little can be said about their origin. The well-layered mica schist and gneiss units were probably argillaceous and quartzose sediments. According to Hadley and Goldsmith (1963, p. B12), the presence of feldspar and mafic minerals and the absence of rocks with more than 65 percent quartz indicate that the sediments may have been muddy or feldspathic sandstone or graywacke or that they contained volcanic material. The interlayered hornblende gneiss and amphibolite may have been iron-rich dolomitic sediments or andesitic or basaltic tuffs (Hadley and Goldsmith, 1963, p. B12); the more massive hornblende gneisses are probably metamorphosed intrusive bodies of gabbro or diorite.

LAYERED GRANITIC GNEISS

The area shown as layered granitic gneiss on the geologic map (pl. 1) includes most of what Keith mapped as "Cranberry Granite" and also the small area that he mapped as "Henderson Granite" northeast of Old Fort (Keith, 1905b). In the Cranberry, Keith (1904, p. 3–4) included granite of various texture and color, schists and gneisses derived from granite, and small bodies of metabasalt, metadiabase, metarhyolite, pegmatite, quartz-diorite, and mica and hornblende gneisses similar to the Carolina and Roan Gneisses of former usage. According to Bryant (1962, p. D13), the Cranberry in the type area consists of masses of gray layered and nonlayered granitic gneiss and layers of green to black amphibolite, hornblende gneiss, and epidote-biotite schist. He redefined the unit as the Cranberry Gneiss because of the prevalence of gneissic structure and the heterogeneous composition (Bryant, 1962, p. D13). Hamilton (1960) found massive uniform granite, layered granite, quartz monzonite and granodiorite, migmatite, and gneiss in areas of northeastern Tennessee mapped as Cranberry by Keith. According to Hamilton (1960, p. 13), at least some of Keith's metarhyolite layers are mylonite. Oriel (1950, p. 32) found many diverse rock types in areas of Keith's Cranberry Granite near Hot Springs, N.C., and in other areas also this unit probably includes many types of metamorphic and plutonic rock.

The age and stratigraphic relationships of the layered granitic gneisses to other rocks in the Blue Ridge are not clear. Keith thought the Cranberry was younger than the gneisses of the Carolina and Roan, but recent workers in the Spruce Pine area have interpreted the Cranberry as interlayered with the mica and hornblende gneisses in a transition zone and consider the Cranberry to be the oldest unit of a thick sedimentary sequence that has been metamorphosed and granitized (Brobst, 1955, p. 581; Eckelmann and Kulp, 1956). Bryant (1962, p. D14) also recognized a mixed zone between Cranberry Gneiss and the mica and hornblende gneisses and suggests that the transitional rocks are a migmatite zone and the Cranberry a more granitized part of that zone. Because of structural complications, it is uncertain whether or not the Cranberry Gneiss lies stratigraphically below the mica and hornblende gneisses (Bryant, 1962, p. D14).

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GRANITE AND NONLAYERED GRANITIC GNEISS

Large masses of lower Precambrian nonlayered granitic gneiss and gneissic granite are found within layered gneiss along the western edge of the Blue Ridge belt and as isolated areas in the Grandfather Mountain window and in the southeastern part of the Great Smoky Mountains. The layered granitic gneiss unit also contains numerous other smaller bodies of nonlayered gneiss not mapped by Keith and too small to show on plate 1. The larger bodies of nonlayered gneiss in the layered gneiss were mapped by Keith as Beech Granite in the Cranberry and Roan Mountain quadrangles (Keith, 1903, 1907c) and as Max Patch Granite in the Asheville and Greeneville quadrangles (Keith, 1904, 1905a). Recent work by Bryant (1962, p. D15) indicates that "the Beech Granite is a coarse-grained inequigranular white to light-pink, cataclastic granite or quartz-monzonite gneiss." According to Bryant, no pegmatite has been found in the Beech Granite of the type area on Beech Mountain west of Boone. The Beech Granite is probably intrusive into the Cranberry Gneiss (Keith, 1903, p. 3; Bryant, 1962, p. D16).

A similar nonlayered granite gneiss occurs in elongate masses and irregular bodies along the edge of the Blue Ridge belt northwest of Asheville. Keith (1904, p. 4) named this gneiss the Max Patch Granite after typical exposures on Max Patch Mountain in Madison County, N.C. He described the gneiss as a light-gray to red coarse-grained granite gneiss which in places contains feldspar that is altered to epidote and saussurite (Keith, 1904, p. 4). Bradley (1874) applied the term "unakite" to some of the more altered Max Patch Granite that consisted of epidote, orthoclase, and quartz. According to Keith, the Max Patch Granite intrudes the layered granite gneiss (Keith, 1904, p. 4).

Oriel (1950, p. 31–33) found little true granite in areas mapped as Cranberry and Max Patch near Hot Springs, N.C. In Haywood County along the eastern edge of the Great Smoky Mountains and southwest of Hot Springs, Hadley and Goldsmith (1963, p. B13–B14) mapped as basement complex an area of plutonic rocks that is continuous with a large area in the adjoining Asheville quadrangle mapped by Keith (1904). They described a finer grained phase of the plutonic series that roughly corresponds to Keith's Cranberry Granite and a coarser phase that corresponds to what he mapped as Max Patch. They also found small bodies of pegmatite rich in pink or flesh-colored potassium feldspar and generally sheared (Hadley and Goldsmith, 1963, p. B14, B20).

Recently, Bryant (1962, p. D5) has named the nonlayered gneiss within the Grandfather Mountain window the Wilson Creek Gneiss. This unit includes rocks that Keith (1903, p. 3) mapped as Cranberry Granite, Carolina Gneiss, and Beech Granite. The Wilson Creek Gneiss has an average composition of quartz-monzonite and is generally a light-gray medium to coarse-grained cataclastic rock. Veins and pods of pegmatite are abundant, but in general are too small to justify prospecting or mining. The pegmatite consists of quartz, microcline, and albite; the maximum grain size is 4 inches (Bryant, 1962, p. D6). According to Bryant (1962, p. D20), the Wilson Creek Gneiss formed as a massive granitic rock, but its genetic relationship to other lower Precambrian rocks is not known.

Nonlayered and layered granite gneisses also occur in the basement complex in the southeastern part of the Great Smoky Mountains. Around Bryson City, N.C., the granite gneiss is a fine- to coarse-grained equigranular to markedly inequigranular rock that ranges in composition from granite to granodiorite (Cameron, 1951, p. 10). Inclusions of biotite and hornblende schist and gneiss and layered granitic rocks rich in biotite and hornblende also are found in the complex. The different rock units represent intrusive rocks of different ages and granitized metasediments. All the rocks have been metamorphosed and deformed after intrusion (Cameron, 1951, p. 10). Pegmatite bodies ranging from thin seams to large irregular and tabular masses as much as 500 feet in length occur in the complex and in the metasediments that surround the complex. The pegmatite fills fractures formed after development of the granite complex and seems to be related more to the later regional metamorphism than to the formation of the granite (Cameron, 1951, p. 42).

Granitic rocks east and northeast of Bryson City are described by Hadley and Goldsmith (1963, p. B13–B24) as biotite flaser and augen gneisses that have a composition of quartz monzonite and granodiorite. Small layers of mica gneiss, hornblende gneiss, and migmatite are common. A few lenses and irregular bodies of sheared pegmatite ranging in width from several inches to several feet occur in the granitic rocks in the Dellwood area (Hadley and Goldsmith, 1963, p. B20). The principal minerals are pink potassium feldspar, subordinate plagioclase and quartz, and scarce biotite and garnet.

UPPER PRECAMBRIAN ROCKS

BAKERSVILLE GABBRO

The term Bakersville Gabbro was first used by Keith (1903) for rocks on Hump Mountain in the southwestern part of the Cranberry quadrangle. The name is taken from exposures near Bakersville, Mitchell County, N.C., where an extensive area is underlain by similar rocks (Kulp and Brobst, 1953). According to Bryant (1962, p. D16–D17), the rock on Hump Mountain is a dark-gray to black, massive to schistose, and locally

porphyritic, metagabbro. Labradorite, monoclinic pyroxene, and opaque minerals are present in the less metamorphosed parts, and hornblende, garnet, calcic oligoclase-andesine, monoclinic pyroxene, biotite and opaque minerals are found in the recrystallized parts. Wilcox and Poldervaart (1958) describe similar metagabbro from near Bakersville as part of a large dike swarm.

The Bakersville Gabbro intrudes both the layered granitic gneiss and the interlayered mica-hornblende gneiss. The gabbro is younger than the early plutonic metamorphism but older than the late regional metamorphism (Kulp and Poldervaart, 1956, p. 399).

A few bodies of metagabbro were also mapped by Keith (1904) near Alexander and Stocksville in Buncombe County. This gabbro Keith considered to be related to the hornblende gneiss of his Roan Gneiss and older than the Bakersville Gabbro which he considered unmetamorphosed. These bodies of metagabbro are not shown on plate 1.

OCOEE SERIES

Metasedimentary rocks of the Ocoee Series of late(?) Precambrian age make up most of the Great Smoky Mountains and also occur in small downfolded areas in the Blue Ridge belt (King, 1955, p. 360). Because detailed information is lacking, the smaller downfolded areas of Ocoee or equivalent rocks are not shown separately in the broad area of mica and hornblende gneiss on plate 1. The metasedimentary rocks include variably metamorphosed conglomerate, sandstone, and siltstone and have been divided into three groups and a number of formations (King and others, 1958). Where highly metamorphosed, the metasedimentary rocks closely resemble the schists and gneisses of the older mica gneiss unit, but they contain no hornblende gneiss layers (Hadley and Goldsmith, 1963; King, 1955, p. 360). Southeast of the kyanite isograd shown on plate 1, the metasedimentary rocks contain small scattered pegmatite lenses; locally, as around Bryson City, large masses of pegmatite are found in the Ocoee Series (Cameron, 1951; Hadley and Goldsmith, 1963, p. B104). The boundary between metasedimentary Ocoee rocks and the mica gneiss unit is not well established in the Alarka, Cowee, and Nantahala Mountains southwest of Dillsboro.

Metasedimentary rocks that may be equivalent to the Ocoee Series have been mapped in the Grandfather Mountain window (Bryant, 1962, p. D9) and parts of the northeastern Tennessee (King and Ferguson, 1960, p. 29–32), but in those areas they contain interbedded mafic and felsic volcanic rocks. In the Grandfather Mountain area the metasedimentary rocks are low-rank phyllites, arkosic quartzites, and graywackes. These rocks contain some quartz veins and quartz-microcline veinlets but no large pegmatites.

PALEOZOIC SEDIMENTARY ROCKS

CHILHOWEE GROUP

Quartzite, phyllite, and arkosic quartzite of the Chilhowee Group of Early Cambrian(?) and Early Cambrian age and the Shady Dolomite of Early Cambrian age are exposed in a thrust sheet below rocks of the basement complex in the Grandfather Mountain window east of the Spruce Pine district (Bryant and Reed, 1962). More complete sections of unmetamorphosed Chilhowee Group, Shady Dolomite, and Rome Formation (Lower Cambrian) are exposed in thrust sheets and windows in the Unaka Mountains to the northwest (Oriel, 1950; King and Ferguson, 1960). None of these formations contains pegmatites.

ROCKS OF THE MURPHY MARBLE BELT

Metasedimentary rocks consisting of phyllite, schist, quartzite, and marble that are distinctly different from the Ocoee Series occur in an elongate area southwest of Bryson City (Keith, 1907a; Van Horn, 1948; King, 1955, p. 363). These rocks have been interpreted as a downfolded mass of Paleozoic metasedimentary rocks (Keith, 1907a), as windows of Chilhowee rocks in the Great Smoky overthrust sheet (Stose and Stose, 1944, p. 377), and as older metasedimentary rocks of the Ocoee Series (Van Horn, 1948, p. 20). According to Van Horn (1948, p. 7–8), small masses of fine-grained pegmatite consisting of plagioclase, quartz, and muscovite, are "distributed in migmatitic fashion" in mica schist near the center of the belt.

CAMBRIAN AND ORDOVICIAN ROCKS

Along the western edge of the Unaka belt, relatively unmetamorphosed sedimentary rocks of Cambrian and Ordovician age occur in windows and thrust sheets. No pegmatite deposits are associated with these rocks.

PALEOZOIC(?) INTRUSIVE ROCKS

ULTRAMAFIC ROCKS

More than 275 bodies of ultramafic rock, mostly dunite but including other varieties of peridotite and pyroxenite, and associated soapstone and amphibolite derived from them, are scattered throughout the Blue Ridge belt in the layered granitic gneiss and the mica and hornblende gneisses (Hunter, 1941, p. 11). These ultramafic deposits are not shown on plate 1, but are shown on the maps by Keith (1903, 1904, 1905b, 1907a–c), Cameron (1951), Brobst (1962). Bryant (1962), and Hadley and Goldsmith (1963). Most of the unaltered ultramafic rocks are dunites consisting of olivine and minor assessory minerals. Pratt and Lewis (1905, p. 28–34) describe 15 other kinds of ultramafic rocks that contain various proportions of olivine, pyroxene, and amphibole, and several types of rock formed by secondary alteration. Contacts between ultramafic rock and the enclosing gneiss and schist are relatively sharp and generally roughly concordant (Pratt and Lewis, 1905, p. 26; Hadley, 1949, p. 113; Miller, 1953, p. 1137). The outer edges of most ultramafic rocks are altered and sheared, and even the fresh dunite in the larger masses is generally granulated. Where cut by joints and faults, the dunite is altered to chlorite, talc, vermiculite, asbestos, or serpentine.

Many of the ultramafic deposits are only a few feet or few tens of feet wide and a few hundred feet long; but one of the largest masses is 2,000 feet wide and 8,000 feet long and covers an area of 300 acres on Buck Creek in Clay County. This deposit consists chiefly of dunite (90 percent), but includes troctolite (8 percent) and some edenite-amphibolite; it has been mined for corundum (Hadley, 1949). Another extensive deposit forms a ringlike structure 6 miles long and 3.5 miles wide between Addie and Webster in Jackson County. According to Miller (1953, p. 1137), the principal rock types there are dunite, websterite, and enstatite pyroxenite.

The age of the ultramafic rocks is not well established, but it is probably early Paleozoic. The ultramafic rocks are younger than the gneisses that they intrude, but, they are also deformed (Cameron, 1951, p. 9; Miller, 1953, p. 1134; Hadley and Goldsmith, 1963, p. B73). In several places in the Spruce Pine district, and in Buncombe and Jackson Counties dunite is cut by later granitic pegmatites. Hadley and Goldsmith (1963, p. B74) consider the metamorphosed ultramafic bodies in the eastern Great Smoky Mountains to be younger than the Ocoee Series, although nowhere are ultramafic bodies found cutting rocks of the Ocoee Series.

The dunite masses have been an important source of corundum (Pratt and Lewis, 1905, p. 358–368), a minor source of chromite, and more recently, a major source of olivine for refractories (Hunter, 1941). Some vermiculite (Murdock and Hunter, 1946) and anthophyllite asbestos (Bryant, 1962, p. D28) have also been mined from altered deposits.

GRANITIC ROCKS AND PEGMATITE

Younger granitic rocks and pegmatite intrude the basement complex throughout much of the Blue Ridge. The largest bodies are the masses of quartz monzonitic to granodioritic composition that Keith (1907b) mapped as Whiteside Granite in parts of Jaskson, Macon, and Transylvania Counties. Smaller masses of coarse-grained muscovite granodiorite, often times called alaskite, intrude mica and hornblende gneiss in the Spruce Pine district (Olson, 1944, p. 22–25; Parker, 1952, p. 8–11; Brobst, 1962, p. A10–A11; Bryant, 1962, p. D18–D19), and dome-shaped bodies of medium-grained massive granite intrude similar rocks in the northern part of Wilkes County and adjacent Alleghany County (Watson, 1910, p. 152; Stuckey and Conrad, 1958, p. 22). Pegmatites, some of them associated with the larger masses of granitic rock, are common in the mica and hornblende gneiss unit (pl. 1). Other dikes and sills of trondhjemite (Hadley and Goldsmith, 1963, p. B71), prophyritic quartz monzonite and leucogranite (Cameron, 1951, p. 12), and granite (Olson and others, 1946, p. 5–6) are widely scattered throughout the district but are not shown on plate 1.

None of these intrusions is dated accurately, but at least some of them are probably Paleozoic. Age determinations reported for minerals from several pegmatites and the Whiteside Granite range from 170 to 708 million years (table 1), but these dates may reflect the final metamorphism and not the time of original crystallization.

WHITESIDE GRANITE

The Whiteside Granite was named by Keith (1907b, p. 4) from exposures on Whiteside Mountain in Jackson County. Similar dome-shaped masses of granite mixed with gneiss occur in adjacent parts of Macon and Transylvania Counties (pl. 1). The areas that Keith mapped as Whiteside contain numerous sills, dikes, and irregular mass of granite interlayered with and cutting mica gneiss. Gneiss in contact with granite generally contains much added feldspar and quartz, and has been described as migmatite (Olson, 1952, p. 5) or lit-par-lit injection gneiss (Sharp and Allen, 1938). The granite itself probably has a range in composition: Heinrich (1953, p. 75) describes it as a tonalite-granodiorite, and Griffitts and Overstreet (1952, p. 787) call it a biotite-muscovite-quartz monzonite. The rock is composed of potassium feldspar, plagioclase, quartz, muscovite, and biotite in various proportions (Olson, 1952, p. 3). Minor amounts of magnetite, ilmenite, pyrite, garnet, zircon, and monazite form the principal accessory minerals. The color is typically white or light gray but becomes darker where the biotite content is greatest. Some of the granite is massive, but much of it is weakly foliated.

Little detailed information about the Whiteside Granite has been published. Differences in heavy mineral content and mode of occurrence between several masses suggest different rocks of more than one age of intrusion (W. R. Griffitts, written commun., 1964). Lead-alpha determinations on monazite and zircon from the Whiteside range from 358 to 708 million years (table 1) and are not definitive. The age of the Whiteside may therefore be Precambrian, Paleozoic, or both. A Paleozoic(?) age is used in this report.

TABLE 1.—*Age determinations on various minerals from the Blue Ridge of North Carolina and Tennessee*

Source rock	Location	Mineral	Age of mineral, in millions of years								Reference
			U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Th^{232}/Pb^{208}	Rb^{87}/Sr^{87}	K^{40}/Ar^{40}	Lead-alpha	U/Pb chemical	
	North Carolina										
	Spruce Pine district: Avery County: C. Ridge.	Muscovite					348±17				Deuser and Herzog, 1962, p. 1999.
	Mitchell County: Abernathy mine	Biotite					311±16				Do.
		Muscovite					340±20				Do.
	Chestnut Flat mine	Uraninite	385	390	400±50						Aldrich and others, 1958, p. 1128.
		Uraninite	370	375	420±50						Do.
		Muscovite					375	335			Do.
		Potassium feldspar.					385				Do.
	Deer Park	Uraninite								340	Føyn, 1938, p. 18; Rodgers, 1952, p. 418.
		Monazite								580	Bliss, 1944; Rodgers, 1952, p. 421.
	Flat Rock mine	Uraninite [1]								350	Hillebrand, 1891, p. 65–67; Rodgers, 1952, p. 419.
		Uraninite [2]								370	Do.
		Uraninite								340	Boltwood, 1907, p. 79; Rodgers, 1952, p. 418.
		Uraninite	344±4	346±5	372±15						Eckelmann and Kulp, 1957, p. 1124.
		Gummite			355±20						Do.
	Hootowl mine	Feldspar						278			Carr and Kulp, 1957, p. 776.
		Muscovite						334±15			Long and others, 1959, p. 594.
Pegmatite	McKinney mine	Samarskite	367±18	353±20	300±40	400±80					Eckelmann and Kulp, 1957, p. 1124.
		Samarskite	314±10	316±10	342±20	302±30					Do.
		Muscovite						334±15			Long and others, 1959; p. 594.
		Muscovite						348±15			Do.
		Feldspar						231			Carr and Kulp, 1957, p. 776.
		Feldspar						242			Do.
	Minpro mine	Feldspar						248			Carr and Kulp, 1957, p. 776.
		Muscovite						341±13			Long and others, 1959, p. 594.
	Stony Point	Uraninite								310	Von Foullon, 1883, p. 7; Rodgers, 1952, p. 419.
	Wiseman mine	Samarskite	307±6	312±13	380±80	205±50					Eckelmann and Kulp, 1957 p. 1124.
	Specific localities not given.	Uraninite [3] Outside layer.								330	Alter and McColley, 1942; Rodgers, 1952, p. 418.
		Middle layer.								340	
		Core								350	
		Samarskite	282±13	292±17	405±60	170±10					Eckelmann and Kulp, 1957, p. 1124.
		Uraninite			355±20						Do.
	Yancey County: Mudhole mine.	Muscovite					328±18				Deuser and Herzog, 1962, p. 1999.
	Wilkes County: Haw mine.	Muscovite					334±17				Deuser and Herzog, 1962, p. 1999.
	Caldwell County: McGee mine.	Muscovite					317±15				Do.

See footnotes at end of table.

TABLE 1.—*Age determinations on various minerals from the Blue Ridge of North Carolina and Tennessee*—Continued

Source rock	Location	Mineral	Age of mineral, in millions of years: U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Th^{232}/Pb^{208}	Rb^{87}/Sr^{87}	K^{40}/Ar^{40}	Lead-alpha	U/Pb chemical	Reference
	North Carolina—Con.										
Pegmatite—Con.	Madison County: Mars Hill.	Feldspar						290			Carr and Kulp, 1957, 776.
		Feldspar						293			Do.
		Monazite								[4] 600	Marble, 1936; Rodgers 1952, p. 421.
		Monazite								[4] 680	Do.
		Monazite								[4] 620	Laue, 1937, p. 58; Rodgers, 1952, p. 42
		Monazite									
		Monazite								[4] 650	
		Monazite								[4] 235±70	Eckelmann and Kulp, 1957, p. 1125.
	Franklin-Sylva district: Jackson County: Gay prospect.	Muscovite						348±13			Long and others, 1959, p. 594.
	Macon County: Grindstaff mine	Biotite					256±14				Deuser and Herzog, 1962, p. 1999.
		Muscovite					508±27				Do.
	Iotla mine	Biotite					293±15				Do.
		Muscovite					512±28				Do.
	Swain County: Deep Creek No. 1, Bryson City district.	Feldspar						287			Carr and Kulp, 1957, p. 776.
		Feldspar						296			Do.
		Muscovite						340±13			Long and others, 1959, p. 594.
Whiteside Granite	Jackson County: 3¾ miles west of Cashiers.	Zircon							689		Jaffe and others, 1959, p. 115–116.
		Monazite							358		Do.
	Macon County: On U.S. Highway 64, north edge of Highlands.	Monazite							368		Do.
	5 miles west of Highlands.	Monazite							413		Do.
		Monazite							437		Do.
		Zircon							708		Do.
Rocks of Murphy marble belt (Valleytown Formation)	Cherokee County: Andrews.	Biotite						373			Kulp and Eckelmann, 1961, p. 409.
Ocoee Group	Swain County: 5.6 miles southeast of Newfound Gap.	Biotite						382			Kulp and Eckelmann, 1961, p. 409.
	Tennessee Polk County: Route 64 near Ducktown.	Biotite					329±13	434±15			Long and others, 1959, p. 595.
	Ducktown	Muscovite						327			Kulp and Eckelmann, 1961, p. 409.
Metadiabase (Bakersville Gabbro?)	*North Carolina* Mitchell County: Red Hill.	Biotite						433±15			Long and others, 1959, p. 594.
		Biotite						457±21			Do.
Granite and nonlayered granitic gneiss: Max Patch Granite	Madison County: Southeastern Great Smoky Mountains (Max Patch Mountain).	Zircon							880		Carroll and others, 1957, p. 187.
Granite and nonlayered granitic gneiss: Granitoid gneiss	Haywood County: Dellwood quadrangle.	Zircon							535		Hadley and Goldsmith, 1963, p. B24.
Granite and nonlayered granitic gneiss: Beech Granite	*Tennessee* Carter County: Route 19E near Hopson.	Biotite					439±17	418±16			Long and others, 1959, p. 594, 587.
		Feldspar					572±29				Do.
	Roan Mountain	Zircon	555	585	700	425					Tilton and others, 1959, p. 174.
		Biotite					420	380			Do.
Granite and nonlayered granitic gneiss: Nonlayered granitic gneiss	*North Carolina* Avery County: Old quarry by road west of Crossnore.	Zircon	700	725	800±50	680					Davis and others, 1962, p. 1991.
		Hornblende						840±25			Hart, 1961, p. 2999.
Granite and nonlayered granitic gneiss: Augen gneiss	Watauga County: Roadcut, U.S. 321 bypass, north side of Blowing Rock.	Zircon	990	1,010	1,055	1,000					Davis and others, 1962, p. 1991.
Granite and nonlayered granitic gneiss: Quartz monzonite gneiss	Caldwell County, quarry near Mortimer.	Zircon	800	860	1,020	670					Davis and others, 1962, p. 1991.
		Biotite					350				Do.

See footnotes at end of table.

TABLE 1.—*Age determinations on various minerals from the Blue Ridge of North Carolina and Tennessee*—Continued

Source rock	Location	Mineral	Age of mineral, in millions of years: U^{238}/Pb^{206}	U^{235}/Pb^{207}	Pb^{207}/Pb^{206}	Th^{232}/Pb^{208}	Rb^{87}/Sr^{87}	K^{40}/Ar^{40}	Lead-alpha	U/Pb chemical	Reference
Layered granitic gneiss (Cranberry Gneiss)	*Tennessee* Carter County: Roan Mountain	Biotite						357±13			Long and others, 1959, p. 594, 587.
	Route 19E, near Hopson.	Biotite						527±18			Do.
	Route 19E, near Hampton.	Biotite					719±25	640±22			Do.
	Pardee Point	Biotite						648±22			Do.
		Biotite						674±22			Do.
	North Carolina Madison County: 2.2 miles southwest of White Rock.	Biotite						695±23			Do.
	Tennessee Carter County: Pardee Point.	Biotite					892±30	800±27			Do.
		Zircon	670	735	940±50	360					Tilton and others, 1959, p. 174; Davis and others, 1962, p. 1991.
		Biotite					890	770			Do.
		Zircon	980	1,060	1,230	1,080					Do.
		Biotite					880				Do.
	Laurel Gap, rare-earth vein cutting gneiss.	Zircon	585	640	820	360					Davis and others, 1962, p. 1991.
	North Carolina Mitchell County: Dayton Bend.	Zircon	1,080	1,140	1,270	950					Tilton and others, 1959, p. 174.
		Biotite					350	320			Do.
	Avery County: Roadcut on Dark Ridge Creek.						810	660			Davis and others, 1962, p. 1991.
Mica gneiss and schist (Carolina Gneiss of Keith)	Ashe County: Ore zone, Ore Knob mine.	Hornblende						1,130			Thomas, 1963, p. 110.
		Mica					320	465			Do.
	Mitchell County: Gneiss, McKinney mine.	Muscovite and Biotite.						341±13			Long and others, 1959, p. 594.
	Buncombe County: Gneiss, Stocksville.	Biotite					330±13	357±13			Do.
	Jackson County: Gneiss, near Gay.	Biotite					333±15	438±14			Do.
	Haywood County, Waynesville.	Muscovite						344			Kulp and Eckelmann, 1961, p. 409.
	4 miles west of Soco Gap.	Biotite						359			Do.
	Macon County: Franklin	Biotite						307			Do.
	Biotite schist, 6.3 miles east of Franklin.	Zircon							620		Jaffe and others, 1959, p. 118.
		Zircon							590		Do.

[1] Before leaching with HCl. [2] After leaching with HCl. [3] Determinations made on three layers of a single crystal. [4] Same material used by Marble, Laue, and Eckelmann and Kulp.

MUSCOVITE GRANODIORITE OF SPRUCE PINE DISTRICT

The granitic intrusives of the Spruce Pine district are important sources of feldspar, scrap mica, and clay, and as such, they have been studied extensively in recent years (Hunter, 1940; Olson, 1944; Parker, 1946, 1952; Brobst, 1962; Bryant, 1962). These intrusives were called granite by Keith (1905b) and Watts (1913, p. 106) and alaskite by Hunter (1940, p. 98), Olson (1944, p. 22), and Brobst (1962, p. A10). Parker (1952, p. 9) used the term "leucogranodiorite, fine-grained pegmatite," and Bryant (1962, p. D18) used "granodiorite." The term "muscovite granodiorite" is used here because the plagioclase content of these rocks is generally greater than the microcline content, but muscovite is present rather than the biotite or hornblende of a normal granodiorite. Locally, where the microcline content is larger, the rock may approach the composition of a quartz monzonite.

According to Brobst (1962, p. A10), the average mineral content of the granodiorite is oligoclase (40 percent), quartz (25 percent), perthitic-microcline (20 percent), and muscovite (15 percent). Accessory minerals that make up less than 5 percent of the rock include biotite, garnet, apatite, allanite, epidote, thulite, pyrite, and pyrrhotite. Grain size ranges from ⅛ to 1 inch and averages more than ½ inch. Locally, large crystals of perthite may be 1 foot or more in length. Much of the rock is sufficiently coarse grained to be called a fine-grained pegmatite (Olson, 1944, p. 22; Parker, 1952, p. 9), and all gradations between coarse-grained light-colored granodiorite and pegmatite occur (Bryant, 1962, p. D18).

The granodiorite is intruded into the mica and hornblende gneiss units as sills, dikes, and irregular masses in several parts of Avery, Mitchell, and Yancey Counties (pl. 1). The largest mass is near Spruce Pine and is at least 4,000 feet wide and 2 miles long (Brobst, 1962, p. A10). Numerous gneiss and schist inclusions are present in all the granodiorite bodies, especially near the margins. Parts of the larger bodies are massive, but most have a crude foliation or layered structure produced by parallel mica flakes and streaks of quartz, feldspar, and garnet. The foliation is generally parallel with the regional trends of the gneiss and schist.

PEGMATITE

Mica-bearing pegmatites occur throughout the eastern half of the Blue Ridge province in North Carolina (fig. 1 and pl. 1), but they are concentrated in the Spruce Pine and Franklin-Sylva districts. Pegmatites are restricted in general to the mica and hornblende gneiss units of the basement complex and, locally, to areas of the Ocoee Series where such rocks have been regionally metamorphosed to at least the kyanite-muscovite subfacies of the amphibolite facies. Some also occur in granite and granodiorite. The region probably contains many more pegmatite bodies than are shown on plate 1, but these bodies are apt to be small or mica poor.

The pegmatites throughout the region are generally similar, but there are minor differences within and between districts. The principal variations are in color of muscovite, kinds and amounts of accessory minerals, and degree of conformity to the structure of the wallrock. More detailed descriptions of the characteristics of the pegmatites in each district are given in the sections on the individual districts.

In the Blue Ridge as a whole, the mica-bearing pegmatites are tabular (65 percent), lenticular (25 percent), or irregular (10 percent). They range in size from thin seams a few inches thick to large masses several hundred feet thick and more than 1,000 feet long. About half of the deposits are discordant with the foliation of the enclosing country rock, but the pegmatites in the northeastern part tend to be concordant, and those in the southwest discordant. The mineralogy is similar throughout the area; plagioclase, quartz, perthitic microcline, and muscovite are the principal minerals. Biotite and garnet are common accessory minerals, and apatite, beryl, pyrite, and tourmaline are less common. Other accessory minerals are sparse but Sterrett (1923, p. 171) listed 65 different minerals associated with the pegmatites. The Spruce Pine district may have a greater variety of accessory minerals than the other districts. The occurrence and origin of some of the accessory minerals are described by Hall (1933; 1934), Ross (1937), and Heinrich (1950).

Grain size throughout the area ranges from fine (less than 1 in.) to very coarse (more than 1 ft) in many individual deposits. Perthite crystals are commonly 1 foot across and rarely as large as 4 or 5 feet across. Muscovite crystals are generally less than 1 foot across, but some are larger than 3 feet across. Plagioclase masses are rarely greater than 1 foot across, and quartz grains are generally less than 1 inch. Other minerals are generally in masses or crystals that are at most a few inches across.

The internal structure of the Blue Ridge pegmatites is simple. Many have a homogeneous distribution of minerals throughout, but some zoning of minerals and texture has been reported in about 40 percent of the deposits and zoning may be present in more. The most common zones are a thin border zone of fine-grained pegmatite, a wall zone of fine- to coarse-grained feldspar, quartz, and muscovite, and a quartz or quartz-perthite core. Intermediate zones with blocky plagioclase or perthite are found in a few deposits.

Poorly zoned deposits contain mica scattered throughout their widths or may contain mica-rich shoots. Zoned deposits generally have sheet mica concentrated in wall zones or along the margins of the core in intermediate zones. Many such deposits have mica-rich shoots, commonly in bulges or rolls in the pegmatite-wallrock contacts. Such shoots generally plunge parallel to the plunge of minor structures in the wallrock. Most deposits that have been mined at a profit contain mica-rich zones or mica-rich shoots. All parts of a zone may not be equally rich; the mica-rich rock may be

only along the hanging-wall side of the pegmatite or, rarely, along the footwall side.

All the mica-bearing pegmatites in the Blue Ridge probably have a similar mode of origin. The pegmatites are similar in composition and probably in age. They occur in similar structural relationships in a variety of wallrocks throughout the area. Composition of the wallrock has only minor influence on composition of pegmatite: pegmatites in metamorphic rocks—especially hornblende gneiss—have somewhat more iron and calcium and slightly less potassium than do pegmatites in granodiorite (Olson, 1944, p. 36). The same sequence of mineral zones in all zoned deposits and the general increase in grain size from the walls inward in both zoned and unzoned deposits are typical of granitic pegmatites in general (Cameron and others, 1949) and are a part of the evidence for magmatic crystallization. The fluid from which the pegmatites crystallized was clearly intruded into the country rock to form both the concordant and the discordant bodies. The discordant bodies occupy fractures, joints, or faults, and a slight alteration and contortion of country rocks along foliation planes beyond the ends of some concordant bodies mark possible channelways for the movement of magma. Some of these foliation planes probably are sites of "bedding plane" faulting.

Crystallization probably took place in virtually a closed system with little addition or loss of material to or from the wallrocks, except for water and other volatiles. Plagioclase, plagioclase-quartz, or plagioclase-quartz-muscovite crystallized first in the fine-grained selvage or border zone. Larger book muscovite continued to crystallize with plagioclase and quartz to form the wall zone of a zoned pegmatite or all of a simple unzoned pegmatite. Microcline began to crystallize later than muscovite, and in many pegmatites the bulk of the interior consists of plagioclase-microcline-quartz-muscovite rock. In some deposits the greater part of the microcline crystallized after the other minerals and forms a nearly pure perthite core or intermediate zone. Quartz ordinarily continued to form until last and is the core in most zoned deposits. Most of the few late fracture fillings consist mainly of quartz.

The source of the pegmatitic fluid is not well established in the Blue Ridge. In the Spruce Pine district many bodies of pegmatite are clearly related to the granodiorite intrusives. Pegmatites in the Cashiers district (Olson, 1952) have a close spacial and probable genetic relationship to the Whiteside Granite, and those in the Franklin-Sylva area also may be related to that granite (Olson and others, 1946, p. 13).

It is quite possible that most of the simple mica-bearing pegmatites in the Blue Ridge are related to a regional metamorphism of Paleozoic age and are not the end products of crystallization-differentiation of a large granitic batholith at depth. Their simple mineralogic composition falls in the low temperature part of the albite-orthoclase-quartz system, as determined by Tuttle and Bowen (1958, p. 55), and they generally lack minerals containing such rare elements as boron, beryllium, cesium, fluorine, lithium, niobium, and tantalum that might be expected in the late differentiates of a large granitic intrusion. The occurrence of pegmatites only in areas where the metamorphic grade has reached at least the kyanite-muscovite subfacies of the almandine amphibolite facies of regional metamorphism suggests that high pressure and temperature conditions in the environment were an important control in the localization of the pegmatites. The pegmatites may well have formed by local melting of constitutents of the metamorphic rocks at still greater depth. Their crystallization, however, was also under deep-seated conditions, for mica-bearing pegmatites are absent in the layered granitic gneiss where it was metamorphosed only to the biotite-albite grade near the Grandfather Mountain area (Bryant, 1962, p. D21–D22), the muscovite-chlorite or biotite-chlorite grade along the Watauga River (Hamilton, 1960, p. 24), or to similar low grades in parts of the eastern Great Smoky Mountains (Hadley and Goldsmith, 1963, p. B104–B106).

Possibly the larger intrusives of the Spruce Pine and Cashiers districts were also the result of local melting and migration of small masses of granitic magma in an area of high-grade regional metamorphism, and owe their size to greater heat and pressure that gave rise to larger masses of magma. Pegmatites associated with these intrusives contain a greater variety and abundance of rare elements than the average pegmatite in the Blue Ridge area—a result of some differentiation in a magmatic source.

All the pegmatites in the Blue Ridge have undergone some deformation after crystallization. Brecciated and rounded feldspar porphyroclasts, granulated quartz masses, and sheared muscovite books in a matrix of recrystallized fine-grained feldspar, quartz, and sericite are common in many deposits. Some deposits have a distinct foliation formed by layers of the finer grained minerals wrapped around larger crystals; other deposits have a brecciated texture. Sheared books of muscovite are bent, ruled, and cracked, and the edges of some books are coated with crushed mica. Shear planes in the pegmatites in the Spruce Pine district commonly have grooves, slickensides, or alined mica flakes that trend northwest parallel to a regional northwest-trending *a* lineation in the country rock. The outer parts of the muscovite granodiorite intrusives in the Spruce Pine district also are crudely foliated and sheared, and contain a similar northwest-trending lineation. Maurice (1940, p. 63) also recognized this deformation and described five varieties of cataclastic texture in Spruce Pine pegmatites.

The amount of shearing in an individual pegmatite is apparently controlled partly by structural attitude and partly by wallrock lithology. Simple tabular pegmatites are generally not so strongly deformed as contorted S-shaped ones. Pegmatites enclosed by thick masses of coarse mica schist are less deformed than those enclosed in mica or hornblende gneiss.

Pegmatite bodies along the margin of the Spruce Pine district, especially those near the contact between interlayered mica and hornblende gneiss with layered granitic gneiss, are more intensely sheared than pegmatites near the center of the district.

Similar cataclastic structures are common in the pegmatites in the other districts of the Blue Ridge province but have not been studied in detail. In general, however, deformed mica books are more abundant in pegmatites throughout the Blue Ridge than they are in similar pegmatites in the Piedmont province (Jahns and others, 1952–53, p. 50).

The age of the deformation is not well known. Some deformation may have occurred during the formation of the pegmatites; some is clearly related to local faulting; however, much of it may be related to the period of regional deformation that followed the main period of regional metamorphism as outlined by Hadley and Goldsmith (1963, p. B107).

STRUCTURE

The structural features of the Blue Ridge are complex and only partly known. Detailed mapping along the western edge in the areas of Ocoee and younger rocks has outlined numerous folds, thrust faults, and windows (pl. 1). The rocks of the basement complex, however, have not been studied in as much detail. The gneisses and schists throughout much of the basement have been deformed and metamorphosed several times. Keith (1904, p. 3) recognized two periods of deformation of these rocks: one produced the foliation, and the other folded and crushed the earlier structures. Hamilton (1960, p. 22) recognized three episodes of deformation and metamorphism in the granitic gneisses in the basement complex along the Watauga River in Watauga and Avery Counties and two episodes of metamorphism near Old Fort, McDowell County (Hamilton, 1957). Bryant and Reed (1962, p. 171) found evidence for four periods of metamorphism in the rocks of the Grandfather Mountain area. A similar complex history is described for the basement rocks in the eastern part of the Great Smoky Mountains (Hadley and Goldsmith, 1963, p. B107).

FOLDS

On the basis of reconnaissance mapping, Keith (1903, 1904, 1905b, 1907a–c) described broad anticlinal and synclinal areas in the basement complex but was unable to delineate large folds because of the lack of key beds in the mica and hornblende gneisses. As a result of recent mapping, Brobst (1962, p. A12) has interpreted the Spruce Pine district as a complex southwest-plunging asymmetrical synclinorium with steeply dipping isoclinal folds on the northwest side and gently dipping more open folds on the southeast. Bryant (1962, p. D25) and Reed (1964b) have found a set of late northeast-trending gentle folds superposed on earlier northwest-trending isoclinal folds in rocks to the northeast of the Spruce Pine district. The mica and hornblende gneiss and schist have been domed near large granodiorite intrusives in the Spruce Pine district (Olson, 1944, p. 32) and around large masses of Whiteside Granite in the Cashiers district (Keith, 1907b, p. 4). Smaller scale folds, both open and isoclinal, are visible in outcrops and roadcuts in many parts of the Blue Ridge. Such folds in the Bryson City area are described by Cameron (1951, p. 17–18) as second-order folds, and are found both in the metasedimentary rocks of the Ocoee Series and in the basement complex. Similar second-generation folds in the basement complex are also described by Hadley and Goldsmith (1963, p. B74–B95) for the eastern Great Smoky Mountains; they were able to map and distinguish several ages of folding in the less metamorphosed rocks of the Ocoee Series.

FAULTS

Large thrust faults have been mapped along the western edge of the basement complex (Keith, 1907a; Hadley and Goldsmith, 1963; Oriel, 1950; Rodgers, 1953; King and Ferguson, 1960) and around the Grandfather Mountain window (Bryant and Reed, 1962), but none have been shown within the basement complex. A shear zone in the Spruce Pine district extends from Penland to a few miles east of Little Switzerland in Mitchell County, but the amount of movement, if any, is unknown (Brobst, 1962, p. A13). Small faults of diverse attitudes are reported in the Spruce Pine district (Parker, 1952, p. 16) and the Franklin-Sylva district (Olsen and others, 1946, p. 6–7). Mylonite that may represent large faults is present in several areas west and south of Franklin in Macon County, and Hamilton (1960, p. 26) reports mylonite and phyllonite along faults in the basement rocks in northeastern Tennessee. The small, but widely distributed, faults are of several ages; some are older and some younger than the pegmatites. In the Franklin-Sylva area many pegmatites are discordant bodies emplaced

in fractures and faults, and even in the Spruce Pine district, pegmatites in fault zones are probably common (Amos, 1959, p. 34). Pegmatites cut by small faults are common in all the districts of the Blue Ridge.

The larger Greenbrier fault mapped in parts of the Great Smoky Mountains is earlier than the main Paleozoic regional metamorphism (Hadley and Goldsmith, 1963, p. B96), but its relation to the structures and the pegmatites in the Blue Ridge belt is not known.

BLUE RIDGE THRUST SHEET

The recent mapping of the Grandfather Mountain window (Bryant, 1962; Bryant and Reed, 1962; Bryant, 1963; Reed, 1964 a, b; Reed and Bryant, 1964) indicates that the basement complex in the Spruce Pine district west of the window is part of an overthrust mass that has moved to the northwest at least 30 miles (Bryant and Reed, 1962, p. 162). No large structural break is known or apparent from Keith's reconnaissance mapping of the basement complex between the Spruce Pine and the Franklin-Sylva districts (Keith, 1904, 1905b, 1907b), and it is quite probable that all the basement complex in the Blue Ridge of North Carolina west of the Brevard belt is part of a large thrust sheet. The amount of movement of this thrust sheet may not be the same everywhere along it, and it is not known which, if any, of the thrust faults exposed along the western edge of the Blue Ridge is the principal fault along which movement took place. Depth to the fault below most of the Blue Ridge is unknown. In the area between the Grandfather Mountain window and the Mountain City window, Bryant and Reed (1962, p. 167) estimate a depth of 5,000 feet, and they suggest a depth of 10,000 feet or more in the Spruce Pine district. The major thrust movement is inferred to be late Paleozoic (Bryant and Reed, 1962, p. 167). If so, it is younger than the mica pegmatites, and part of the deformation of the pegmatites may be related to this period of faulting.

METAMORPHISM

The basement complex in the Blue Ridge has been metamorphosed several times, and the effects of older periods of metamorphism are partly obscured by later events. The following metamorphic and structural events, however, are recorded in the Blue Ridge belt: (1) a plutonic episode in Precambrian time about 1,000–1,100 million years ago; (2) a period of folding and faulting in the early Paleozoic; (3) a second period of dynamothermal metamorphism reaching a thermal maximum in the early or middle Paleozoic; (4) another period of regional deformation accompanied by fewer thermal effects, probably in mid-Paleozoic time; and (5) a late Paleozoic deformation that culminated in large scale thrust faulting. Details of the metamorphic history of the basement complex in northeast Tennessee are described by Hamilton (1960), in the Grandfather Mountain area by Bryant (1962), Bryant and Reed (1962), and Reed (1964b), and in the eastern Great Smoky Mountains by Hadley and Goldsmith (1963). A summary of the metamorphic history of the Spruce Pine district has been made by Kulp and Poldervaart (1956), and a chronology of the major metamorphic events of the Blue Ridge is given by Long, Kulp, and Eckelmann (1959) and Kulp and Eckelmann (1964).

The oldest metamorphism recognized is a plutonic episode of Precambrian age during which a thick sequence of sedimentary rocks was metamorphosed to gneiss and schist (Bryant, 1962. p. D20; Hadley and Goldsmith, 1963, p. B23). Along the northwestern edge and in the deeper parts of the section these rocks were transformed progressively into a more nearly granitic rock forming a series of layered granitic gneisses intruded by bodies of nonlayered granite and granodiorite. Age determinations on zircons from both the layered and nonlayered granitic gneiss (table 1) give discordant isotopic ages, and have been interpreted to mean that the plutonic episode took place about 1,000–1,100 million years ago (Tilton and others, 1959, p. 175). Age determinations on micas from the layered granitic gneiss and the mica gneiss units yield younger ages and indicate the effects of later metamorphic events.

This Precambrian metamorphism was followed by the deposition of the late(?) Precambrian Ocoee Series and then a period of early Paleozoic folding and faulting in the Great Smoky area (Hadley and Goldsmith, 1963, p. B107). A second period of dynamothermal metamorphism then took place, probably during the early or middle Paleozoic. In the Great Smoky region, sedimentary rocks of the Ocoee Series were metamorphosed to the chlorite grade in the west and to higher grades in the southeast. Along the western edge of the Blue Ridge belt the basement rocks were retrograded at this time where the grade of the new metamorphic environment was less than that of the Precambrian plutonic metamorphism (Hamilton, 1960, p. 22; Hadley and Goldsmith, 1963, p. B96–B107). In the central part of the Blue Ridge belt, where metamorphism reached the kyanite-staurolite subfacies of the amphibolite facies, the basement rocks were recrystallized and the Ocoee rocks were altered to coarse schist and feldspathic gneiss. During this period of early or middle Paleozoic metamorphism the mica pegmatites were intruded in areas that reached kyanite grade. Age determinations on a variety of minerals from these pegmatites (table 1) yield mostly discordant dates that range from 170 to 420 million years. Because all the pegmatites contain evidence of some postcrystallization deformation, these ages are probably minimal, and the true age of the Blue Ridge pegmatites may be 400–450 million years. Micas from gneiss near or in the pegmatite districts also give discordant K/Ar and Rb/Sr ages that range from 330 to 438 million years.

According to Hadley and Goldsmith (1963, p. B106), a period of regional deformation followed the thermal maximum of the Paleozoic metamorphism in the Great Smoky area. They found evidence for the development of slip cleavage, second generation folds, and some shearing and recrystallization but no important mineralogic changes. A broad region involving Paleozoic and older rocks in the Grandfather Mountain window and parts of the Blue Ridge thrust block northwest and north of the window was also metamorphosed to a rather uniform biotite-albite grade after the thermal maximum had been reached in the basement complex in the Spruce Pine district to the southwest (Bryant and Reed, 1962, p. 174–175). Because of the possible overlapping of metamorphic zones due to the late Paleozoic thrust faulting, the age of this low-rank metamorphism is not fully established. Some of the observed effects may be related to a late stage of the main Paleozoic metamorphism, and some may be related to the period of thrusting. Deformation of the pegmatites in the Blue Ridge probably is related to this late deformation and may be the metamorphic episode of 350 million years ago, recognized by Kulp and Eckelmann (1964).

Little metamorphism accompanied the last major period of deformation that culminated in the late Paleozoic faulting and formation of the Blue Ridge thrust sheet. In the Great Smoky area, faulting during the late Paleozoic is characterized by unrecrystallized gouge and no obvious metamorphism (Hadley and Goldsmith, 1963, p. B107). A similar lack of recrystallization is noted along faults and mylonite of this age in northeast Tennessee (Hamilton, 1960, p. 26). In the Grandfather Mountain area some recrystallization to biotite-albite grade seems to be related to the period of faulting (Bryant and Reed, 1962, p. 175). Some of the faulting seen in pegmatites throughout the Blue Ridge may be related to the late Paleozoic deformation.

As noted by Bryant and Reed (1962, p. 175), the retrogressive metamorphism of rocks along the Brevard fault constitutes a later metamorphic episode that followed the thrusting and preceded the emplacement of diabase dikes of Triassic(?) age.

ECONOMIC ASPECTS OF PEGMATITE MINERALS

MICA

The principal mica minerals are muscovite (white), biotite (black), and phlogopite (amber). All have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. The micas are common minerals, but only muscovite is of commercial importance in North Carolina.

Two types of mica are sold: sheet mica, which must be relatively flat, free from most defects, and be large enough so that it can be cut into specified sizes; and scrap mica, which is all mica that does not meet sheet mica specifications and is generally ground to a powder. Small sheets of untrimmed mica of poorer quality that can be punched or trimmed into disks 1 inch or larger in diameter are classified as punch mica and are included in the general term "sheet mica." Sheet muscovite is an important insulating material in the electronic and electrical industries. Built-up mica made from very thin sheets and reconstituted mica made from scrap can be substituted for larger sheet mica for some uses (Skow, 1962, p. 11). Scrap mica is used in the roofing, wallpaper, rubber, paint, and other industries.

SHEET MICA

Sheet-quality muscovite is obtained from the large crystals or books scattered throughout unzoned pegmatites or concentrated in certain units of zoned pegmatites. The value of sheet mica depends on the color, size, and quality of the natural crystals. The manner in which the crystals are obtained by mining and the care and skill of preparation are also important factors affecting the value.

About 30 percent of the deposits in the Blue Ridge contain reddish-brown (ruby) muscovite, 24 percent contain brown (rum), and 34 percent green; the remainder contain both ruby and green varieties. The green mica is more likely to be associated with quartz cores and the reddish brown or brown with plagioclase-rich rock. Deposits near or in granitic bodies tend to have green or greenish-brown mica, and those that are farther away tend to have brown or reddish brown. Areal distribution of mica according to color has been shown by Olson (1944, pl. 2) for the Spruce Pine district.

Crude books of mica must be at least 2 inches across to yield trimmed sheet mica. The average commercial book is about 5 inches across and about one-fifth to one-half as thick as it is wide. Blocks measuring 8–12 inches across are common. A few larger blocks that weigh 50–300 pounds are found. The largest block of muscovite reported from the Spruce Pine district was a book of "A" mica weighing 4,320 pounds from the Fannie Gouge mine in Yancey County. It was 36 by 42 inches across and 32 inches thick (Urban, 1932, p. 4). Another large block of mica weighing more than 4,000 pounds was found in 1907 at the Iotla Bridge mine in Macon County. It measured 29 by 36 inches across and 48 inches thick (Sterrett, 1923, p. 235).

The quality of sheet mica is determined by the amount and kind of staining and the degree of structural imperfections. Quality of sheet mica varies widely within and between mica districts and even within a single deposit or mica-rich shoot. Detailed discussions of the quality and classification of mica have been written by Jahns and Lancaster (1950) and Skow (1962), and only a brief summary is given here.

The best sheet mica is clear, flat, and free of gas bubbles and mineral inclusions. Mica that contains primary or secondary inclusions or impurities is called stained mica. The primary impurities include air bubbles, mottling, and mineral intergrowths and inclusions; the secondary impurities include air creep; clay, iron, and manganese oxide inclusions; and organic or vegetable stain (Jahns and Lancaster, 1950, p. 12). Specks, spots, and streaks of magnetite, hematite, and pyrite occur sparsely or in dense concentrations between sheets of stained mica in unweathered deposits. Films of clay, limonite, or manganese oxides coat the sheets of mica in some weathered deposits. Various kinds of staining occur in each district, and some individual deposits contain both stained and clear mica. Green mica is more commonly stained than reddish-brown mica. Pegmatites that contain biotite tend to have reddish-brown or brown muscovite that is free of stain. Mineral stain occurs in about half the mines in the Blue Ridge.

Some muscovite crystals contain small intergrowths or inclusions of other minerals, such as biotite, quartz, plagioclase, garnet, apatite, thulite, zoisite, epidote, tourmaline, and kyanite. Muscovite and biotite are generally intergrown with their cleavages parallel, and about 15 percent of the deposits in the Blue Ridge contain such intergrowths. Quartz and plagioclase occur interlayered with muscovite, and garnet occurs as flattened crystals or, more rarely, as euhedral inclusions between sheets of mica. The other minerals are generally flattened parallel to the mica cleavage, but they penetrate the mica. All such mineral inclusions make splitting the mica into sheets difficult and produce holes in the sheets. Mica that contains mineral inclusions that make splitting difficult is generally said to be "tied."

Structural defects of the mica crystals are also of primary and secondary origin. The most common primary defects are reeves and wedge structure. Reeves are lines, striations, or shallow corrugations that lie in the plane of the cleavage. They represent the edges of discontinuous sheets of mica, wrinkles in other sheets that are alongside them, and the edges of individuals in twinned crystals. Reeves are oriented perpendicular to the traces of the prismatic and clinopinacoidal faces on the basal surfaces of the mica crystals. Where two sets of reeves intersect at an angle of nearly 60°, the resulting mica is said to have "A" structure. "Herringbone" structure, which resembles a feather or fish skeleton, is formed by two sets of reeves intersecting at an angle of about 120° and characteristically flanking a central line of reeves that is perpendicular to the trace of clinopinacoidal faces (Jahns and Lancaster, 1950, p. 9). Wedge structure is caused by interlayering of sheets of unequal size. Wedge structure is commonly associated with "A" and "herringbone" structure.

Some muscovite books do not split freely and are termed "locky," "tangled," or "tacky" (Jahns and Lancaster, 1950, p. 7). Such books generally have discontinuous sheets, partial intergrowth of sheets, or internal distortions, and are largely of scrap value only.

Secondary structural defects include bending, cracking, twisting, and ruling, all caused by deformation of the mica during or after crystallization. Bending ranges from slight waves to right angle or S-shaped bends. Ruling is a secondary cleavage that cuts the basal cleavage at an angle of nearly 67°. Deformation of the mica in pegmatities of the Blue Ridge is common and widespread. At least 40 percent of the deposits have some bent mica, and a third or more contain some ruled mica.

In profitably mined pegmatites the book mica generally constitutes 2–6 percent of the rock mined. Locally, rich shoots or pockets may have as much as 40 percent muscovite, but large volumes of pegmatite have 2 percent or less. The recovery of good sheet mica from the crude book mica varies with the type and quality of the mica and the standards of mining, preparation, and grading. Complete quantitative data are not available, but estimates of recovery of good trimmed mica from crude mica range from 2 to 8 percent for the average mine and are as much as 19 percent from good quality crude mica in a few mines.

Prices of sheet mica depend on the size and quality of the sheet. In 1963 they ranged from 7 cents a pound for sheets 1½ inches across to $8 a pound for sheets 8 inches or more across. During World War II the Government support prices for all sheets 1½ inches by 2 inches and larger ranged from $1.10 to $8 a pound. From 1952 to 1962 the Government prices ranged from $15 to $17.70 a pound for sheets 1–2 square inches of ruby mica classified as good stained or better. Sheets 3–6 square inches brought $40 a pound, and sheets 10 square inches and larger brought the top price of $70 a pound. Similar sized sheets of stained mica ranged from $5 to $7.55, $8 to $18.25, and $18 to $31.90; heavy stained mica ranged from $3 to $4, $6 to $6.85, and $13 to $14.80. Nonruby of equivalent quality generally sold for less. The somewhat erratic nature and small size of most mica concentrations, the great range of quality of material, the expense of mining, and the large amount of hand labor needed for preparation limit sheet-mica mining to periods of very high prices. Since the end of the Government purchasing program in June 1962, little sheet mica has been mined in North Carolina.

Reserves of sheet mica cannot be calculated from the data available for no development work has preceded mining, and no mica-bearing rock is blocked out. An appraisal of the probable amount of mica remaining in the ground, based on the premise that the abundance of pegmatite bodies at depth is almost certain to be virtually the same as at the surface, indicates that at least as much mica remains as has been mined. The finding and mining of this mica will depend largely on such economic factors as domestic market and prices, which influence the amount of prospecting.

During the last period of Government mica buying, 1952–62, most of the larger producing mines were those that had been big producers in the past, and many were worked out or left in a condition that will make further mining difficult. The rate of new discoveries was small during both World War II and the 1950's, even though exploration was encouraged by the Federal Government through financial assistance. Deposits exposed at the surface have generally been prospected, and the difficulty and cost of finding unexposed deposits are great. Detailed geologic studies of structural control, country-rock alteration, and geochemistry and geophysics may help locate areas of additional pegmatite.

Pegmatites do, however, have characteristics that can be of aid in prospecting.

1. Large mica-bearing pegmatites tend to occur in groups; in the Spruce Pine district, for example, several very large mines are clustered together in the Bandana area. It is therefore logical to look for additional pegmatites near large mines. Careful geologic mapping will help establish in many places a pattern in the localization of large deposits, for some seem to occur en echelon or in a belt like a string of beads, and others are related to the axes of folds in the country rock or to faults.
2. Pegmatites that are concordant or partly concordant to the foliation of the wallrock are apt to plunge parallel to the plunge of minor structures in the wallrock. Elongate mica concentrations, generally called shoots or streaks, also tend to plunge parallel to the plunge of the pegmatite. A repetition of structural features may have produced additional shoots or extensions of known deposits down plunge.
3. The shape of the pegmatite body may influence the location of mica concentrations. In pegmatites that pinch and swell, mica may be more abundant either near the constrictions or in the swells. Mica is generally more abundant near sharp bends or rolls in the wallrock or along the crests of pipelike or tonguelike bodies. Mica may also be concentrated along the hanging wall or the underside of a wallrock inclusion.
4. The size of the pegmatite body is also an important factor. Unzoned pegmatites 3–10 feet thick and 100–200 feet long have been mined successfully by removing all the pegmatite, but where sheet muscovite is sparsely scattered throughout an unzoned body more than 20 feet thick, so much barren rock has to be removed that mining for mica alone is unlikely to be profitable. In zoned deposits, mining can be restricted to the mica-rich zones, and the rest of the pegmatite need not be mined. Thin tabular pegmatites less than 100 feet long are commonly too small to justify the expense of exploration.
5. Determination of the mineralogy and zoning of the pegmatite is important. Sheet mica generally occurs in oligoclase- and quartz-rich rock and not in perthite-rich rock. A perthite-rich pegmatite, however, may have a wall zone of plagioclase-quartz-mica that contains sheet mica. Pegmatite with a quartz core may have sheet mica along the core margin and also in the outer part of the wall zone. The presence of quartz float may indicate a zoned pegmatite. A lack of evidence for zoning in surface exposures, however, does not necessarily mean that the deposit is not zoned at depth. Diamond drilling is an aid in determining the presence, size, and location of different zones. By demonstrating the continuation of pegmatite along the trend of a persistent shoot, such drilling can indirectly indicate size of mica deposits.
6. The quality of mica at the surface may indicate the quality at depth. Mica that has clay or "vegetable" stain may be clear below the depth of weathering. Pegmatites that contain mica with primary stain at the surface probably have stained mica at depth unless clear mica and stained mica form separate shoots. Pegmatites that contain some biotite probably have reddish-brown or brown muscovite relatively free from stain, but where biotite is very common, there is generally not much sheet muscovite. In many deposits the quality and quantity of mica are better along the hanging wall than along the footwall. Mica along the margin of a quartz core tends to be reeved or "A" and greener than mica in a wall zone.
7. Pegmatites that have been greatly sheared or faulted contain deformed mica. If the deformed mica occurs in thick chubby books or in very large books, some sheets may be produced with careful trimming.
8. When a pegmatite body containing sheet mica has been found, the only way to appraise the deposit is to expose it in surface trenches or underground workings. Diamond drilling will aid in determining the presence or absence of pegmatite or of pegmatite zones but will supply little direct information concerning the quantity or quality of the mica.

SCRAP MICA

Many pegmatite deposits contain only scrap mica, and a large amount of scrap is produced during the mining, trimming, and fabricating of sheet mica. Most scrap mica, however, is produced from weathered granodiorite bodies and as a byproduct from the mining of feldspar and kaolin. From 1943 to 1962 North Carolina produced more than 930,000 tons of scrap mica, or about 63 percent of the total United States production. The annual production in the State ranged from 25,000 tons worth $516,367 in 1943 to nearly 62,000 tons worth $1,384,280 in 1962. More than three-fourths of the North Carolina production was from the Spruce Pine and Franklin-Sylva districts. The geology, mining, and milling of scrap-mica deposits in these and other districts are described in detail by Broadhurst and Hash (1953). They estimate that the reserves of scrap mica in weathered granodiorite of the Spruce Pine district, exclusive of kaolin deposits, are in excess of 25 million tons of material containing 12–18 percent mica (Broadhurst and Hash, 1953, p. 15). In addition, reserves of scrap mica in kaolin deposits have been estimated to be 7.5 million tons, and the amount of scrap mica that can be recovered as a byproduct from feldspar flotation is in excess of 38 million tons (Brobst, 1962, p. A15–A16).

In 1962 scrap mica was produced from 2 mines in Avery County, 2 in Macon County, 14 in Mitchell County, and 8 in Yancy County. In the same year 11 grinding mills were active in the Blue Ridge (Beck and others, 1963). In 1963 scrap mica was valued at the mine at $20–$30 per short ton. The price paid depends on the color and the freedom from such impurities as clay and quartz. Mica that is very pale in color appears white when ground and is more desirable. Scrap mica produced from the rifting and trimming of sheet mica is high quality because of its relative freedom from quartz, feldspar, and clay.

FELDSPAR

Feldspar is the general name for a group of aluminum silicate minerals that contain varying amounts of potassium, sodium, and calcium. The principal potassium feldspars are orthoclase and microcline, which have the same chemical composition ($KAlSi_3O_8$) but different crystal form. The sodium-calcium feldspars, called plagioclase, form a series of minerals that range in all proportions from pure $NaAlSi_3O_8$ (albite) to pure $CaAl_2Si_2O_8$ (anorthite). Natural orthoclase and microcline generally contain 10–25 percent $NaAlSi_3O_8$, and plagioclase generally contains 5–15 percent $KAlSi_3O_8$. Intergrowths of orthoclase or microcline with albite are called perthite. Perthitic microcline (potash spar), albite (soda spar), and oligoclase (soda limespar) are the feldspars in the pegmatites of the Blue Ridge.

Feldspar mining in North Carolina began in Mitchell County in 1911 (Watts, 1913, p. 100) and within a few years became an important industry. For many years the State has produced half or more of the feldspar produced in the United States, and since 1953 the State production has averaged about 250,000 tons annually. Until recently, much of the feldspar was perthite and oligoclase hand cobbed from large crystals in zoned pegmatites. Since 1951 finer grained pegmatite and granodiorite have been mined in bulk, and a mixture of potassium and sodium feldspar has been recovered by milling and flotation. In 1953 about 35 percent of the feldspar produced in the State was obtained by flotation (Gunsallus and Uswald, 1956, p. 442); in 1962 about 90 percent was from flotation concentrates and 10 percent from hand sorting, (Beck and others, 1963, p. 778).

The Spruce Pine district is the principal source of feldspar recovered by flotation methods. In 1962 six operators produced feldspar in this manner from nine mines in Mitchell County, and two operators produced it from two mines in Yancey County (Beck and others, 1963, p. 790, 793). Some hand-cobbed feldspar was produced in Mitchell, Swain, and Yancey Counties.

The average price of crude feldspar was $10.31 per long ton in 1962 and $9.51 in 1960 (de Polo and Tucker, 1963, p. 537). The average price of ground feldspar was $12.71 per short ton in 1962 and $13.40 in 1960. From 1956 to 1960 about 55 percent of the feldspar sold in the United States was used in glass, 32 percent in pottery, 5 percent in enamel, and 8 percent in other ceramic uses, scouring soaps, and abrasives. There is an increasing shortage of high-grade potassium feldspar, but there is also an increase in the use of lower grade and finer grained materials recovered through milling and flotation. Reserves of feldspar in granodiorite within 50 feet of the surface in the Spruce Pine district are estimated by Brobst (1962, p. A15) to be in excess of 200 million tons.

KAOLIN

Modern mining of kaolin for high-quality ceramic products was started at Webster in Jackson County in 1888, but the Cherokees had apparently mined clay and sold it to English traders as early as the 17th century (Kerr, 1880, p. 462; Watts, 1913, p. 9–10). In 1767, Josiah Wedgwood sent T. Griffiths to get clay from the Cherokees at Cowee Town on the Little Tennessee River about 5 miles northwest of present-day Franklin in Macon County. Griffiths cleaned out an old clay pit, mined 12–15 tons of clay, and transported about 5 tons to Charleston, S.C., for shipment to England (Griffiths, 1929). Discovery of good quality clay in Cornwall in 1768 stopped further mining in North Carolina.

The Webster deposits were the main center of production in North Carolina for about 30 years, but clay mines were opened in Mitchell County in 1904, in Macon County in 1905, and in Swain County shortly after that. The last to be developed were those in Avery County in 1937. The deposits in Jackson, Macon, and Swain Counties were exhausted in the early 1920's, and the only deposits that were being worked in 1963, were those of the Harris Clay Co. in Avery County.

The kaolin deposits in the Blue Ridge are residual deposits formed by the weathering of feldspar in pegmatite and granodiorite. Most of the pegmatitic deposits are described by Watts (1913), Ries and others (1922), Bayley (1925) and Hunter and Hash (1949). The larger deposits in granodiorite are described by Hunter (1940) and Parker (1946). The clay is generally a mixture of two clay minerals: hydrated halloysite and kaolinite. The ratio of halloysite to kaolinite ranges from 30:1 to 1:1 and averages 10:1 (Sand, 1956, p. 33). Depth of weathering in individual deposits in the Spruce Pine district ranges from 10 to 135 feet and averages about 40 feet (Parker, 1946, p. 22). According to Bayley (1925, p. 63), a deposit near Webster was worked to a depth of 125 feet. With depth the kaolin grades into partly weathered feldspar, and throughout most deposits some unweathered feldspar remains. The recovery of clay from deposits in pegmatite is as high as 40 percent, but the recovery of clay in deposits in granodiorite ranges from 8 to 22 percent (Parker, 1946, p. 24).

The pegmatitic kaolin deposits consist of relatively pure clay that formed from feldspar-rich zones. Some of this clay is of high quality, free of impurities, but of small volume. In the early days of mining, kaolin from such deposits was mined, dried, and shipped directly. Less pure kaolin was washed to eliminate quartz and mica. The large deposits in granodiorite are mined today by power equipment in large opencuts. The kaolin is separated from impurities by a complex process of grinding, washing, screening, settling, and flotation (Parker, 1946, p. 25).

Total production of kaolin from the Blue Ridge is not known, but annual production from 1921 to 1940 ranged from 6,000 to 25,000 short tons and averaged 13,000 short tons. The amount of washed kaolin available in four groups of deposits near Spruce Pine was estimated by Parker (1946, p. 26–41) to range from 3 to 7 million short tons. Hunter (1940, p. 102) estimated reserves of crude kaolin in Avery, Mitchell, and Yancey Counties at 51 million tons from which about 4½ million tons of finished kaolin might be recovered.

QUARTZ

Some high-grade quartz has been produced from pegmatites in the Blue Ridge. Many zoned pegmatites contain cores or large pods of massive gray, smoky, or white quartz. Quartz from the Chestnut Flat mine in Mitchell County was used for glass in the 200-inch telescope for the Mount Palomar Observatory in California (Olson, 1944, p. 59). In recent years there has been a small production of white quartz for special aggregate in prestressed concrete. Quartz that was clean and free from iron stain sold for $8.50 a ton at Spruce Pine in 1960. Byproduct quartz is recovered from the feldspar and clay flotation plants for use as sand.

BERYL

Beryl is so rare a constituent of Blue Ridge pegmatites that no regular production of beryllium ore is possible. A total of a few tons of beryl may have been recovered from pegmatites mined for mica in the Spruce Pine district, but no accurate production figures are available.

Gem beryl has been mined at several localities in Mitchell County and one in Yancey County. More detailed information on gem occurrences is given by Kunz (1907).

NIOBIUM–TANTALUM MINERALS

Columbite-tantalite and samarskite occur in small quantities at a few mines in the Spruce Pine district. Several hundred pounds of both minerals have been produced as byproducts of feldspar or mica mining, but resources appear to be small.

URANIUM AND RARE-EARTH MINERALS

Uraninite, uranophane, gummite, autunite, clarkeite, and torbernite occur in exceedingly small amounts in a few pegmatites generally in or near granodiorite in the Spruce Pine district and, more rarely, in pegmatites in the other districts. The total amount in any one deposit is small, and only rarely are specimens found.

Allanite, which contains cerium and other rare earths, is a common accessory mineral in the Spruce Pine district and less common in the other districts. Only a few small crystals are found in any one deposit, and there has been no commercial production. Many specimens of monazite, a rare-earth phosphate, have been found in the Gusher Knob feldspar mines, Avery County, in the Crabtree Creek area, Mitchell County, and also near Mars Hill, Madison County, but the total amount may be less than 100 pounds.

PEGMATITE DISTRICTS

The mica-bearing pegmatites of the Blue Ridge are grouped into districts for convenience in describing them in this report. The mines and prospects in each district are listed alphabetically in table 4, starting at the north with the Jefferson-Boone district. The locations of the mines are shown on plates 2–6. The table and figures do not include the mica mines of the Cashiers district described by Olson (1952), nor the feldspar deposits of the Bryson City district described by Cameron (1951).

JEFFERSON-BOONE DISTRICT

The Jefferson-Boone district in Ashe and Watauga Counties contains more than 70 mica mines and prospects (pl. 2). Mica mining probably began in Ashe County at the Hamilton and Tarkington mines as early as 1867 and at the Little Phoenix and North Hardin mines in 1880. Some prehistoric mining was apparently done by Indians at the Little Phoenix and Walnut Knob mines (Sterrett, 1923, p. 172). More than 45 mines and prospects were opened or reopened during World War II, when production from 27 mines amounted to 11,500 pounds of mica valued at $36,400. About 20 mines were active at various times between 1951 and 1962, and production for the district amounted to nearly 80,000 pounds of sheet and punch worth about $315,000. Five mines were explored during this period with the aid of DMEA loans. None of the mines were being worked in April 1962, and many of the older mines are difficult to find. The total production of the district from 1867 to 1962 is estimated to be more than 200,000 pounds of sheet and punch but probably less than 300,000 pounds. There are no detailed production records before 1941 for this district, but few of the mines have produced much more than 10,000 pounds of full-trimmed sheet mica. Although none of the deposits is known to be mined out, many of the workings are in such poor condition that mining could be resumed only with difficulty.

The pegmatites in the Jefferson-Boone district are chiefly tabular or lenticular bodies. About two-thirds are concordant to the foliation of the country rock. They range in thickness from 1 to 70 feet and average less than 10 feet. In length they range from less than 50 to more than 350 feet.

The pegmatites are medium to coarse grained. The principal minerals in order of abundance are plagioclase, quartz, perthite, and muscovite. Garnet, biotite, apatite, and beryl are common accessory minerals; vermiculite, pyrite, magnetite, hematite, and uraninite are rare. About one-third of the pegmatites have a plagioclase-quartz-muscovite wall zone and a quartz core; a few have a perthite-quartz core and several have a perthite core. In general, the quality and quantity of the muscovite are only fair. The books tend to be small, many are deformed, and concentrations are small. Most of the muscovite is reddish brown or ruby; some is green.

WILKES DISTRICT

The Wilkes district is along the Blue Ridge Front in the western part of Wilkes County and the adjoining eastern edges of Ashe, Caldwell, and Watauga Counties (pl. 2). Mining at 45 or more mines and prospects has been intermittent since 1895. During World War II about 30 deposits were mined or prospected, and production was about 5,000 pounds of sheet muscovite worth $22,000. Between 1951 and 1962, production from 15 mines was less than 3,000 pounds valued at less than $6,000. Total production for the district is unknown, but it probably does not exceed 50,000 pounds of sheet muscovite. A few of the mines have been operated for scrap mica.

Because the pegmatites of the Wilkes district are generally weathered and poorly exposed, few of the deposits have been mapped in detail. In general, the pegmatite bodies seem to be tabular or lenticular. Most are less than 5 feet thick, but a few are 25 feet or more thick. Some of them are as much as 200 feet long. More than half are probably concordant to the foliation of the enclosing country rock, which is generally mica schist. The pegmatite is medium to coarse grained and contains as the dominant minerals plagioclase, quartz, and muscovite. Perthite is found in a few deposits. Garnet, biotite, magnetite, and tourmaline are reported as accessory minerals from some of the mines. A few pegmatites have a plagioclase-quartz-muscovite wall zone and a quartz core, but most seem to be poorly zoned.

The muscovite is mostly green, yellowish green, or brownish green. Some reddish-brown or ruby mica is found in the western part of the district. Much of the mica is bent or reeved. The average quality is only fair.

SPRUCE PINE DISTRICT

The Spruce Pine district covers about 300 square miles in Avery, McDowell, Mitchell, and Yancey Counties, N.C. (pl. 3). The district has been active for many years and has consistently been the principal producer of mica and feldspar in North Carolina. Mica was mined by the Indians in prehistoric times; traces of their pits and trenches found by the first white settlers were considered to be the workings of old Spanish silver mines (Kerr, 1875, 1881; Phillips, 1888; Simonds, 1896). In 1868, T. L. Clingman prospected the Sinkhole mine, in Mitchell County, which had been the site of extensive prehistoric diggings. Clingman sank shafts and drove tunnels showing an abundance of mica in an area where the Indians had dug a series of trenches 20 feet deep and 1,800 feet along strike (Phillips, 1888; Simonds, 1896). The prospect was abandoned, but the following year work was begun at the mine by the firm of Heap and Clapp of Knoxville, Tenn. Shortly thereafter the Ray mine was opened in Yancey County by G. D. Ray (Sterrett, 1923, p. 168), and within a few years there were more than a score of active mines, many of which were operated by Heap and Clapp.

Some information is available concerning 714 mines and prospects in the Spruce Pine district (table 4), but probably there are as many more prospects and small mines about which little is known. Production data for the district are poor for the period before World War I. Kesler and Olson (1942) gave incomplete production records for 130 mines for the period 1917–40, and records were kept by the Colonial Mica Corp. for the production from 708 mines and prospects for the period June 1942 through 1945. More than 100 mines had a significant production during the period 1953 through 1962. Most mines operated for sheet mica only, however, were closed in June 1962 when the Government buying program ended.

Within the Spruce Pine district there are 67 mines that have a recorded individual production greater than 10,000 pounds of sheet mica and 146 mines that have an individual production greater than 500 pounds but less than 10,000 pounds of sheet mica. Most of the production of the district has come from a few very large mines, as shown in table 2.

During the period 1951–62 the Spruce Pine district was actively explored, and much of this exploration was aided by the Defense Minerals Exploration Administration. A total of 322 applications for aid were received on 269 different pegmatite bodies. Of the 147 contracts granted, 22 were in Avery County, 80 in Mitchell County, and 45 in Yancey County. Thirty-five exploration projects were certified as discoveries, and three of these, the Cattail, Sinkhole, and R. B. Phillips mines, were among the large producers of the 1950's.

The general geology of the Spruce Pine district has recently been mapped and described by Olson (1944), Parker (1952), Kulp and Brobst (1956), and Brobst (1962). The pegmatites are described by Sterrett (1923), Maurice (1940), Kesler and Olson (1942), Olson (1944), Parker (1952), and Brobst (1962). Recent mapping along the eastern edge of the district

TABLE 2.—*Recorded production of sheet-and-punch mica from the Spruce Pine district, North Carolina*

	Sheet and punch (pounds)	Percent
1917–40: [1]		
20 largest mines	2, 482, 006	80
110 other mines and prospects	622, 211	20
Total (130)	3, 104, 217	100
1942–45: [2]		
20 largest mines	456, 456	58
688 other mines and prospects	331, 639	42
Total (708)	788, 095	100
1953–62: [3]		
10 largest mines	[4] 946, 000	44
>200 other mines and prospects	1, 209, 000	56
Total (>200)	2, 155, 000	100

[1] Data from Kesler and Olson (1942, table 2).
[2] Data from Colonial Mica Corp.
[3] Data from U.S. Bureau of Mines and Defense Minerals Exploration Administration.
[4] Estimate.

has added details concerning regional structure and metamorphism (Bryant, 1962; Reed, 1964a, b). In table 4 the district has been divided arbitrarily into areas for convenience in listing the mines and prospects. Deposits in any one area are in general similar, but there are minor differences between areas.

Several thousand pegmatites are exposed in the Spruce Pine district, but only a small fraction contain minable deposits of sheet mica. The known pegmatites are distributed unevenly throughout much of the district (Brobst, 1962, pl. 1), and there are some areas containing few or no pegmatites, such as Simmons Knob northeast of Newdale, Yancey County, and Big Bald Mountain on the Avery-Mitchell County line. The pegmatites range from small pods and thin seams to large masses hundreds of feet thick and thousands of feet long. Some of the largest bodies are mined for feldspar and a few for both feldspar and mica. Some large deposits are mined only for sheet mica, and many small bodies a few feet thick and less than 100 feet long have been mined successfully. The large masses of fine-grained pegmatite or granodiorite are mined for feldspar and scrap mica. The deeply weathered granodiorite deposits are mined for clay and scrap mica.

Wallrock for about half of the deposits is mica gneiss and for about one-fourth, interlayered mica and hornblende gneiss. About 10 percent of the deposits are enclosed in hornblende gneiss and about 10 percent cut the larger bodies of fine-grained pegmatite or granodiorite. Throughout the district about 70 percent of the deposits are concordant to the foliation of the enclosing country rock. Some tabular bodies are contorted and follow folds. Discordant bodies follow joints

or faults. Many large pegmatites which appear concordant to the regional structure are discordant in detail and probably are in shear zones. Elongate bodies and minor bulges or rolls in the pegmatites plunge obliquely downdip parallel to the plunge of minor structures in the country rock.

Contacts between pegmatite and country rock are generally sharp. Mica gneiss and schist have been little altered along contacts, but hornblende gneiss in contact with pegmatite has been altered to biotite schist for a few inches to a foot or more. Contacts of pegmatite and granodiorite are generally obscured by similarity in grain size and mineralogy.

The pegmatites are tabular (57 percent), lenticular (29 percent) or irregular (14 percent). Many of the tabular bodies are probably elongate lenses that have three unequal axes. Some tabular bodies pinch and swell either along strike or downdip, or both; where this characteristic is most pronounced, a series of lenses follow a narrow zone in the metamorphic country rocks. Most lenticular bodies are discoidal with one axis shorter than the other two; but some have one very long axis and two short ones, and they are best described as tonguelike or pipelike.

The sheet-mica-bearing pegmatites are generally not large; few are thicker than 100 feet or longer than 1,000 feet. Half of the deposits are 10 feet or less thick, and only 20 percent are more than 20 feet thick. About 40 percent may be more than 200 feet long, but 45 percent are probably less than 100 feet long. Some of the largest deposits have been mined downdip 300–400 feet, but many bodies pinch out in less than 100 feet in depth.

The internal structure of Spruce Pine pegmatites is relatively simple (Cameron and others, 1949, p. 62–64). Nearly 75 percent of the deposits have no apparent internal zoning of contrasting mineral composition or texture. Of the 25 percent that are zoned, two-thirds have a wall zone of feldspar, quartz, and mica and a core of massive quartz. The remainder have perthite-plagioclase-quartz, perthite-plagioclase, perthite-quartz, or perthite cores. About 20 percent of the zoned bodies have one or more intermediate zones of various proportions of feldspar, quartz, and mica. A few deposits have secondary units of fine-grained pegmatite or quartz cutting the earlier zones, and some have small replacement units of fine-grained plagioclase replacing microcline and quartz.

Mineralogy of the pegmatites is also simple. The most abundant minerals are plagioclase, quartz, perthitic microcline, and muscovite. The type of feldspar was recorded for about 80 percent of the deposits. About 30 percent of them contain only plagioclase; 15 percent have abundant plagioclase and minor perthite; 30 percent contain a little more plagiocalse than perthite; 20 percent contain a little more perthite than plagioclase; 4 percent contain much more perthite than plagioclase; and only 1 percent contain perthite alone.

Plagioclase is generally white; but some is clear and glassy, and some is light pink or green where altered to thulite or epidote. Some clear and untwinned oligoclase of gem quality is present in a few deposits. Grain size ranges from less than an inch to masses several feet across; dimensions of several inches are common. Plagioclase is most abundant in wall zones and outer intermediate zones. Most of the muscovite of commercial size and quantity is found in plagioclase-rich pegmatite.

The plagioclase ranges from albite to calcic oligoclase. Maurice (1940, p. 173–178) found that a belt of pegmatites with the more calcic plagioclase extends northeast from Micaville to Bakersville and is flanked by pegmatites containing the more sodic plagioclase. From Maurice's data, Olson (1944, p. 28) concluded that the more sodic plagioclase is in pegmatite in or near granodiorite, in migmatite related to granodiorite, or in very large pegmatites, The more calcic plagioclase is in pegmatite farther from granodiorite.

Most of the pegmatites contain about 25 percent quartz as small- to medium-sized grains mixed with feldspar, as graphic intergrowths in feldspar, or as massive cores in some zoned deposits. The quartz is generally gray, white or smoky; little is transparent. Euhedral and even subhedral crystals are rare.

Microcline is widespread and abundant in many of the pegmatites. Practically all of it is perthitic, and much of it has a graphic texture. The microcline is white to light-cream or pink. Grain size is medium to very coarse. Most of the microcline is in intermediate zones or cores.

Muscovite is present in all the pegmatites. It ranges from the fine-grained scaly form called sericite to large books several feet across. Total muscovite content may be as much as 15 percent in the granodiorite and pegmatite (Brobst, 1962, p. A10), but sheet muscovite probably forms from 2 percent to no more than 8 percent of any one deposit. Much of the sericite formed late as an alteration product either from residual solutions during crystallization or from metamorphic effects of subsequent deformation.

The color, quality, and size of the sheet-mica crystals vary widely in different parts of the district. Color ranges from light reddish brown (ruby) through light brown (rum) to light brownish green, light green, and dark green. Some sheets are mottled by irregular color variations, and some have alternating color bands generally hexagonal or rhombic in plan. Reddish-brown mica is found in 23 percent of the deposits, brown in 20 percent, and various shade of green in 55 percent. The remaining 2 percent of the deposits have both green and brown mica. In areas of gneiss, reddish-brown and brown mica predominate, and in areas in or near the granite masses brownish green and green mica predominate. This areal distribution of mica according to color in the Spruce Pine district has been shown by Olson (1944, pl. 2).

Much good quality mica has been mined in the district, but large amounts of the sheet mica contain various defects. The principal defects are staining, mineral inclusions and intergrowths, "A" structure and reeving, bending, cracking, and ruling. Some form of staining, such as specks, spots, and streaks of magnetite, hematite, pyrite, limonite, and clay, is found in at least occasional pieces of mica from 54 percent of the deposits, and intergrowths of muscovite with biotite or other minerals are found in 15 percent of the deposits.

"A" structure and reeving are common defects in deposits of green mica, especially where the green mica is associated with large masses of quartz. Deformation of the mica crystals after formation has produced bending in 40 percent of the deposits and cracking and ruling in 34 percent. The degree of deformation varies within the district. Near the center of the district around Spruce Pine only 20 percent of the deposits contain some bent mica, but to the northeast near Plumtree, 53 percent contain some bent mica and near Black Mountain, 67 percent.

A more detailed discussion of the properties of mica and lists of some characteristics of the mica from many of the Spruce Pine deposits are given by Jahns and Lancaster (1950).

The Spruce Pine pegmatites contain less than 5 percent accessory minerals. In 625 pegmatites for which data are available the most common accessory minerals are garnet in 60 percent of the deposits and biotite in 40 percent. Apatite (12 percent), pyrite (9 percent), vermiculite (7 percent), allanite and thulite (6 percent) are also widespread. Beryl has been reported in 28 of the 625 deposits, epidote and tourmaline in 32, pyrrhotite in 12, and columbite in 10. The following minerals have been reported from less than 10 deposits: autunite, calcite, chalcopyrite, chlorite, clarkeite, cleavelandite, covellite, cyrtolite, gahnite, gummite, hyalite, kyanite, lepidolite, magetite, monazite, samarskite, siderite, sphalerite, spodumene, torbernite, uraninite, uranophane, zircon, and zoisite.

BUNCOMBE DISTRICT

The Buncombe district is an area of widely scattered pegmatites between the Spruce Pine district to the northeast and the Franklin-Sylva district to the southwest. The district is about 24 miles wide and 30 miles long in Buncombe, McDowell, Madison, and Yancey Counties (pl. 4). Ninety mines and prospects are known, but there may be many more small prospects that are lost and forgotten. Sterrett (1923, p. 184–188) describes briefly 11 deposits in Buncombe County. According to the Colonial Mica Corp. records, about 50 deposits had a total production from 1942 to 1945 of nearly 13,000 pounds of sheet and punch mica worth $39,000. At least 20 mines were active at various times from 1952 to 1962, and 3 mines were explored with DMEA financial assistance. Total production from 1952 through 1962 was 9,975 pounds of sheet and punch worth more than $59,000. Complete production records are not available, but probably no mine has an individual production greater than 10,000 pounds of sheet-and-punch mica. Most of the mines have produced less than 500 pounds. Total production for the district may be no more than 50,000 pounds.

The pegmatites in the Buncombe district are similar to those in adjacent areas. Most of the deposits are weathered, tabular (65 percent) or lenticular (27 percent) bodies in mica gneiss or schist. Three deposits are in hornblende gneiss and three cut dunite. Nearly three-quarters of the deposits are less than 10 feet thick, and only 5 percent are greater than 20 feet thick. About 60 percent are concordant to the foliation of the country rock. One-third of the pegmatites have a feldspar-quartz-mica wall zone and a quartz core; the remainder have no apparent zoning. Three of the zoned deposits have a perthite intermediate zone. Plagioclase is the principal feldspar, but perthite is present in some deposits. Biotite is present in at least 40 percent of the deposits and may be the principal mica in some. Garnet is common, and allanite, apatite, beryl, sulfide minerals, tourmaline, and vermiculite are rare accessory minerals.

The muscovite is reddish brown (75 percent), brown (10 percent), and green (15 percent). In general, the quality and quantity are only fair. At least 30 percent of the deposits have mica that is bent, cracked, ruled, or stained. The average size of the sheet mica is small.

WOODLAWN DISTRICT

The Woodlawn district in McDowell County, contains at least 12 small mines and prospects in an area about 10 miles long and several wide that is separated from the Spruce Pine district by an area 1–3 miles wide that contains few or no pegmatites (pl. 4). Very little is known about the deposits in McDowell County. Sterrett (1923, p. 224) mentions only two deposits, although the principal mining activity was apparently from 1894 to 1918. According to records of the Colonial Mica Corp., production from 1942 to 1945 came from 18 mines in McDowell County, at least some of which were in the Woodlawn district, and amounted to less than 2,000 pounds of sheet-and-punch mica worth about $7,350. About 15 mines and prospects have been worked since 1952 in McDowell County, but their locations are unrecorded. Total production was 600 pounds of sheet mica valued at nearly $4,500.

The pegmatites are generally deeply weathered, small, tabular or lenticular bodies 1–10 feet thick in mica gneiss or schist. Plagioclase is the principal feldspar, but perthite is present in some of the deposits. Biotite and garnet are the principal accessory minerals.

The mica is generally green or greenish brown. Reddish-brown mica is present in at least two of the deposits. The quality of the sheet mica is poor and the quantity is small. Much of the mica is stained.

FRANKLIN-SYLVA DISTRICT

The Franklin-Sylva district is second among southern Appalachian mica districts in number of mines and in total production. The district covers an area about 12 miles wide and 50 long in Haywood, Jackson, and Macon Counties and extends a short distance into Clay County (pls. 5, 6). Most of the mica mines are centered about Franklin in Macon County and Sylva in Jackson County. Although the number of mines and pegmatites decreases sharply away from the center of the district, the largest single producer is the Big Ridge mine in Haywood County, well outside the center of the district. This mine was opened in 1867 and was one of the first mica mines to be operated in North Carolina in modern times. As in the districts to the northeast, several of the large mines were originally worked by Indians for mica (Smith, 1877, p. 441–443) and clay (Watts, 1913, p. 10; Griffiths, 1929). Modern clay mining in the district was started in 1888 near Webster (Watts, 1913, p. 10), but little clay has been mined in the district since the 1920's. Some feldspar has been mined sporadically, generally as a byproduct of mica mining.

Information has been assembled on 433 mica deposits in the district (table 4), but there are probably a total of 500–700 mines and prospects. Sterrett (1923) described more than 100 deposits in Haywood, Jackson, and Macon Counties. Some of these deposits are in the Cashiers district east of the Franklin-Sylva district and are not included in the table. Records of the Colonial Mica Corp. show that from 1942 to 1945 some mining was done at 24 mines in Haywood County, 189 in Jackson County, and 157 in Macon County. Olson and others (1946) show the locations of 326 mines and describe in detail 20 mines worked during World War II. More than 150 mines were active in the district from 1952 to 1962. In Haywood County, 8 deposits were explored with DMEA financial assistance; in Jackson County, 13, and in Macon County, 46. Nineteen deposits were certified as discoveries, and several of those in Macon County became significant producers.

Production records for the district are not complete. The available data are summarized in table 3. During each period of production about 10 percent of the mines have produced 65–85 percent of the sheet-and-punch mica.

TABLE 3.—*Recorded production of sheet-and-punch mica from the Franklin-Sylva district, North Carolina*

County	1922–1942 [1]		1942–1945 [2]		1953–1962 [3]	
	Number of mines	Pounds sheet and punch	Number of mines	Pounds sheet and punch	Number of mines	Pounds sheet and punch
Haywood	1 2	1,184,672 3,923	1 23	85,716 4,540	---- ----	---- ----
Total	3	1,188,595	24	90,256	5	1,118
Jackson	6 48	287,099 149,960	8 181	55,938 30,289	5 49	27,354 19,838
Total	54	437,059	189	86,227	54	47,192
Macon	7 54	532,283 138,757	15 142	117,330 30,774	7 84	267,087 133,261
Total	61	671,040	157	148,104	91	400,348
District total	118	2,296,694	370	324,587	150	448,658

[1] Data from Olson (1946) and records of Asheville Mica Co.
[2] Data from Colonial Mica Corp.
[3] Data from U.S. Bureau of Mines.

Individual pegmatite bodies range from thin stringers an inch or less thick to large masses 150–350 feet thick. About 70 percent of the mica-bearing deposits are 10 feet or less thick. Most of the deposits are less than 200 feet long, but some elongate bodies are 500–1,400 feet long. Although a few of them have been mined to depths of 300 feet, most are not known to go deeper than 100 feet. Nearly all the deposits are weathered to depths ranging from 10 to 100 feet.

More than half of the deposits are tabular, about 20 percent are lenticular, and 22 percent are irregularly shaped. About 80 percent are discordant bodies. The wallrock is mica gneiss (92 percent), interlayered mica and hornblende gneiss (6 percent), or hornblende gneiss (2 percent). Numerous thin dikes south and west of Franklin strike north or north-northeast and are vertical. In the district as a whole, however, strike and dip are not uniform. The crests, keels, rolls, and minor structures in the pegmatites generally plunge steeply and may be parallel to the plunge of minor structures in the country rock.

The pegmatites have a simple internal structure. About two-thirds are zoned; 92 percent of these have quartz cores, and the remainder have plagioclase-perthite-quartz, perthite-quartz, or perthite cores. Wall zones are generally feldspar-quartz-muscovite in 60 percent of the deposits, plagioclase-quartz-muscovite in

20 percent, or plagioclase-perthite-quartz-muscovite in 20 percent. About 10 percent of the deposits have one or more intermediate zones of plagioclase-perthite-quartz, perthite-quartz, or perthite. A thin border zone of feldspar-quartz-mica or quartz-mica pegmatite is present in some of the deposits. Late-stage fracture fillings or replacement units are rare. A few deposits contain cores that are sheared and have thin strips of biotite along fractures. Some deposits have veinlets of quartz, quartz-muscovite, or plagioclase-muscovite that cut outer zones. Perthite is partly altered to plagioclase and muscovite along shears in a few deposits.

The principal minerals are quartz, oligoclase, perthitic microline, and muscovite. The chief accessory minerals are biotite and garnet. Pyrite, pyrrhotite, and apatite are present in a few deposits, and allanite, ankerite, beryl, chalcopyrite, epidote, hedenbergite, kyanite, and tourmaline are reported from less than 2 percent of the deposits. Vermiculite, kaolinite, and limonite, are common secondary minerals in the weathered pegmatites.

The muscovite in the Franklin-Sylva district is generally reddish brown (36 percent) or brown (44 percent). About 30 of the 435 well-known deposits contain both brown and green mica, and 55 deposits have only green mica. The mica ranges widely in quality. Nearly half of the deposits contain some mineral-stained mica, and 12 percent contain muscovite with biotite intergrowths. Deformation of mica is also widespread in the district, and at least 45 percent of the mines contain some mica that is bent, ruled, or cracked. In a few mines much of the mica is deformed and is only scrap quality. Comparison of production data from Franklin-Sylva (Olson and others, 1946, p. 18) with that of Spruce Pine (Kesler and Olson, 1942, p. 36) suggests that the average size of recoverable sheet mica is slightly smaller in the Franklin-Sylva district.

TABLE 4.—*Summary description of mica mines and prospects in the Blue Ridge of North Carolina*

Source of information:
Unpublished data in files of—
CMC, Colonial Mica Corp.
DMEA, Defense Minerals Exploration Administration
OME, Office of Minerals Exploration
USGS, U.S. Geological Survey
Also—
OF, U.S. Geological Survey open-file map, which may be examined at the U.S. Geological Survey Library, Washington, D.C.; at the office of the U.S. Geological Survey, Knoxville, Tenn.; and at the office of the State Geologist, Raleigh, N.C.

Principal periods worked: WWI, World War I; WWII, World War II; int, intermittent.
Production: Small, <500 lb; moderate, 500-10,000 lb; large, >10,000 lb.
Size of pegmatite: D, depth; L, length; T, thickness; avg, average.
Internal structure: B, biotite; F, feldspar; M, muscovite; P, perthite; Pl, plagioclase; Q, quartz.

Mine or prospect					Description of muscovite	Production	Pegmatite						Wallrock	Extent of weathering	Remarks (Internal structure, texture, and mineralogy of pegmatite)
Locality No. on pl. 2	Name	Source of information	Principal periods worked	Workings (measurements, in feet)			Shape	Size (feet)	Attitude			Relation to wallrock structure			
									Strike	Dip	Plunge				
JEFFERSON-BOONE DISTRICT															
Ashe County															
20	Beaver Creek mine	CMC	WWII		Moderate stain	Small			NE	SE		Concordant	Interlayered biotite and hornblende geniss.		F-Q-M pegmatite.
12	Buck Mountain mine	USGS, CMC	1913, 1930, WWII	Shaft 55, drift 80; shaft 60, drift 10; shaft 20; cut 40, adit 40.	Ruby, moderate "A" structure, biotite intergrowths, small concentrations near walls and core.	Moderate sheet	Tabular	6-10 T, >200 L, >60 D.	NE	Steep		do.	Biotite gneiss	Unweathered	Pl-P-Q-M-B wall zone, medium grained; accessory garnet, apatite; discontinuous Q core.
25	Conner prospect	CMC	1927, WWII, 1953	Small cut 50 long, 2 shafts 15 deep.	Reddish brown, hard, clear, cracked, small, bent, ruled.	Small sheet		4-6 T	NE	Vertical			Hornblende gneiss.	Weathered	F-Q-M pegmatite; poorly exposed.
21	Coon Den mine	CMC	1920, WWII	2 cuts, short incline	Reddish brown, hard, clear, cracked; minor "A" structure, small.	do.			NE	Steep		Concordant	Mica gneiss		Pl-Q-P-M pegmatite; accessory vermiculite, garnet, apatite, beryl. 2-12-in. mica-rich zone along northwest wall.
7	Councell prospect	CMC	WWII	Shaft 20	Reddish brown, hardly small	do.			NE	SE				Unweathered	F-Q-M pegmatite.
19	Duncan (Harris) mine	USGS, Sterrett (1923, p. 176).	1885-88, 1906-7, 1918, WWII.	Cut 115, 2 shafts 60 and 108, 2 adits and numerous stopes.	Pinkish buff, moderately ruled, cracked, mineral inclusions, tied.	Moderage sheet (WWII).	Irregular, lens.	1.5-8 T, avg 5, 100 D.	NE	SE	40° SW	Partly concordant.	Mica gneiss	Weathered (100 ft).	Pl-P-Q-M pegmatite, medium grained; accessory garnet, apatite, pyrite, sericite, yellow beryl.
17	Duncan prospect	CMC	1930, WWII	2 pits	Small books	Small sheet									F-Q-M pegmatite.
29	Tom Duncan mine	USGS	WWII	Cut 80	Reddish brown, flat, small	Moderate sheet	Lens	3 T, >80 L	NE	SE		Partly concordant.	Interlayered mica schist and hornblende gneiss.		Pl-Q-P-M pegmatite.
22	Dugherty (Darty) mine	CMC	1892, WWII	Pit 20 long, 15 deep	Reddish brown, hard, ruled, "A" structure, locky, bent, small.	Small sheet	Pinch and swell.	5-10 T, >100 L	NE	SE		do.	Hornblende gneiss.	Unweathered	Pl-Q-P-M pegmatite; accessory biotite, blue-green to yellow beryl, apatite, garnet.
1	Foster mine	Sterrett (1923, p. 173), USGS.	1897; int	Crosscut, extensive stopes	Pinkish buff, hard, small	Moderate sheet		12-18 T	N. 55° E	50° SE		Concordant	Hornblende gneiss; biotite alteration.		F-Q-M pegmatite.
15	Goodman mine	Sterrett (1923, p. 176), CMC.	1890-96, WWII	Cut 140; 2 shafts, caved	Yellowish olive, common stain, ruled, bent, small.	do.	Lens		NE	SE		do.	Mica gneiss	Weathered	Pl-Q-M wall zone, medium grained; accessory biotite, apatite, garnet; P-Q core. Poorly exposed.
13	Hamilton mine	Sterrett (1923, p. 173), USGS.	1875, 1890-1900, 1907-12, 1950's.	Cuts ,3 adits, shaft, drifts, partly destroyed by cut 150.	Reddish brown, biotite intergrowths, bent, ruled.	do.		>6 T	N. 10° E	Steep E		Partly concordant.	Interlayered hornblende and mica gneiss.	do.	Pl-Q-P-M-B pegmatite, coarse grained; accessory garnet, apatite, yellow to yellow-green beryl. Perthite concentrated in interior.
18	Hardin (North Hardin) mine.	Sterrett (1923, p. 173), USGS.	1880, WWI, 1931, WWII, 1952-57.	Cuts, shafts, adits, stopes, in area 600 long, 100 deep.	Ruby, mottled, minor ruling, haircracks, reeved, bent.	Moderate sheet (1943-57).	Lenses	1.5-10 T, avg 5 >350 L, >100	NE	SE	Steep	Concordant	Biotite gneiss	Weathered (30 ft).	Pl-Q-P-M pegmatite, fine to medium grained; accessory apatite, biotite, garnet, yellow beryl, sericite. Some graphic texture P-Q.
16	South Hardin mine	Sterrett (1923, p. 175).		Cut 75, shaft 30, adit	Reddish brown	Moderate sheet		7 T at surface	NE	SE		do.	do.		F-Q-M pegmatite, fine to coarse grained; accessory yellow to blue-green beryl. Pods and platy masses of quartz near footwall. Muscovite associated with quartz.
10	Hodson prospect	CMC	WWII	Small pit	do.	Small sheet	Sill	2 T	NW			do.	Interlayered hornblende and biotite gneiss.	Weathered	Kaolinized F-Q-M pegmatite.
28	Houck mine	CMC	1910, WWII	Shaft 40, adit	do.	do.		6 T		NW					Pl-Q-P-M pegmatite, medium grained; accessory apatite, garnet.
26	Byard Houck prospect	CMC	WWII		Reddish brown, small	do.	Tabular	3 T				Discordant		Weathered	Kaolinized F-Q-M pegmatite.
6	Howell prospect	CMC	WWII		Small, clay stain	do.								do.	Kaolinized F-Q-M wall zone, medium grained; Q core.
17	Rich Howell prospect	CMC	1935, 1942	Cut 25, short adits	Clear	do.		4-5 T							F-Q-M wall zone, medium to coarse grained; discontinuous Q core.
32	Johnson mine	DMEA	1952-56	Cut 260, shaft 40	Reddish brown, clear; minor cracks, ruling, biotite intergrowths, bent.	Moderate sheet	Lenses	3-4 T, 40 L, largest lens.	NW	SW	S	Concordant	Interlayered biotite and hornblende gneiss.	Saprolite (100 ft).	Kaolinized Pl-Q-P-M pegmatite, medium to coarse grained; accessory apatite; graphic texture common.
27	Laws prospect	CMC	WWII	Shallow trenches	Reddish brown, small	Small sheet									F-Q-M pegmatite; accessory beryl in quartz blocks.
	Little prospects:														
4	No. 1	USGS	WWI, WWII	6 cuts, 3 shafts 30-60, adit 140, drift 68.	Greenish brown, flat "A" structure, minor stain, ruling, biotite intergrowths, tied.	Moderate sheet	Tabular	>45 T at N. end, >300 L, >60 D.	NE	Vertical		Concordant(?)	Mica gneiss	Weathered	Kaolinized Pl-P-Q-M-B wall zone; accessory yellow to yellow-green beryl; garnet; Q core.
4	No. 2	USGS	WWI, WWII	Cut 135	Small		do.	>20 T, >135 L	NE	do.		do.		do.	Kaolinized F-Q-M pegmatite.