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LITHIUM RESOURCES OF NORTH CAROLINA

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MINING LITHIUM ORE NEAR KINGS MOUNTAIN, NORTH CAROLINA

Large quantities of high grade spodumene ore are produced from the quarry of Foote Mineral Company pictured above. The quarry spans several pegmatite dikes from which ore is quarried and delivered to the concentrating plant shown in the background.

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THE LITHIUM RESOURCES OF NORTH CAROLINA

By

Sam D. Broadhurst

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INTRODUCTION

The rise of lithium to a place of prominence among industrial mineral products has been phenomenal. In a relatively short time it has become an important ingredient of many ceramic bodies, lubricants, and other items of commerce. It has become of considerable importance in the development of nuclear energy, and other uses are being developed through widespread research. The rapid increase in demand for lithium and anticipated industrial requirements for the immediate future have placed the lithium resources of North Carolina in a highly favorable economic and strategic position.

Deposits of lithium minerals in North Carolina constitute the largest block of economically recoverable reserves known in the Western Hemisphere and have been estimated to represent nearly 93 percent of the total domestic reserves.[11/*] Located favorably for mining, processing, and marketing, these deposits provide the United States with a well protected major source of supply. While the lithium industry is assured sufficient ore from both domestic and foreign sources to meet foreseeable needs for years ahead, the present rapid development of the North Carolina deposits makes an appraisal of these resources desirable.

* References are at end of report.

Purpose and Scope

This report presents general information concerning lithium and its occurrence in North Carolina. It is a compilation of data from several published and unpublished reports, from conferences with geologists and mining engineers familiar with the various occurrences of lithium, and from field observations by the writer. The report is one of a series published by the Division of Mineral Resources of the Department of Conservation and Development as a part of its inventory of the State's mineral resources, and its preparation and publication were authorized by State Geologist Jasper L. Stuckey.

Acknowledgments

Much of the basic information used in the preparation of this report was obtained from Bulletin 936-J, Circular 309, and Bulletin 1027-G of the United States Geological Survey and from Guides to Southeastern Geology, a publication of the Geological Society of America. The writer wishes to acknowledge help given him by T. L. Kesler of Foote Mineral Company; J. N. McClure, Dan Michalek, and Clyde Robinson of Lithium Corporation of America; E. J. Martin of Basic Atomics, Incorporated; and Douglas B. Sterrett and Earl C. Van Horn, consulting geologists. These gentlemen and the many property owners and other interested persons throughout the State have contributed to the report.

LITHIUM

Properties and Uses

Lithium, the lightest of all solid bodies, has an atomic weight of 6.94 and a specific gravity of 0.534. Chemically, it is classed as an alkali metal along with sodium, potassium, rubidium, and cesium.

Lithium is very active chemically, reacting readily with many of the elements. It has favorable gas-absorption properties, a strong affinity for water, acts as a powerful flux in ceramics, and is capable of releasing enormous amounts of energy. Because of its great versatility, lithium has a wide variety of industrial applications.

The basic lithium compounds of commerce are the carbonate and hydroxide; from these, the metal and most other compounds are derived. A major portion of current production is used in the preparation of ceramic products and all-purpose greases, and increasing amounts are being consumed in the development of nuclear energy. Lithium is an ingredient in fuels now being tested for rockets and similar types of propulsion equipment. Other uses include air conditioning, organic synthesis, hydrogen generation, brazing and welding, metallurgy, alkaline storage batteries, dry-cell batteries, cosmetics, pharmaceuticals, and photography.

Occurrence

Lithium is a widespread element, making up approximately 0.006 percent of the earth's crust. Known concentrations of economic importance, however, are not common and are limited to two types, namely, as salts in brines and as lithium-bearing minerals in pegmatites.

Natural brines - commonly occurring in warm, arid regions - are composed of a series of complex salts, in which lithium is a minor constituent. Expressed as a percentage, the lithia content is negligible in most brines; but where deposits are large, lithia may be present in sufficient volume to justify recovery. The only brine deposit now being worked is a complex alkali type, containing principally sodium and potassium chlorides, borates, carbonates, and sulphates. The lithia content averages about 0.015 percent.

In the mineral form, lithium is most commonly combined with aluminum silicates and phosphates, and occurrences, with few exceptions, are confined to pegmatites. These are relatively small, narrow, tabular, dike-like bodies, composed for the most part of feldspar, quartz, mica, and often one or more of the rarer minerals. Most of the lithium occurs in spodumene, a silicate mineral. Where the lithia content of a pegmatite is 1 percent or greater, it is considered to be of potential economic importance. Many of the deposits now being mined average between 1.2 percent and 1.7 percent lithia.

Brines and pegmatites are both important commercial sources of lithium, but pegmatites are generally considered to be the more desirable and to contain larger recoverable reserves. The lithium resources of North Carolina are confined to pegmatite occurrences.

Lithium Minerals

Lithium is a constituent of some 145 known minerals.[15] Only four of these - spodumene, amblygonite, lepidolite, and petalite - are considered as being of major commercial importance. In the United States, spodumene, amblygonite, and lepidolite are the chief ore minerals. All three are present in the pegmatites of North Carolina, but only spodumene has been found in commercial quantities.

Spodumene ($Al_2O_3 \cdot Li_2O \cdot 4SiO_2$) usually occurs as lathlike crystals and ordinarily is light gray to greenish-gray in color. Theoretically, it contains 8.03 percent lithia. The actual lithia content varies widely but ranges usually between 7 percent and 8 percent, that in North Carolina averaging about 7.3 percent. Two gem varieties are recognized: hiddenite, a clear emerald-green spodumene; and kunzite, the lilac-colored variety.

Amblygonite ($Al_2O_3 \cdot P_2O_5 \cdot 2LiF$) contains from 6.7 percent to 9.65 percent lithia. This mineral is usually milky white to gray in color, has a vitreous to pearly luster, and is translucent to transparent. It occurs generally as coarse, cleavable masses in pegmatites.

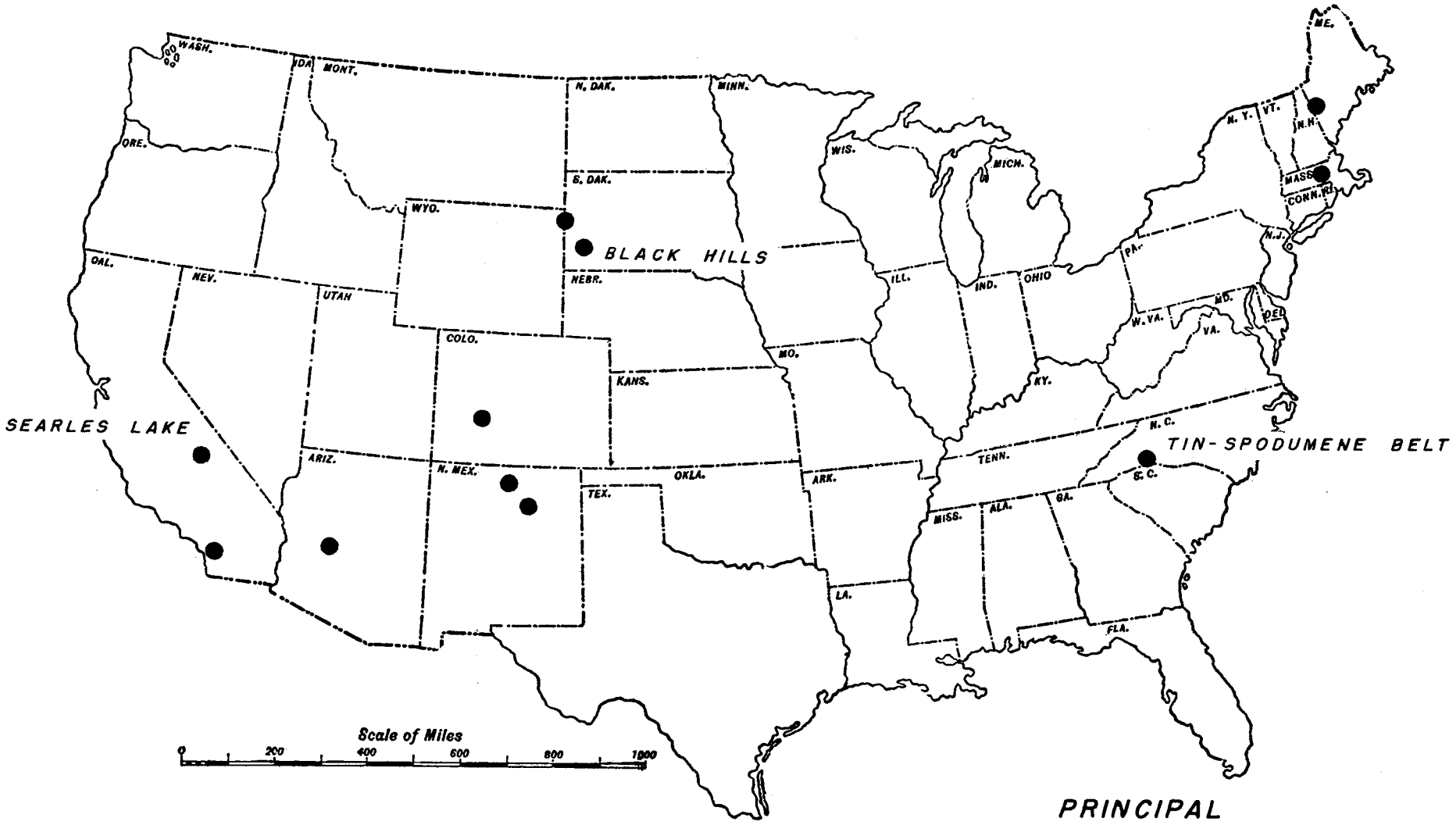
Lepidolite ($Al_2O_3 \cdot 3SiO_2 \cdot 2K, LiF$), the lithia mica, contains from 3 percent to 4 percent lithia and normally is found as compact aggregates of small plates. The mineral has a pearly luster, and its color varies from rose-red to lilac-gray and from yellowish-white to grayish-white. It is most commonly associated with albite and other pegmatitic minerals.

Domestic Source of Supply

The United States contains the largest known reserves and is the major producer and consumer of lithium in the world. Spodumene from the tin-spodumene belt of North Carolina; dilithium sodium phosphate from the brines of Searles Lake, California; and spodumene, amblygonite, and lepidolite from the Black Hills of South Dakota are the chief domestic sources of supply. (See Plate 1.) Lithium deposits occur also in Arizona, Colorado, New Mexico, Wyoming, and the New England States, but mineable reserves in these states are limited. Foreign ore is of increasing importance to the domestic industry, especially that from Canada and Africa.

Production

The earliest production of lithium reported in the United States was in 1889,[11] although minor quantities of gem spodumene were mined in North Carolina as early as 1880.[8] Prior to 1917, lithium mining was small and erratic. The average annual production in the United States from 1900 to 1917 was only 581 tons, but between 1918 and 1920 it



PRINCIPAL

LITHIUM LOCALITIES

IN THE

UNITED STATES

PLATE I

amounted to 6,500 tons, reaching a maximum of 11,696 tons in 1920. Following World War I, production decreased but continued through the 1920's. It ceased during the early thirties, but by the middle of the decade it had begun to rise. From 1939 until 1945 the lithium market was stimulated by military demands, production reaching 13,319 tons in 1944. A curtailment of government contracts late in 1944 resulted in drastic reductions in production; however, production had accelerated by 1950 and passed the wartime peak in 1952. Since that time it has continued to set alltime records. (See Figure 1.)

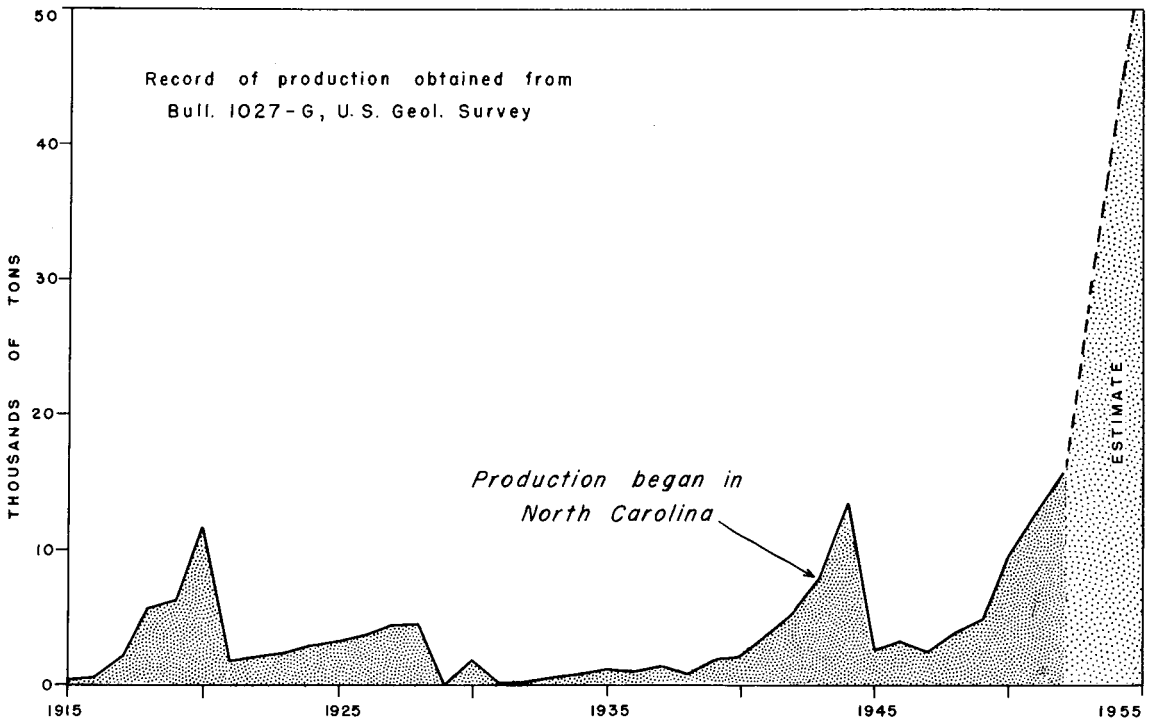


Figure 1. Production of lithium minerals in the United States 1915-1955

Expansion of the lithium industry in the United States since World War II has been spectacular. Production amounted to but 2,446 tons in 1945, but it had reached 15,611 tons in 1952. Because of the role of lithium in the nation's atomic energy program, actual production figures since 1953 are not available for publication. Production for 1953 was estimated at

28,000 tons, and by 1955 a production of about 50,000 tons was anticipated. Production capacity in North Carolina alone would indicate the 1955 figure is conservative.

LITHIUM RESOURCES OF NORTH CAROLINA

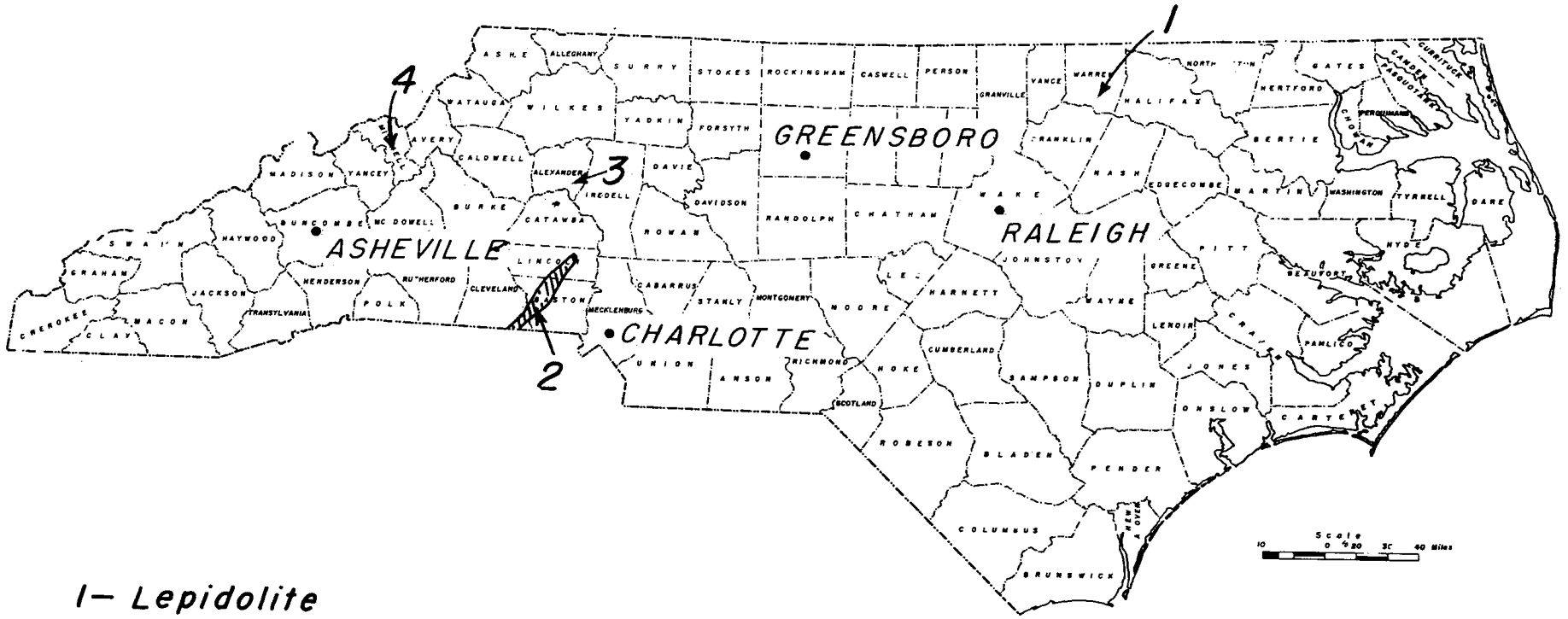
Distribution

There are four principal localities in North Carolina in which lithium minerals occur: (1) the Kings Mountain mining district, (2) southeastern Alexander County, (3) near Spruce Pine, Mitchell County, and (4) south-central Warren County. The general locations of these occurrences are shown on Plate 2.

Spodumene-bearing pegmatites crop out in a narrow belt, extending from near Cheraw, South Carolina, northeastward through Kings Mountain to beyond Lincolnton, North Carolina. This zone, referred to as the tin-spodumene belt of the Carolinas,[6] contains the principal lithium reserves in the United States. The most important deposits are in that portion of the belt lying in and adjacent to the Kings Mountain mining district, North Carolina.

The green, gem variety of spodumene, hiddenite, is present in a few small pegmatites in southeastern Alexander County. The largest deposit lies immediately south of N.C. Highway 90, a short distance west of the village of Hiddenite. Known occurrences are neither large enough nor rich enough to constitute economic reserves.

Near Spruce Pine, Mitchell County, several specimens of the lilac-colored spodumene, kunzite, were found in a pegmatite being mined for



1– Lepidolite

2– Spodumene (common variety)

3– Spodumene (hiddenite)

4– Spodumene (kunzite)

TIN-SPODUMENE BELT

LITHIUM MINERALS IN NORTH CAROLINA

PLATE 2

feldspar. No additional occurrences of this mineral have been reported in the State.

Small flakes of lepidolite, the lithia mica, occur on the Fowler farm, 2.5 miles southeast of Inez, in south-central Warren County. The mineral is intergrown with quartz and is a vein-type occurrence; but, because of deeply weathered conditions existing in the area, only float material is exposed. Most of the material has been found in several cultivated fields north of Maple Branch. No significant tonnage is indicated at this locality.

History of Development

The earliest record of mining for lithium minerals in North Carolina was about 1880 and was for the gem spodumene, hiddenite.[8/] Following the discovery of this mineral near Stony Point, Alexander County, in 1879, several attempts were made to develop the deposits, the most concentrated efforts being between 1880 and 1889, in 1907, and about 1925. While some excellent specimens were recovered, the deposits were not large or rich enough to warrant systematic mining.

Spodumene-bearing pegmatites were known to occur in the vicinity of Kings Mountain and Lincolnton for many years, but early interest was restricted largely to the small amounts of cassiterite, an oxide of tin, which is present in some of the dikes. Various attempts were made between 1880 and 1937 to concentrate this mineral, but little notice was taken of the spodumene until the midthirties. L. M. Williams began prospecting the area about 1935 and acquired control of many of the larger deposits. In the same year, Frank Hess of the United States Bureau of Mines visited the area and made a report which focused considerable attention on the

deposits. The United States Bureau of Mines and others carried out beneficiation studies during this period. Phil Hoyt erected a small experimental decrepitation kiln north of Kings Mountain about 1936 but did not go into production. Between 1938 and 1942, T. L. Kesler of the United States Geological Survey mapped the more important deposits and pointed out the potentials of the district. By the late thirties, United Feldspar and Minerals Company had erected a pilot plant at Spruce Pine and was carrying out tests on the ore. This company later marketed a mixture of spodumene and feldspar under the trade name of Lithospar, but the tonnage of spodumene mined for this purpose was small.

Prior to 1940, the lithium market was such that little effort was made to develop the deposits on a large scale. The first major production in North Carolina was in 1942, when The Solvay Process Company erected a flotation plant 1.5 miles south of Kings Mountain. Production began May 17, 1942, and continued until February 1945, when a cancellation of government contracts forced the plant to close. The total production during this period was less than 15,000 short tons.

In the fall of 1950, Foote Mineral Company acquired the plant and properties of The Solvay Process Company. The mill was renovated, and the production of concentrates started July 29, 1951. By the early fifties, Lithium Corporation of America had acquired considerable holdings in the tin-spodumene belt and, in the spring of 1954, announced plans for the erection of a processing plant near Bessemer City, Gaston County. Production began early in 1955.

Since 1950, interest in the lithium deposits of the tin-spodumene belt has developed rapidly. By the summer of 1956, most of the better

known occurrences were under lease, and many of them had been core-drilled. As of June 1956, ten companies owned or held lithium properties under lease. Among those controlling the more important known deposits are: Foote Mineral Company, Lithium Corporation of America, National Lithium Company, Basic Atomics, Incorporated, Kawecki Chemical Company, and International Minerals and Chemical Corporation.

Present Industry

The major production of lithium ore in the United States is from North Carolina. As of July 1, 1956, two plants with combined capacities in excess of 1,500 tons per day were operating at or near capacity levels, and plans for the erection of additional plants were under study.

The largest operation in the State is that of Foote Mineral Company, located 1.5 miles southwest of Kings Mountain. This company controls at least 50 percent of the present indicated reserves in the belt, much of it being confined to a few large closely spaced pegmatites. These deposits are readily adaptable to open-pit mining and are being developed by a single quarry, which spans several of the dikes. Ore is hauled by truck for a few hundred yards to the mill, where it is crushed, screened, and sent through heavy media and flotation units for concentration. Mill feed averages about 20 percent spodumene, or approximately 1.5 percent lithia. The initial plant capacity in 1951 was about 360 tons[2/] per day and since that time is reported to have been increased to more than 1,000 tons per day. Mill concentrates are shipped by rail to Sunbright, Virginia, for conversion to lithium carbonate. Small quantities of beryl, cassiterite, and tantalite have been recovered during the operation. Feldspar and mica are potentially important byproducts.

Lithium Corporation of America controls the second largest proved reserves, its properties being located throughout the tin-spodumene belt. Mining was first undertaken at the Murphy-Houser deposit in the Beaverdam Creek area of northern Gaston County but was discontinued temporarily in favor of larger and richer deposits along Indian Creek in southern Lincoln County. The present mine is near the confluence of Indian Creek with South Fork of the Catawba River, 3.5 miles south of Lincolnton.[13/] Mining is by open-pit methods. The ore, containing approximately 20 percent spodumene, is hauled by truck about 12 miles to the plant, where it is crushed and stockpiled prior to being processed.

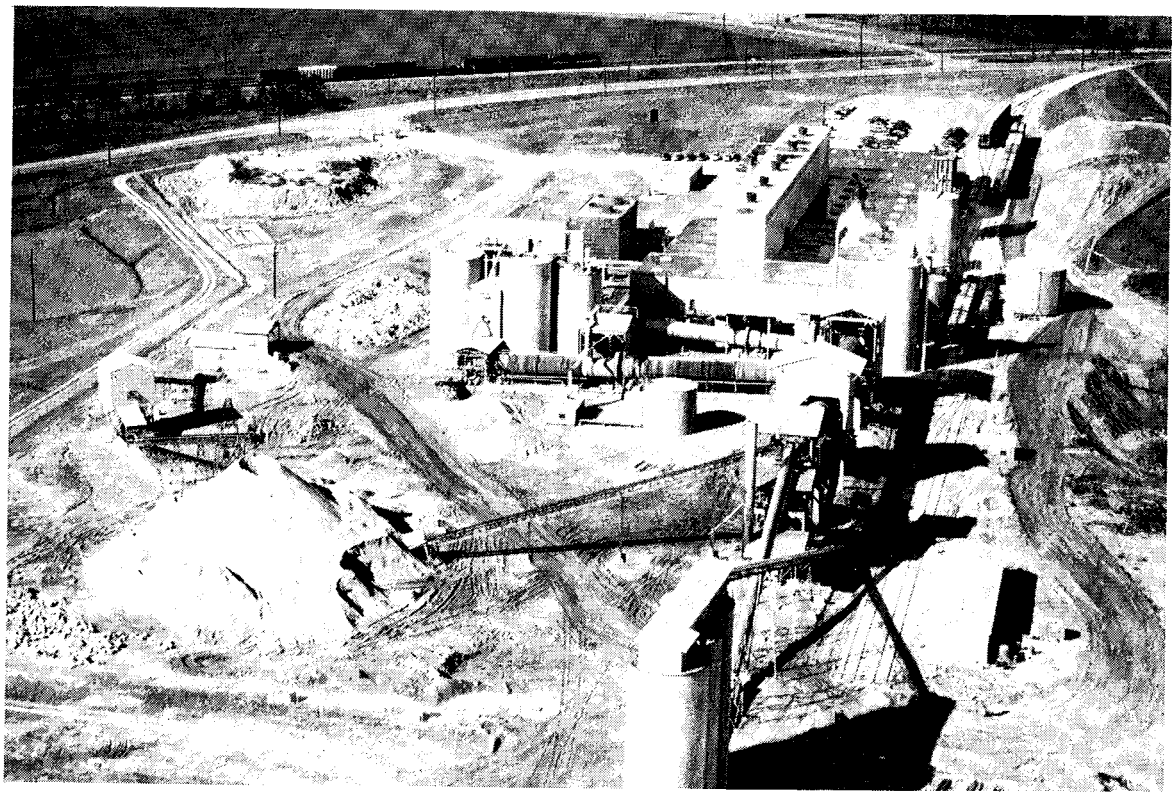


Figure 2. Mill and processing plant of Lithium Corporation of America near Bessemer City, N. C.

The plant is located along the Southern Railway, just south of Bessemer City, in western Gaston County. An acid-leach process is used in removing the lithium from its ore, and the mill products are lithium carbonate and hydroxide.[14/] Mill feed is delivered to decrepitation kilns

in which the spodumene is altered from its natural form to the more soluble beta form. After cooling, it is ground in the presence of sulphuric acid and passed through a roasting kiln. Heating the mixture results in the formation of lithium sulphate by ion exchange. This compound is leached from the ore, and lithium carbonate and hydroxide are derived from the liquor. Original mill capacity was estimated at approximately 500 tons per day. Both domestic and foreign (Canadian) ores are processed at this plant.

While the construction of additional plants has not begun, Basic Atomics, Incorporated, and National Lithium Company have proved substantial reserves and are carrying out beneficiation tests. Universal Lithium Corporation, Lincoln Lithium Company, and Kings Mountain Lithium Company are actively engaged in exploration.

THE TIN-SPODUMENE BELT

Location

The tin-spodumene belt lies within the south-central Piedmont region of North Carolina. It extends from Grover, on the state line in southeastern Cleveland County, northeastward for about thirty miles, passing through or near the towns of Kings Mountain and Lincolnton. (See Figure 3.) Its northeastern limits have not been established definitely, although it has been traced to the Buffalo Shoals area in central Lincoln County. South of Kings Mountain the belt is often less than one-quarter mile wide. Northeastward the width varies, ranging from about one-quarter mile to nearly two miles.

Topographically, the region is characterized by a gently rolling, well drained surface, broken occasionally by steep-sided hills and ridges

rising several hundred feet above the surrounding terrain. Within the tin-spodumene belt proper the topography is somewhat subdued, except along the major drainage, where it is often quite rugged. With the exception of the immediate pegmatite outcrop areas and lower stream valleys, most of the land is cleared and farmed intensively.

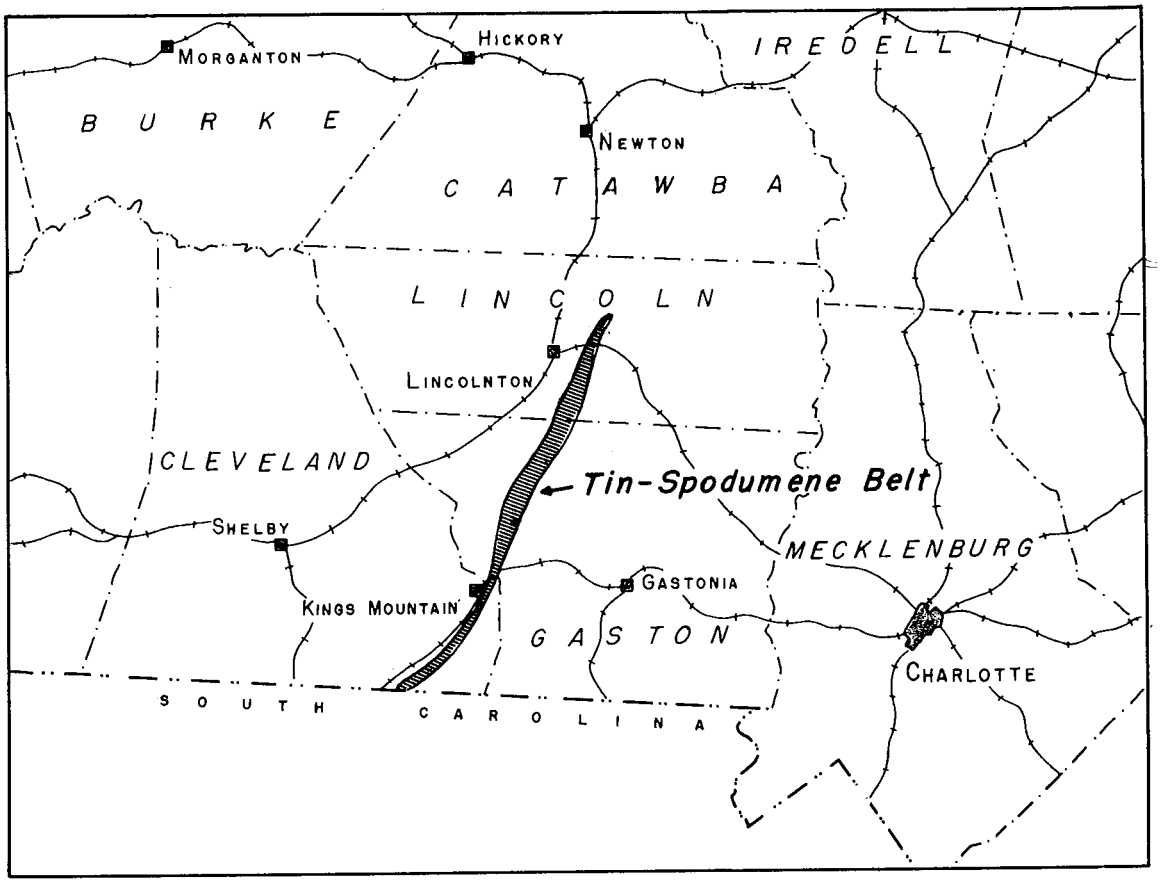


Figure 3. General area covered by the tin-spodumene belt in North Carolina.

The belt lies adjacent to one of the major industrialized areas in North Carolina. Most of the properties containing spodumene pegmatites are accessible by a network of paved and sand-clay secondary roads, state highways, and federal highways. The southern half of the belt is served by the Southern Railway, and the northern half, by the Seaboard Air Line Railroad. Commercial air service is available at Charlotte, North Carolina, 25 miles east of Kings Mountain.

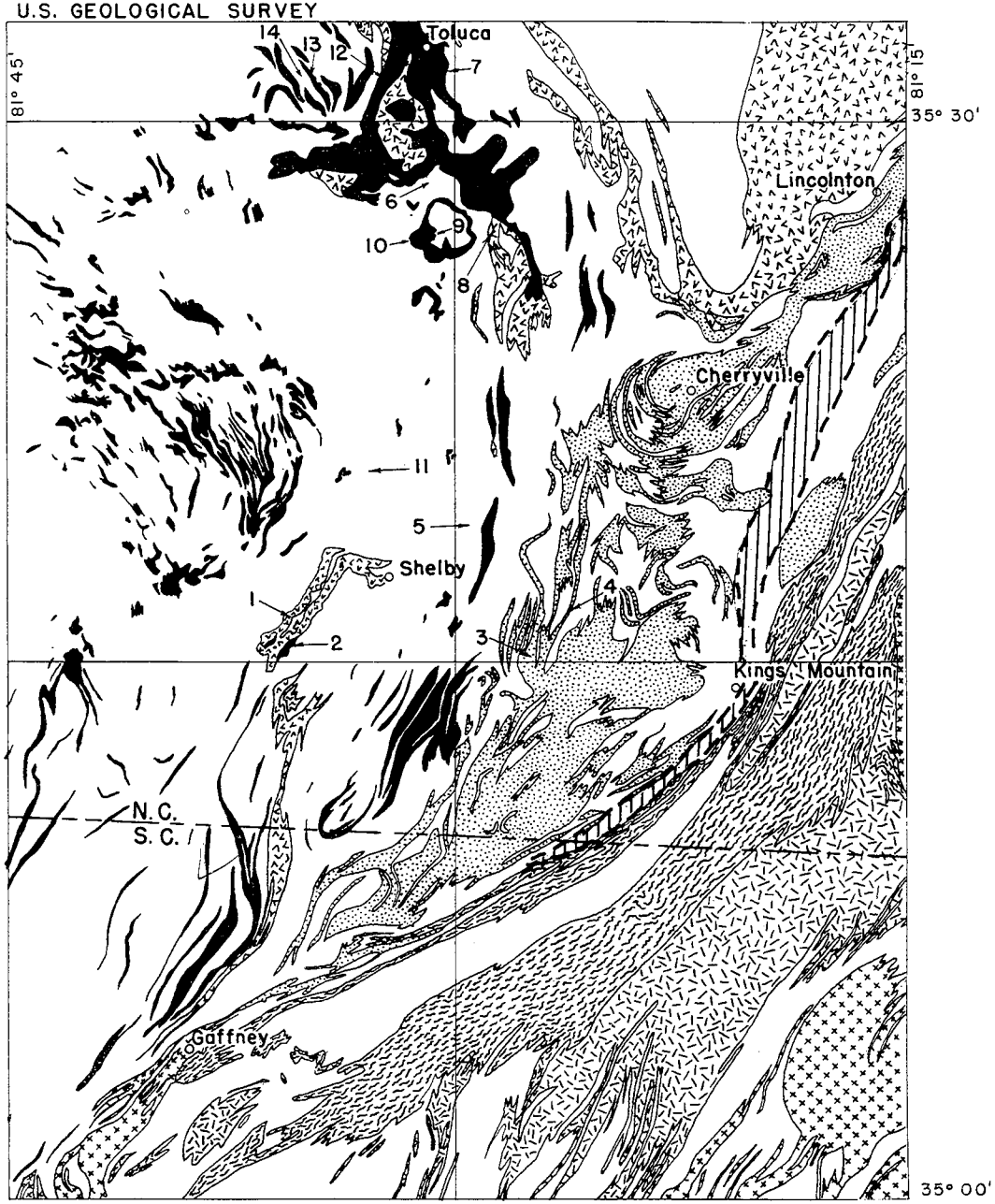
General Geology

The south-central Piedmont of North Carolina is underlain by a wide variety of intimately associated metamorphic and igneous rocks, the ages of which range from pre-Cambrian(?) to Triassic. In the Kings Mountain area, Kesler[1] considers the oldest rocks to be a series of weakly metamorphosed sediments which crop out in long narrow belts east of Kings Mountain and Lincolnton. These consist principally of slate, phyllite, volcanics, quartzite, conglomerate, dolomite, limestone, and calcareous shales, the more siliceous of which form the Kings Mountain ridge belt. Overlying the metasediments and apparently grading into them are rocks of the Carolina gneiss,[5] a moderate- to high-rank metamorphic group consisting of schistose members of wide compositional and textural variety. Most prevalent are muscovite-biotite gneisses and schists of apparent sedimentary origin.

Intrusive rocks include those of granitic, dioritic, and gabbroic compositions. Predominating are the massive to foliated granites and associated pegmatites. A large granitic pluton, the Cherryville quartz monzonite,[12] underlies a considerable area west of Kings Mountain and is considered as being the youngest granite in the region. A few diabasic dikes of Triassic age are present.

Most of the layered rocks have northeasterly strikes. Dips vary from nearly flat to vertical and are often toward the northwest. Kesler interprets the structure as a "rather tightly compressed anticline whose core includes the siliceous metasediments of the Kings Mountain ridge belt."[7] The spodumene-bearing pegmatites are confined principally to a narrow belt of Carolina gneiss lying between the metasediments on the east and the Cherryville quartz monzonite on the west. A map of the general geology is shown on Plate 3.

U.S. GEOLOGICAL SURVEY



GEOLOGY

OF THE

SHELBY, LINCOLNTON, GAFFNEY, AND KINGS MOUNTAIN QUADRANGLES, N.C.-S.C.

0 5 10 15 Miles

1953

EXPLANATION

- Low-rank metamorphic rocks. Includes Gaffney marble, Blacksburg schist, Kings Mountain quartzite, and Battleground schist.
- Cherryville quartz monzonite
- Yorkville granite
- Toluca quartz monzonite
- Bessemer granite
- High-rank metamorphic rocks. Consists of Roan gneiss and undifferentiated schistose rocks of the Carolina gneiss.
- Biotite gneiss unit of the Carolina gneiss
- Area covered by tin-spodumene belt

Source: Adapted from Griffitts and Overstreet (1952, fig. 1).

PLATE 3

Geology of the Tin-Spodumene Belt

The tin-spodumene belt forms a narrow, sinuous zone which strikes northeastward, paralleling in general the layering and foliation of the principal rock units in the area. It lies adjacent to the group of slightly metamorphosed sediments, which persist along its southeastern border. The northwestern limits are not as well defined, but they are indicated in places by the presence of bodies of Cherryville quartz monzonite or the mica-rich pegmatites associated with them.

Much of the belt is underlain by "interlayered hornblende-biotite gneiss and muscovite schist and gneiss, accompanied by very small quantities of chloritic gneiss and schist, quartz-tourmaline gneiss, augite-andesite gneiss, and enstatite-oligoclase gneiss."[6] In parts of the belt, the more prominent layering and schistosity are parallel, often striking toward the northeast and dipping steeply toward the northwest; in others, dips are low and, except for gently undulating folds, the rocks appear nearly flat-lying. Jointing is prominent throughout most of the area, and some thrust faulting is indicated.

Pegmatites were intruded along the more readily accessible zones of weakness within the gneisses and schists. The largest and most persistent dikes are those filling northeasterly trending fractures in areas of alternating mica and hornblende gneisses and schists. Most of the dikes lie parallel with the layering and schistosity within the rock units. A great number of the smaller pegmatites were emplaced along prominent joints, many of which strike toward the northwest. Kesler[6] notes that dikes filling joint planes are most common in areas underlain largely by hornblende gneiss, a fairly competent rock type.

Pegmatites

Type and Distribution

There are several types of pegmatites present in the general area of the tin-spodumene belt. Griffiths[3] recognizes three, based upon mineral content: spodumene-microcline-albite-quartz pegmatite, microcline-albite-quartz pegmatite, and perthite-oligoclase-quartz-muscovite pegmatite. He states: "Although the separation is imperfect, the spodumene-bearing pegmatites are commonest in the middle part of the belt."

The spodumene dikes are distributed somewhat sporadically, occurring singly, in pairs, or as small clusters. Immediately southwest of Kings Mountain, the belt is narrow, and the pegmatites crop out in profusion, often being large and quite close together. In the central part of the belt, they are abundant but usually occur singly or in small, somewhat widely spaced groups. Toward the northeastern end of the belt, outcrops are sparse and are restricted to a relatively narrow zone often less than one-fourth of a mile wide.

Size, Shape, and Attitude

The pegmatites range in size from small stringers measured in inches to large bodies hundreds of feet wide and several thousand feet long. While most of the exposures are less than 10 feet wide and 100 feet long, there are a great number of dikes which range between 10 feet and 35 feet in width and are from 200 feet to more than 800 feet in length. Immediately southwest of Kings Mountain, several large, closely spaced bodies crop out within an area about two miles long and one-half mile wide. The largest of these pegmatites is about 2,000 feet long and has a maximum width of nearly 400 feet. One averages about 100 feet in width and has been traced along strike for approximately 3,200 feet. With the exception of the large dikes in the vicinity of Kings Mountain and

an occasional one toward the northeast, most of the pegmatites considered as probable ore bodies have widths of from 10 to about 75 feet and lengths of from 200 to 1,000 feet. Depths to which the deposits extend are not predictable in every case, although many of the more steeply dipping bodies have been proved to between 250 and 300 feet deep and will extend deeper. It is reported that one dike was encountered 900 feet beneath the surface. In contrast, a number of pegmatites having bold outcrops proved to be quite shallow, some less than 200 feet.

The shape of the pegmatite varies with the structure controlling emplacement, but it is essentially tabular. Many are simple linear bodies in plan, while others are highly irregular, often bending or making abrupt turns. Offshoots from the main body into the country rock are common. Contacts with the country rock vary from sharp, well defined lines to those which are gradational.

Attitudes of the pegmatites are also somewhat erratic, many occupying steeply dipping fractures within the country rock and others appearing to lie at low angles, possibly along gently plunging folds. Throughout the belt the general trend of most of the larger pegmatites is toward the northeast, parallel to the principal layering in the gneisses and schists. Dips vary from nearly vertical to as low as 20 degrees and are often toward the northwest. Southwest of Kings Mountain, in an area underlain largely with mica-rich gneisses and schists, most of the pegmatites strike northeastward and dip at high angles toward the northwest. Northeast of Kings Mountain the amount of hornblende gneiss in the country rock increases in certain areas, and in these localities the trend of the pegmatites becomes less consistent, strikes ranging from northeast to northwest.

Spodumene and Associated Minerals

Approximately thirty minerals have been identified in the spodumene-bearing pegmatites.[6] The dikes, however, are composed predominantly of albite, microcline, and quartz. Spodumene is common, and mica, beryl, columbite, and cassiterite are often present in small amounts. Griffiths[3] gives the content of these minerals in one ton of average spodumene pegmatite ore, as follows:

Mineral	Percent	Units
Spodumene	20	1.45 Li_2O
Beryl	0.4	0.03 BeO
Feldspar	45	
Mica	3	
Columbite	0.006	
Cassiterite	0.024	

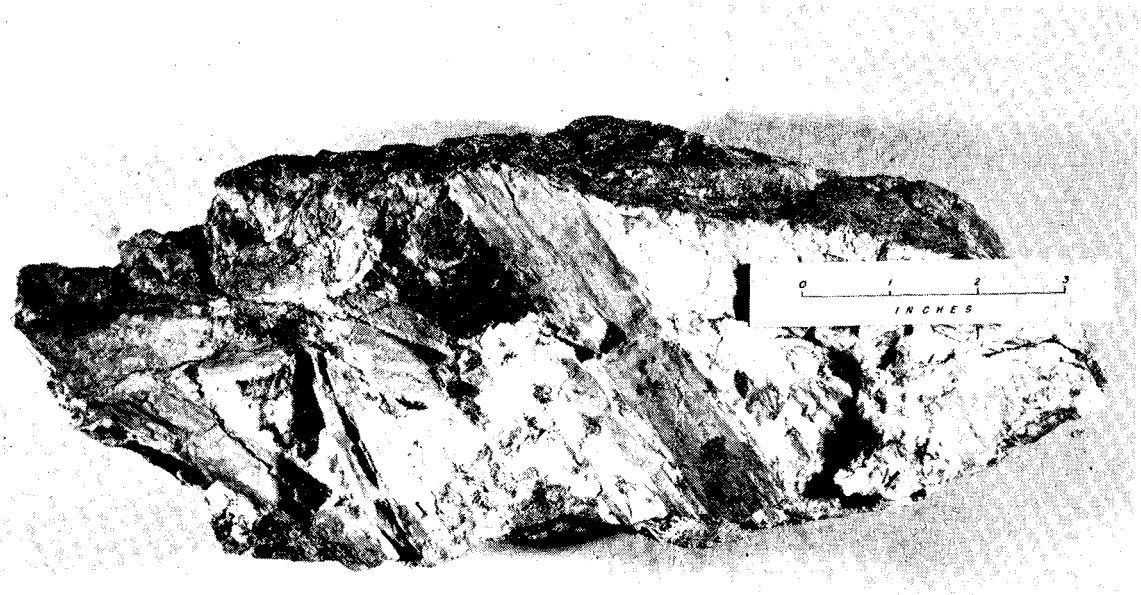


Figure 4. Lathlike crystals of spodumene in pegmatite rock from quarry of Foote Mineral Company, Kings Mountain, N.C.

Spodumene occurs as gray to green, lathlike crystals which are characteristically fractured. They range in size from those measured in fractions of an inch to crystals more than 3 feet long and as much as 10 inches thick. Most of them are less than 6 inches long and 1 inch wide. Generally, the crystals are not well oriented and persist throughout much of the pegmatite. Although there are local concentrations of spodumene within a dike, the mineral does not appear to fall into any pronounced zonal arrangement.

Some of the smaller pegmatites contain as much as 50 percent spodumene, but most bodies considered as potential ore deposits average between 10 percent and 20 percent. In several of the deposits now being mined, the ore contains from 18 percent to 22 percent spodumene. In terms of lithia (Li_2O), relatively unweathered spodumene contains between 7 percent and 8 percent and, for the belt as a whole, will average about 7.3 percent. Selected samples of unweathered crystals from 10 pegmatites throughout the southern half of the belt averaged 7.73 percent lithia. Analyses of three selected crystals showed iron content of 0.24 percent, 0.43 percent, and 0.47 percent, respectively.

Weathering

Most of the pegmatites have been affected by weathering processes, but the degree and depth of alteration is erratic and varies widely. Exploration has shown that topography is not always an important indicator of the weathering profile. Many of the dikes appear relatively unaltered a few feet beneath the surface, but as a general rule these bodies contain well kaolinized seams, which often extend to considerable depths. Other pegmatites are in advanced stages of alteration. Where present, excessive kaolinization in many cases is restricted to the upper twenty or thirty

feet of a pegmatite. There are exceptions, and drilling has encountered highly kaolinized rock at depths of more than a hundred feet.

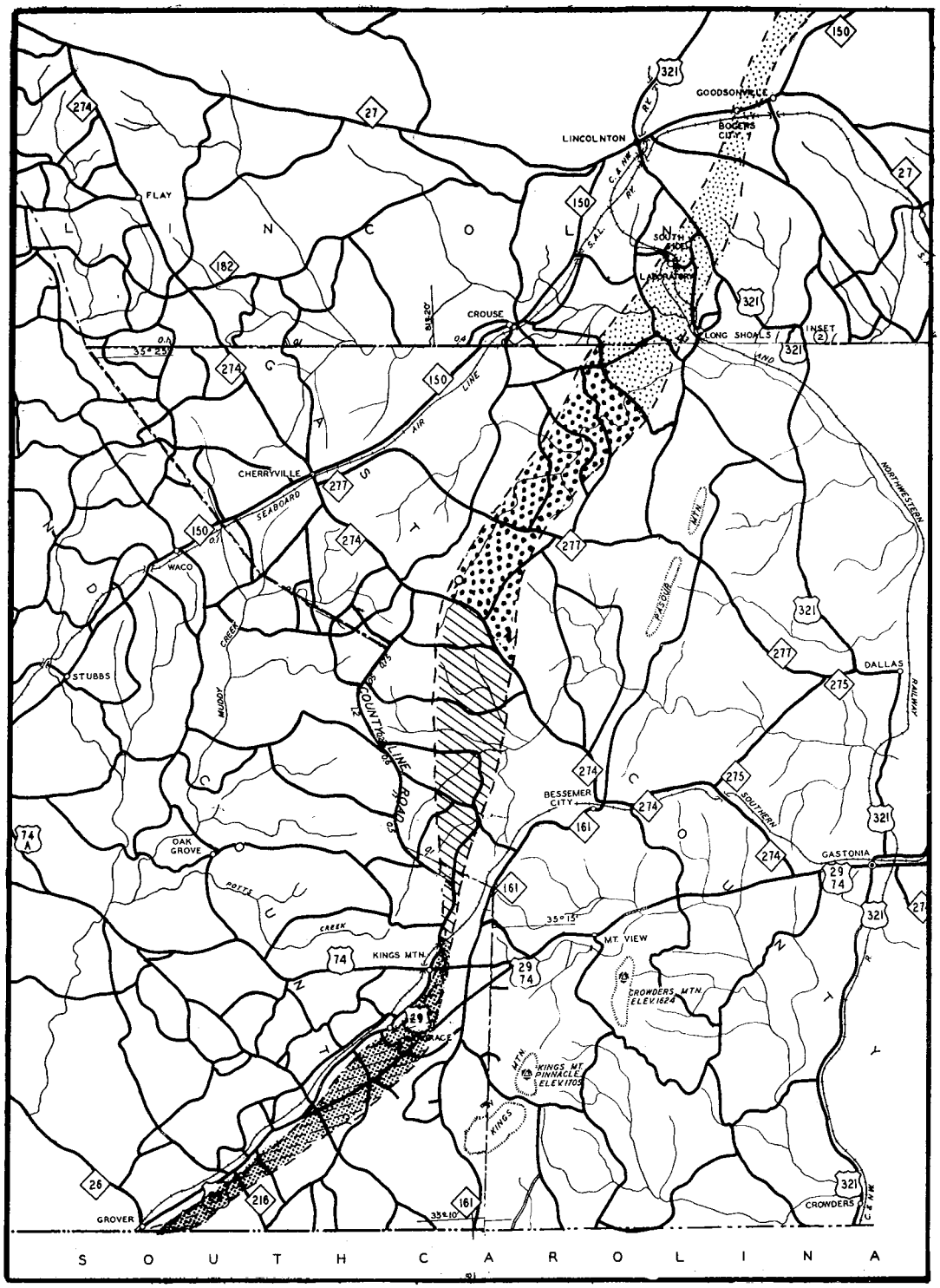
Weathering is one of the more important economic aspects of the spodumene-bearing pegmatites, since it often affects directly the lithia content of an ore and presents concentration problems, especially where flotation processes are employed. While small amounts of moderately weathered ore can be tolerated, well kaolinized portions of most pegmatites are not economical to mine and, therefore, must be discarded.

Description by Areas

Pegmatites are not distributed uniformly throughout the tin-spodumene belt, some sections having high concentrations of outcrops and others appearing relatively barren. While there is no major difference in the overall occurrence of the dikes, the belt may be divided into four principal areas for convenience of description. These are the Kings Mountain, Long Creek, Beaverdam Creek, and Lincolnton, as shown on Plate 4. Parts of the Kings Mountain, Beaverdam Creek, and Lincolnton areas have been mapped and described in detail,[6/] but little information has been published concerning the remainder of the belt.

Kings Mountain Area

This part of the tin-spodumene belt averages less than one-half mile wide and extends from the state line near Grover to the town of Kings Mountain, a distance of approximately seven miles. It represents one of the narrowest portions of the belt but contains a major portion of the recoverable reserves. Many pegmatites, ranging in size from small stringers to bodies several hundred feet wide and up to 2,000 feet long, are distributed throughout the area. Most of them strike northeastward and dip at


N
SCALE
MILES
0 1 2 3 4
Kings Mountain Area
Long Creek Area
Beaverdam Creek Area
Lincolnton Area
SUBDIVISION BY AREAS OF THE
TIN-SPODUMENE BELT
IN NORTH CAROLINA
LINCOLNTON
GOODSONVILLE
BOGERS CITY
FLAY
CROUSE
LONG SHOALS
INSET (2)
CHERRYVILLE
SEABOARD
AIR LINE
WACO
STUBBS
MUDDY CREEK
SOUTH BOUND
BESSEMER CITY
OAK GROVE
POTTS CREEK
KINGS MTN.
GRACE
MT. VIEW
CROWDERS MTN. ELEV 1624
KINGS MT. PINNACLE ELEV 1705
KINGS
GROVER
DALLAS
GASTONIA
CROWDERS
SOUTHERN RAILWAY
NORTHWESTERN
S O U T H C A R O L I N A

steep angles to the northwest. The more important deposits are concentrated near the central part of the area and at its northeastern end.

In the vicinity of Grover, pegmatites are distributed sparingly and in many instances occur singly or in pairs. Most are quite small, but there are several from 20 to 35 feet wide and from 200 to more than 800 feet long. Interesting exposures are on the Dillingham property, east of Grover, where one or more holes have been drilled into the principal dike. Considerable exploration has been carried out on the Westmorland property, one-fourth of a mile southwest of N. C. Highway 216. One pegmatite at this locality is traceable for nearly a thousand feet. Toward the northeast, several dikes have been explored on the Patterson property. Dikes crop out on other properties in the immediate vicinity, but little is known of their continuity. No major ore bodies have yet been found, but exploration is continuing.

In the central part of the Kings Mountain area, more than a hundred pegmatites, having widths of five feet or more, crop out within a zone about one-fourth mile wide and one mile long. Most are small to medium bodies, few exceeding 50 feet in width and 500 feet in length. The spodumene content is as much as 25 percent in some bodies, but the average for the group is estimated at from 16 percent to 18 percent. The greatest concentrations of outcrops appear on the Detmar and old Dixon properties, located one-fourth mile east of the junction of U. S. Highways 29 and 29-A and west of the secondary road between Behtlehem Church and Dixon School.

The largest and commercially the most important pegmatites in the tin-spodumene belt lie within an area about one-fourth mile wide and one and one-half miles long, which extends from near the Compact School Road

northeastward to within one mile of the town of Kings Mountain. This part of the belt is between U.S. Highways 29 and 29-A and lies northwest of Mill Creek. Most of the larger pegmatites are located a few hundred yards east of Park Yarn Mill. Many dikes crop out within this part of the tin-spodumene belt, and at least 18 are more than 1,000 feet long, the greatest measured length of a single dike being 3,250 feet.[6] Widths range from about 5 feet to nearly 400 feet. The spodumene content varies from less than 5 percent to more than 22 percent and will average between 16 percent and 20 percent for the larger dikes. Much of the ore now being mined averages about 20 percent spodumene. Known deposits have been explored quite thoroughly, and many of them have been core-drilled. Drilling has proved some of the pegmatites extend to depths in excess of 400 feet, one having been reported at a depth of 900 feet.[3]

The central and northeastern portions of the tin-spodumene belt in the Kings Mountain area have been mapped in detail, and a map showing the distribution, size, and geologic setting of the pegmatites is published as Plate 39 of U.S. Geological Survey Bulletin 936-J. Most of the larger dikes are controlled by Foote Mineral Company, and those at the northeastern end of the area are being worked extensively. The dikes in this area represent the largest and some of the most readily accessible reserves in the United States.

Long Creek Area

The Long Creek area is in western Gaston County and extends from near Kings Mountain northeastward for approximately seven miles to Tryon School, located on N.C. Highway 274, five miles northwest of Bessemer City. The zone in which most of the pegmatites crop out is from one-fourth to one mile wide, and most of it lies within the drainage basin

of Long Creek.

Spodumene-bearing pegmatites occur throughout the area but are not as numerous or as closely spaced as those in adjacent areas. Many occur singly or in small groups. In most instances, they appear to have been emplaced along steeply dipping joint planes, cutting across the general layering of the country rocks. Some conform to the schistose structures within the country rock, which in places lie nearly flat. Strikes vary from northeast to northwest.

Few outcrops are more than 50 feet wide, but many are between 20 and 35 feet wide and between 500 and 1,000 feet long. Some of the larger dikes have been proved to depths of more than 250 feet by core drilling. Others do not extend to any appreciable depth, in spite of contrary surface indications. It is estimated that the spodumene content of many of the dikes in the area will average between 15 percent and 20 percent, while representative samples of some of the more promising bodies contained between 20 percent and 25 percent.

Pegmatites of potential economic importance occur in the vicinity of Long Creek Church, near the southwestern end of the area. Approximately one-fourth of a mile south of the church, several outcrops occur on the Scism and adjacent Randolph properties. A relatively rich dike underlies a part of the church property and extends for about a thousand feet toward the southeast on the Ormand lands. The pegmatite is narrow and weathered somewhat deeply in places but contains good quality ore. Two prominent dikes crop out on the Sarvice property, one mile northwest of Long Creek Church. These dikes are parallel and are separated at the surface by a few feet of hornblende gneiss. They are traceable for nearly a thousand feet, and their combined outcrop widths are approximately fifty

feet. The spodumene content is estimated at 22 percent.

In the central part of the Long Creek area, north of Long Creek Church, there are several potential ore bodies. Approximately 1.25 miles north of the church several dikes crop out on the Ware property and adjacent Hovis and Hager lands to the north. Toward the west, relatively rich spodumene dikes crop out on the Bridges lands. One dike on the W. E. Bridges land is exposed for about eight hundred feet and appears to contain a high percentage of large spodumene crystals. About one-half mile southwest of Sunnyside, on N.C. Highway 274, two or more dikes occur near an old mill site on the Joel Wright property. Surface indications are that the bodies range from 10 to 25 feet wide and are traceable for nearly 1,000 feet along strike. On the Lingerfelt farm, northeast of the Wright property and three-fourths of a mile south of Tryon School, spodumene-bearing pegmatites crop out along a small hill several hundred yards southwest of the house. Float material is present over a sizable area approximately a hundred yards northwest of the house. Exposures are also present on the Hovis and other lands to the west and south.

An exception to the general size and attitude of the dikes in this part of the belt is a large flat-lying pegmatite which crosses the Hallman and Beam properties at the northeastern end of the Long Creek area, one-half mile southeast of Tryon School and east of N.C. Highway 274. This body, locally known as Cap Rock, is exposed over an area from 100 to about 300 feet wide and several thousand feet long. It has been core-drilled and is reported to be from 250 to 300 feet thick and to dip at less than 15 degrees. The spodumene content is estimated at 20 percent. Indications are that this is one of the largest deposits known north of Kings Mountain and, if not weathered too badly, contains a considerable volume of ore.

The Long Creek area has been prospected extensively, and many of the better known deposits are under lease. Although the pegmatites do not crop out in great profusion, where present they are often rather persistent along strike, and many of them offer possibilities for development.

Beaverdam Creek Area

The Beaverdam Creek area is 5 miles east of Cherryville, Gaston County, and lies between the Long Creek area on the south and the Lincolnton area on the north. Its maximum width is approximately one mile, and its length is about 7 miles, extending from Tryon School, on N.C. Highway 274, northeastward to near the Lincoln County line. Most of the larger known pegmatites lie north of N.C. Highway 277 and are along the valleys of Beaverdam and Little Beaverdam Creeks, especially near the confluence of these two streams. Among the better known properties on which spodumene pegmatites crop out are the Beam, Kiser, Mauney, Whiteside, Allen, Cherry, Murphy, Houser, Hastings, and Carpenter. A map of most of the area is published as Plate 40 of the United States Geological Survey Bulletin 936-J.

The Beaverdam Creek area is characterized by a great number of small pegmatite outcrops. Few are more than 35 feet wide and 750 feet long, most of them being less than 10 feet wide and 200 feet long. The largest dike found to date crosses the Murphy and Houser properties and is nearly 1,800 feet long and from 25 to 30 feet wide. Most of the pegmatite outcrops are narrow and relatively straight, but some of them are very irregular in shape. Strikes range from N. 45° W. to N. 45° E., the more persistent bodies trending northeastward. The spodumene content varies from about 5 percent to more than 25 percent.

A considerable amount of spodumene ore is indicated in the Beaverdam Creek area, but it is difficult to appraise the potential reserves of the area as a whole. The persistence at depth of many of the bodies is in doubt. Larger dikes having good continuity along strike will probably extend several hundred feet downward; however, a great many of the outcrops are narrow and relatively short, and the pegmatites must be proved by subsurface exploration.

Lying immediately to the west and in places intermingled with the spodumene-bearing pegmatites are several large miclocline-albite-quartz pegmatites. These dikes are present along the western border of a considerable portion of the tin-spodumene belt and are rather prominent in the Beaverdam Creek and Lincolnton areas. They contain little or no spodumene; but, because of their proximity to the spodumene-bearing dikes, they have been the object of considerable speculation by persons not versed in minerals.

Lincolnton Area

The Lincolnton area is the northernmost part of the tin-spodumene belt. It extends from approximately one mile south of the Gaston County line northeastward for about eleven miles into central Lincoln County, passing between Long Shoals and Laboratory, south of Lincolnton, and lying between U.S. Highway 321 and N.C. Highway 150, northeast of Lincolnton. Its maximum width is about two miles. Most of the larger known deposits are in the Laboratory-Long Shoals-Southside vicinity. Toward the north the belt is less well defined, but scattered outcrops of spodumene-bearing pegmatites are present in the Buffalo Shoals area, northeast of Lincolnton.

Pegmatites in the Lincolnton area are similar in occurrence and mineralogy to those toward the southwest, differing principally in general

attitude. While relatively flat-lying dikes are present occasionally in other parts of the belt, they are more common in the Lincolnton area. Several of the larger pegmatites dip from 20 degrees to 35 degrees. Such dikes parallel in general the foliation in the country rock. Nearly horizontal-appearing lenses of quartz monzonite crop out adjacent to or in the immediate vicinity of many of the pegmatites, and the emplacement of these bodies may have been an important factor in determining the attitude of the dikes.

The size of the pegmatites ranges from small stringers to those reported to be nearly 150 feet thick and to extend along strike for more than 1,000 feet. Because of the attitude of many of the dikes, it is difficult to determine their potentialities from surface indications.

Spodumene-bearing pegmatites are common through the southern half of the area. Large outcrops are present on the Carpenter property, located in Gaston County approximately 1.5 miles south of Long Shoals. The principal outcrop lies along a hillside south and east of Beaverdam Creek and north of Tysons Chapel. Core drilling has proved the slope of the hill to represent the general dip of the pegmatite.

North of the Carpenter property and lying between Beaverdam Creek and South Fork of the Catawba River, several pegmatites crop out on the Mauney, Kiser, and adjacent lands. While the dikes are relatively rich in spodumene, outcrops are not long or continuous. Little exploration has been carried out in this area, but surface indications are not favorable for developing large tonnages of mineable ore.

One mile west of Long Shoals and immediately south of Indian Creek, three or more spodumene pegmatites crop out on the Arrowood property. All

are small and have relatively shallow dips, but they can be traced for several hundred feet along strike. One of the group has been proved to extend at least 250 feet beneath the surface.

The only spodumene being produced commercially in the Lincolnton area is from the Lithium Corporation of America's Indian Creek Mine, located immediately north of the Arrowood property and northwest of the confluence of Indian Creek with South Fork of the Catawba River. The ore body consists of three closely spaced pegmatites, which strike northeastward and dip toward the northwest at from 30 degrees to 45 degrees. They have been traced for more than 900 feet along strike. Spodumene content is estimated at 20 percent.

One-half mile north of Long Shoals and lying a few hundred yards east of the secondary road between Long Shoals and Southside, a large dike underlies parts of the Gates, Mostellar, and Austin lands. It has been core-drilled and is reported to be about 150 feet thick and to have been traced for a thousand or more feet along strike. About one mile to the north and 100 yards west of the Long Shoals-Sunnyside road, a relatively rich pegmatite crops out on the Whiteside and Rhyne lands. It can be traced for several hundred feet along strike and dips at about 35 degrees toward the northwest. The thickness is reported to be between 30 and 40 feet.

Two miles southeast of Lincolnton and east of U.S. Highway 321, several dikes crop out on the old Ka-Ma-Tin property. These pegmatites have been explored at various times for cassiterite and recently have been drilled to determine their potentialities for spodumene. Although the grade of ore is satisfactory, some of the dikes are weathered deeply. Approximately one mile northwest of this property, a spodumene-bearing

pegmatite is exposed for several hundred feet along the edge of the golf course of the Lincolnton Country Club.

Outcrops occur sparingly in the Buffalo Shoals area of north-central Lincoln County. Most are concentrated in a narrow belt, lying from one to two miles west of and generally paralleling N.C. Highway 150. Known occurrences do not appear of sufficient size for large-scale development. Outcrops are generally narrow and do not extend for appreciable distances. One of the most persistent is on the Rhyne and Goodson properties and can be traced for about a thousand feet. Its width is approximately ten feet. In spite of poor surface showing, some exploratory drilling may be warranted. The Buffalo Shoals area marks the northernmost point to which the tin-spodumene belt has been traced. While an occasional spodumene pegmatite may be found toward the northeast, there are no indications of the presence of potentially recoverable ore in this direction.

Reserves

Calculating reserves in pegmatites is hazardous, since it is difficult to predict accurately from outcrop evidence the extent and attitude of a given body at depth. Therefore, reserve figures based upon surface indications are at most generalizations, and detailed exploration is often necessary before a true picture can be developed. The purpose in estimating reserves during the present investigation is to show the general distribution of the more readily mineable ore throughout the tin-spodumene belt.

Previous Estimates

Several estimates of the spodumene reserves in the tin-spodumene belt have been published in recent years. These vary widely, depending

upon the limiting factors used and the subsurface information available at the time. One of the first was by Kesler[6] and was limited to the Kings Mountain and Beaverdam Creek areas. Including only the larger pegmatites and restricting their depths to 100 feet, he estimated reserves in these areas to be about 4,325,000 tons of mineable ore, averaging 15 percent spodumene. By using 7 percent as the average lithia (Li_2O) content of the spodumene, he calculated the ore reserve to contain about 45,500 tons, or 4,550,000 units of lithia. These figures were compiled prior to any appreciable subsurface exploration and are conservative.

Griffiths[3] made a rough estimate of the total spodumene resources by assuming one-third of all pegmatite material throughout the belt, calculated at 66,000,000 tons to a depth of 300 feet, to contain 10 percent spodumene. This represents 6,600,000 tons of spodumene, or about 48,000,000 units of lithia.

Lithia reserves for the United States were compiled by Norton.[11] For the entire belt, he estimated the indicated reserve of 1.7 percent ore to a depth of 400 feet to be 4,000,000 units. By lowering the grade of ore to 1.3 per cent lithia and extending the deposits to a depth of 450 feet, he estimated the inferred reserve at 124,000,000 units. Indicated and inferred reserves totaled 128,000,000 units.

Present Estimate

In calculating reserves for this report, an attempt was made to include only those pegmatites which appeared to be most favorable for development. Outcrop areas were measured by pacing. The following limiting factors were used in preparing the estimate:

Minimum horizontal dimension of dikes	10'x200'
Weight-volume ratio	1 short ton = 12 cu. ft.
Depth varies with dike (maximum)	300'
Spodumene content (minimum)	15%
Li_2O content of spodumene	7.3%

Final reserve figures were calculated after an inspection of major outcrop areas and consultation with geologists, mining engineers, and drillers familiar with the pegmatite occurrences.

Reserves of spodumene ore which appear favorable for mining are estimated at 41,500,000 short tons for the entire tin-spodumene belt. Much of it will average 1.25 percent lithia, and a considerable portion will range between 1.3 percent and 1.6 percent. The distribution by areas of reserves of lithium ore in the tin-spodumene belt in North Carolina is presented below. No attempt was made to differentiate between weathered and unweathered pegmatite rock. In many of the dikes from 15 percent to 30 percent of the first 100 feet is weathered sufficiently to affect the grade of ore.

Area	Pegmatite Ore (short tons)	Spodumene (short tons)	Lithia (units)
Kings Mountain	22,900,000	4,250,000	31,050,000
Long Creek	10,500,000	1,795,000	13,100,000
Beaverdam Creek	3,000,000	545,000	3,980,000
Lincolnton	5,100,000	945,000	6,900,000
Totals	41,500,000	7,535,000	55,030,000

The reserves listed above do not represent the total amount of spodumene in the tin-spodumene belt. Large volumes are present in the hundreds of small pegmatites which abound throughout the belt, but economic recovery of such material is yet to be proved. Undoubtedly, there are sizable tonnages of ore below the limiting depth of 300 feet, and as mining progresses much of it will be recovered.

FUTURE OUTLOOK

Estimated reserves of readily recoverable lithium ore in the tin-spodumene belt are sufficient to maintain the current rate of production for more than seventy-five years. The reserve estimates are conservative and are expected to increase as development work advances. In its annual

report for 1955, Foote Mineral Company listed its measured and indicated ore reserve at 23,985,506 tons, or enough to operate at present levels for at least fifty years. Lithium Corporation of America's reserves assure that company of an extended period of operation. Additional proved ore indicates that the tin-spodumene belt is capable of supporting increased production facilities if the present demand for lithium continues. A major drop in price would make many of the smaller deposits now considered as workable uneconomical to develop.

The large volume of high-grade ore, location with respect to markets, and accessibility for mining and milling make the spodumene deposits in North Carolina the most important single source of lithium in the United States. These deposits are in a highly favorable economic position. Their location and quality assure the United States of a well protected major source of lithium.

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