UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
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T. L. KESLER, C. B. HUNT, R. P. FISCHER
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THE TIN-SPODUMENE BELT OF THE CAROLINAS

A PRELIMINARY REPORT

BY

T. L. KESLER

Strategic Minerals Investigations, 1942
(Pages 245-269)

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THE TIN-SPODUMENE BELT OF THE CAROLINAS

A PRELIMINARY REPORT

By T. L. Kesler

ABSTRACT

Cassiterite and spodumene, of possible economic importance, occur in a belt, 24.5 miles long and 1.8 miles in maximum width, extending southwestward from Lincolnton to Grover, N. C. This belt is in the Piedmont province, an upland with an average altitude of 1,000 feet, and is readily accessible by rail and highway. The region is underlain by crystalline limestone, quartzite, schists, gneisses, and granite. The rocks strike northeast and, in most of the belt, dip steeply northwest. Most of them are deeply weathered.

The tin-spodumene belt lies mostly in North Carolina between Lincolnton and the State line. Cassiterite occurs sparsely in hundreds of spodumene-bearing pegmatite bodies, which were emplaced in joints where the rocks are uniformly competent, and parallel to the layering where competent and incompetent rocks are interlayered. Locally, cassiterite is sufficiently abundant in the pegmatite bodies and in closely associated greisen (quartz-muscovite rock) to be of possible commercial value. There are at least 91 such deposits of potential tin ore in North Carolina, and 1 near Gaffney in South Carolina.

The deposits vary widely in thickness along their strike and dip; about 18 are more than a foot thick. The maximum strike length is 275 feet. Little is known about the downward extensions of the bodies, but irregular shapes and unpredictable dimensions are to be expected. The tin content of the ore ranges in general from a trace to more than 6 percent, and the grade in any one deposit is likely to be far from uniform. Records of production from the Ross mine, near Gaffney, indicate that its ore averaged possibly 2 percent of tin; this is probably exceptional. Small placer deposits, of which three are known, and thin cassiterite-bearing soils of small extent, might yield 150 tons of metallic tin, but these deposits are likewise low in grade.

Because of their small size, low grade, and scattered distribution, the deposits are not being mined at present, and it seems unlikely that any now exposed could be mined profitably unless the price of tin became extremely high.

Many of the pegmatite bodies contain 15 percent or more of spodumene, and unusually rich parts of bodies average from 30 to 50 percent. The commercial possibilities of the spodumene probably exceed those of the cassiterite, and it is estimated that two unusually favorable areas contain a reserve of at least 650,000 tons of spodumene (more than 20,000 tons of metallic lithium) to a depth of 100 feet.

INTRODUCTION

The tin-spodumene belt of the Carolinas is a long and narrow strip of the southeastern Piedmont (see fig. 27) that contains many bodies of tin- and spodumene-bearing pegmatite. The belt lies about 50 miles east of the Blue Ridge and 85 miles west of the Fall Line. The Piedmont is a moderately dissected upland having a general altitude here of about 1,000 feet. A few ridges and peaks consisting of unusually resistant rocks rise above this level; an irregular ridge known as Kings Mountain which lies 2 miles east of the belt, near the town of Kings

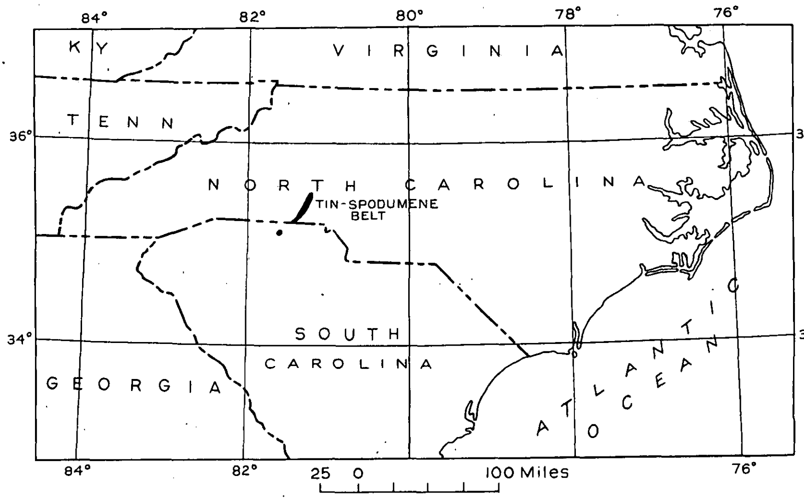


Figure 27.--Index map showing location of the Carolina tin-spodumene belt.

Mountain, reaches an altitude of 1,705 feet. (In this report the name Kings Mountain refers to the town and not the ridge.) The belt is drained by the South Fork and Broad Rivers. Most of it is cultivated, but steep slopes and rocky areas, such as those underlain by the pegmatite bodies described below, are wooded.

Paved highways between the towns and villages, and inter-connecting, well-graded roads make the entire region accessible.

From Kings Mountain southward to the State line, the main line of the Southern Railway and U. S. Highway No. 29 run parallel to the belt and less than a mile west of it. Lincolnton is served by the Seaboard Airline Railroad.

Most of the hundreds of pegmatite bodies contain a little cassiterite together with spodumene and other minerals that are not found in the pegmatites of the surrounding region. Locally, in the pegmatite and in greisen (quartz-muscovite rock) associated with it, cassiterite is abundant enough to be of possible commercial value. It is only these relatively rich occurrences of cassiterite that are referred to in this report as deposits. Deposits, in this sense of the word, occur at short intervals from a point 2 miles southeast of Lincolnton to a point 0.8 mile due east of Grover, N. C., very near the State line, and coincide with the occurrence of spodumene. The length of the belt is 24.5 miles, and the maximum width, southeast of Crouse, 1.8 miles; the belt contains at least 91 deposits of possible commercial grade, most of which, however, are very small. The only known tin deposit in South Carolina occurs 12 miles to the southwest, near Gaffney, in a pegmatite that apparently contains no spodumene.

Field work and acknowledgments

The field work on which this report is based comprised (1) detailed plane-table mapping of six local areas in the belt (four of which are outlined on plate 38), and (2) reconnaissance examination of the remainder of the belt and of areas extending 6 miles beyond the extreme occurrences of cassiterite at Lincolnton and Gaffney. Most of the work was carried on during the months from October to May inclusive in 1938-39 and 1939-40, but some field work was done as early as August 1938 and as late as April 1942. The plane-table work during the first season was done largely by P. M. LeBaron, R. A. Edwards, R. M. Barbour, and

H. E. LeGrand, that during the second season by H. E. LeGrand and J. C. Morris. LeGrand and Morris also made most of the reconnaissance examinations of deposits lying outside the areas mapped in detail.

Helpful discussion and advice on specific problems were contributed by W. T. Schaller and C. S. Ross, though the interpretations presented are those of the writer. Charles Milton identified columbite-tantalite, tin-bearing rutile, molybdenite, and a complex group of supergene phosphates and oxides. H. G. Ferguson, F. C. Calkins, W. C. Smith, and T. B. Nolan reviewed the manuscript, and made numerous helpful suggestions.

Previous work

Material relating to the geology, mineralogy, and economic development of the tin deposits and associated spodumene is contained in 44 reports, articles, and maps. The more important of these are listed in the following annotated bibliography.

(1) Dabney, C. W., Jr., Note on cassiterite from Kings Mountain, N. C.: Elisha Mitchell Sci. Soc. Jour., 1883-84, pp. 79-81, 1884.

The first published account of the discovery of cassiterite in the belt; contains two analyses of the mineral that erroneously list tungsten as a constituent.

(2) Furman, J. H., The tin deposits of North Carolina: New York Acad. Sci. Trans., vol. 8, pp. 136-145, 1889.

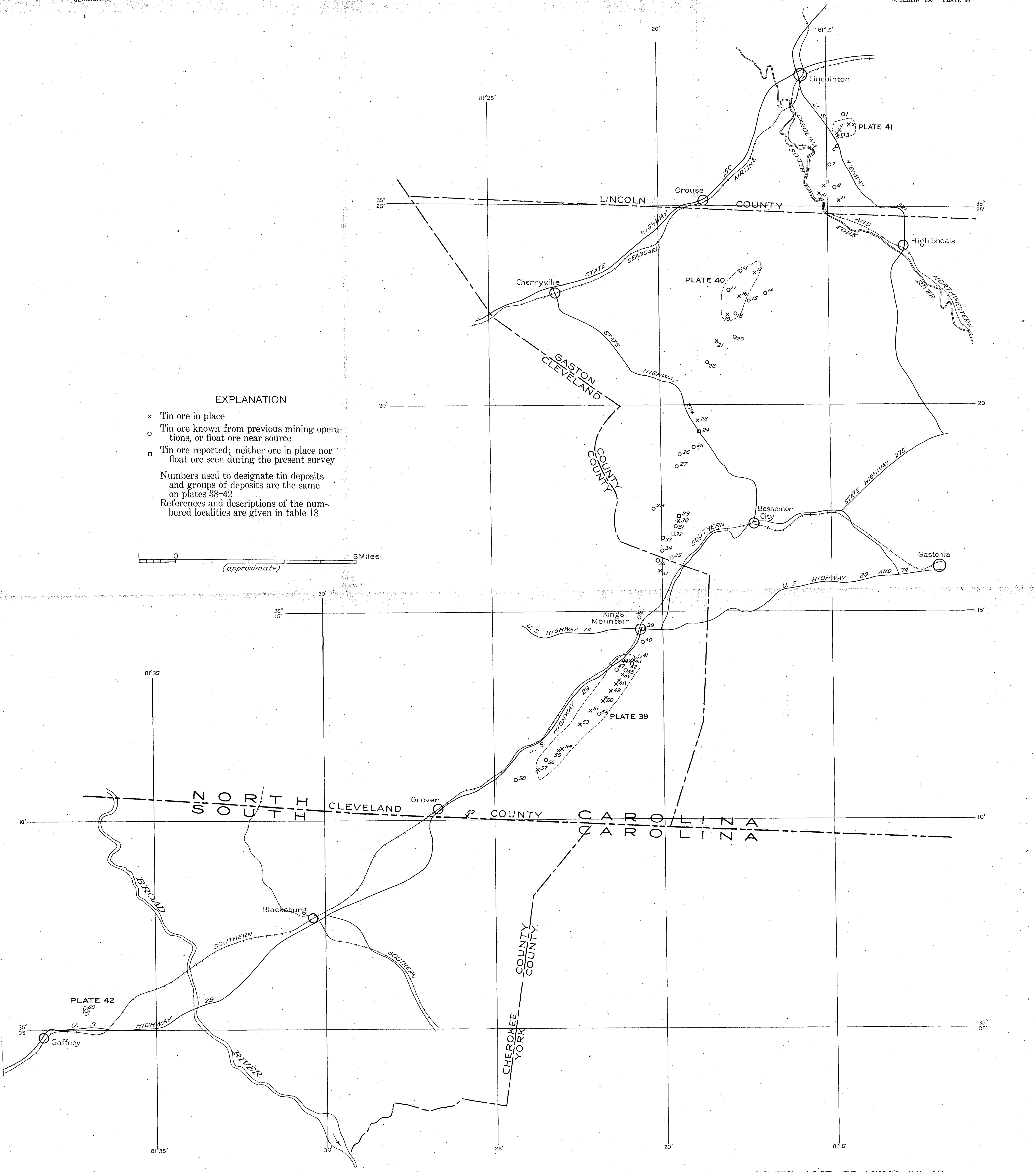
An illustrated account of observations on the geology of the belt by the first, and one of the most active, prospectors. Contains useful facts, together with doubtful interpretations.

(3) Ledoux, A. R., Tin in North Carolina: Eng. and Min. Jour., vol. 48, pp. 521-522, 1889.

A record of the general results of tin prospecting by open cuts, shafts, and diamond drilling in a portion of the belt about 2 miles long, presumably southwest of Kings Mountain.

(4) Pratt, J. H., and Sterrett, D. B., The tin deposits of the Carolinas: North Carolina Geol. Survey Bull. 19, 62 pp., 1904.

Describes the deposits and discusses their origin.



OUTLINE MAP OF THE CAROLINA TIN-SPODUMENE BELT, SHOWING LOCATIONS OF TIN DEPOSITS AND PLATES 39-42

(5) Graton, L. C., A reconnaissance of some gold and tin deposits of the Southern Appalachians: U. S. Geol. Survey Bull. 293, pp. 31-57, 1906.

Gives a good account of the discovery and early prospecting of the deposits, detailed descriptions of the Jones, Faires, and Ross mines, and an estimate of the total production of the belt to May 1905. Pegmatites of various compositions, interpreted in the present report as the product of successive mineral-bearing solutions that circulated with various degrees of freedom, were regarded by Graton as representing a genetically related series of intrusions.

(6) Sloan, Earle, Catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey, ser. 4, Bull. 2, pp. 85-93, 1908.

Describes and illustrates workings and geologic features at the Ross mine, and records the total production of concentrates from pegmatite and placer to December 1906.

(7) Keith, Arthur, and Sterrett, D. B., Tin resources of the Kings Mountain district, N. C. and S. C.: U. S. Geol. Survey Bull. 660-D, pp. 123-146, 1917.

A general discussion of the geology of the region, with descriptions of the principal mines and prospects, most of which were abandoned at the time.

(8) Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Gaffney-Kings Mountain folio (No. 222), 1931.

Contains part of the economic material in Bulletin 660-D, but is considerably more specific in treatment of geology. The folio does not recognize the genetic relation, found in the present study, between schistose crystalline limestone and the gneisses and schists that enclose the pegmatite bodies.

(9) Fraas, Foster, and Ralston, O. C., Beneficiation of spodumene by decrepitation: U. S. Bur. Mines Rept. Inv. 3336, 13 pp., 1937.

The natural α spodumene in pegmatite matrix, heated to 1,050° to 1,180° Centigrade, was converted to β spodumene, which was selectively disintegrated by gentle grinding and separated from the coarser quartz and feldspar.

(10) Boyd, J. E., Jr., Pyrometric properties of spodumene-feldspar mixtures: Am. Ceramic Soc. Jour., vol. 21, pp. 385-388, 1938.

Fusion tests of mixtures containing 20 to 40 percent of spodumene with either potash or soda feldspar showed that P. C. E. values were lowered several cones below those of the feldspars alone. The addition of spodumene to a mixture of equal parts of the feldspars showed even greater contrast. The paper includes an analysis of the spodumene, which is quoted on page 269.

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(11) Hess, F. L., The spodumene pegmatites of North Carolina: Econ. Geology, vol. 35, pp. 942-966, 1940.

Discusses the origin of the pegmatite in the tin-spodumene belt and the quality and possible amount of the spodumene. Some of the pegmatite minerals are believed to have been deposited, in several stages, by solutions that circulated through fractures in assumed prelithium, granitic pegmatite, whereas, in the present report, all of the minerals are believed to have been deposited by solutions in successive stages, but in different order, and an "original" pegmatite is not postulated.

(12) Norman, James, and Gieseke, E. W., Beneficiation of spodumene rock by froth flotation: Am. Inst. Min. Met. Eng. Tech. Pub. 1161, (Mining Technology), 9 pp., April 1940.

Samples of spodumene-bearing pegmatite from two localities were ground and treated with solutions of NaOH and NaOH with Na_2S to remove films of weathering products from the mineral grains. The films interfered with the flotation of spodumene with a soap collector, in contrast to feldspar and quartz. After cleaning, concentrates containing from 5.40 to 6.59 percent Li_2O were obtained, principally with the use of oleic acid; a mixture of spodumene and feldspar containing 4.98 percent Li_2O was separated by similar treatment.

(13) Engel, E. L., and Shelton, S. M., Tin ore from North Carolina, in Ore-testing studies, 1939-40: U. S. Bur. Mines Rept. Inv. 3564, p. 15, 1941.

Tin ore with feldspathic gangue, containing 1.06 percent tin, crushed to pass 10 mesh, was separated into four sand products in a laboratory hydraulic classifier. The sand products were treated on a laboratory concentration table, and yielded concentrates that assayed 68.81 percent tin, or 92.3 percent of the total tin.

(14) Gabriel, Alton, Slavin, Morris, and Carl, H. F., Minor constituents in spodumene: Econ. Geology, vol. 37, pp. 116-125, 1942.

Spectrographic analysis of spodumene from three areas in the belt showed the presence of minor amounts of Fe_2O_3, MnO, TiO_2, SnO_2, Ga_2O_3, Na_2O, and K_2O; one of the samples contained Rb_2O. On the basis of X-ray and petrographic studies, it is concluded that the impurities are probably isomorphous replacements in the crystal structure of the spodumene.

Production

Some production of cassiterite concentrates from the Carolinas is recorded[1/] for the years 1903-04, 1906-07, 1910,

1/ Mineral Resources U. S. and Minerals Yearbook.
Pratt, J. H., The mining industry in North Carolina during 1911 and 1912: North Carolina Geol. Survey Econ. Paper 34, pp. 16, 73, 1914.

1912-13, 1918, 1930, and 1937, but specific tonnage is given in only a few instances. Graton [2/] estimated that the total production of metallic tin to May 1905 probably did not exceed 50 short tons, a little more than half of which came from the Ross mine near Gaffney. Sloan [3/] reported that the Ross mine alone had produced a total of approximately 130 tons of concentrates (about 85 tons of metallic tin) up to December 1, 1906, which seems excessive in view of Graton's estimate of 19 months earlier. But even if Sloan's figure for the Ross mine is correct, the recorded production of metallic tin from the entire belt is not more than 110 short tons. Dates and scales of operations subsequent to 1906 are known only approximately, but it seems unlikely that additional unrecorded production would raise the total above 300 tons.

GEOLOGY

Country rocks

Most of the tin-spodumene 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-andesine gneiss, and enstatite-oligoclase gneiss. These foliated rocks were mapped by Keith and Sterrett [4/] as parts of the Roan gneiss and Carolina gneiss, and regarded as pre-Cambrian, whereas the crystalline limestone and interlayered fine-grained muscovite schist and quartzite which crop out in a nearly continuous zone along the eastern side of the belt were regarded as Cambrian. The observations made during the present investigation indicate that, at least in the areas mapped in detail, the gneisses are strongly

2/ Graton, L. C., A reconnaissance of some gold and tin deposits of the southern Appalachians: U. S. Geol. Survey Bull. 293, pp. 9, 54, 1906.

3/ Sloan, Earle, A catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey, ser. 4, Bull. 2, p. 92, 1908.

4/ Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Gaffney-Kings Mountain folio (No. 222) 1931.

metamorphosed parts of the marble-schist-quartzite sequence, and not older rocks. Neither sharp contacts nor the strike faults mapped by Keith and Sterrett were found to separate the two groups of rocks; there appears, rather, to be a gradational zone between them in which transitional types of rocks occur. The rocks strike generally northeast and dip steeply northwest except in the vicinity of Gaffney, where they dip southeast.

Large, extremely irregular bodies of granitic rock called the Whiteside granite by Keith,[5/] occur in the belt and in the region to the west. The mineral composition of this rock, where adjacent to pegmatite bodies, is similar to that of the pegmatite, but simpler, consisting largely of microcline, quartz, and sodic plagioclase. In places the two rocks intergrade. Pegmatite bodies in the vicinity of Kings Mountain form a peripheral zone along the sinuate east side of a large body of the granitic rock (pl. 39). This areal relationship suggests that the pegmatite minerals that are also constituents of the granitic rock probably were derived from the granitic rock or from its source. The pegmatite minerals that are not constituents of the granitic rock may have had a different source.

All of the rocks, including the pegmatite bodies, described below, are cut by dikes of fine-grained diabase, similar to those that have been intruded into Triassic rocks farther east in the Piedmont. The diabase dikes are steeply dipping, tabular bodies, which range in thickness from a few inches to 35 feet, and trend N. 40°-50° W., but two dikes less than 1 foot thick were seen that are parallel to the bedding in weathered micaceous limestone.

Pegmatite

The tin- and spodumene-bearing pegmatite bodies are mostly tabular, of lenticular horizontal section, and of unknown verti-

5/ Keith, Arthur, op. cit.

cal dimensions. The most regular in outline were emplaced in major joints that strike northwestward across the metamorphic rocks; few of these are more than 25 feet thick or 450 feet long. Other, more numerous, bodies lie parallel to the strike of interlayered country rocks. These are less regular in plan than those in the joints and are larger, attaining a maximum thickness of 395 feet and a maximum length of 3,250 feet. Of the hundreds of pegmatite bodies in the belt, most are less than 10 feet thick, and the smallest are lenslike aggregates of quartz and feldspars less than an inch in length.

The pegmatite of the Carolina belt differs notably from all that seen by the writer elsewhere in the Southern Appalachian region, except the tin-bearing pegmatite of Coosa County, Ala. The pegmatite in both areas consists largely of fine-grained albite and quartz, but the Alabama pegmatite is simpler in mineral composition than that of the Carolinas, and apparently contains no lithium minerals and very little coarse-grained microcline. The pegmatite of the Carolina belt is closely associated with much quartz-muscovite rock termed greisen, some of which contains cassiterite.

Minerals.--The dominant constituents of the pegmatite are fine-grained albite and quartz. The coarse oligoclase which characterizes much of the pegmatite in the Blue Ridge province occurs here only in very small quantity, and muscovite, though generally present, is too fine-grained and scarce to be of commercial value except as a possible minor byproduct. Microcline and spodumene, which are common but rarely dominant, are mostly medium- to coarse-grained. The crystals are characteristically fractured, and are veined with the fine-grained albite and quartz; a few of the smaller crystals of microcline are euhedral, but no euhedral crystal of spodumene was seen during the present study. The maximum observed dimension of microcline is 45 inches. The spodumene crystals are lath-shaped; the maximum length observed is 38 inches, and the maximum thickness 10.5 inches.

Cassiterite occurs persistently enough to be characteristic, though in general it is not abundant. It is dark brown in color, and is conspicuous among the white and light-colored minerals of the pegmatite. The grains are mostly between 0.5 mm. and 2.0 cm. in maximum diameter. They are angular and fractured and, although they commonly show one or more crystal faces, only two complete crystals are known to have been found. Cassiterite can be confused with only two other pegmatite minerals, columbite-tantalite and ilmenite, but the three can easily be distinguished by their streak alone: that of the cassiterite is light tan to cream-colored, that of columbite-tantalite is chocolate brown, and that of ilmenite is black.

The spodumene offers probably greater commercial possibilities than the cassiterite, particularly if regarded as the chief product in a possible concentration procedure that would yield other pegmatite minerals as byproducts. The possible reserves of recoverable spodumene in two outstanding areas are considered on pages 267-269. Spodumene is distributed unevenly in the pegmatite bodies, but less so than cassiterite. Many of the finer-grained bodies consist predominantly of albite and quartz, and carry little spodumene, but many of the coarser-grained bodies may contain an average of 15 percent or more. Spectrographic analysis of the spodumene [6] has shown the presence of eight minor impurities which are believed to be isomorphous constituents of the mineral. These are listed above in the annotated bibliography (p. 250).

A complete list, in alphabetical order, of the minerals that have been found in the pegmatite bodies during the present study is given on the following page. Minerals listed as hypogene

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6/ Gabriel, Alton; Slavin, Morris; and Carl, H. F., Minor constituents in spodumene: Econ. Geology, vol. 37, p. 119, 1942.

include those that were deposited by igneous emanations from a deep-seated source, together with small amounts of actinolite, hornblende, biotite, clinozoisite, and graphite derived from the wall rocks. The minerals listed as supergene were formed by weathering of the hypogene minerals. Hypogene minerals that apparently are not fairly well disseminated through the pegmatite are indicated by an asterisk.

Hypogene

Amblygonite†	Scarce.
Apatite	Scarce.
Beryl	Scarce, locally common; mostly resembles quartz.
Cassiterite	Scarce except in shoots.
*Chalcopyrite	Very scarce.
Columbite-tantalite	Scarce.
*Dufrenite	Very scarce.
*Dumortierite	Very scarce.
*Garnet	Scarce.
*Lithiophilite	Very scarce.
*A blue manganese phosphate	Very scarce.
Microcline	Common; locally abundant.
*Molybdenite	Very scarce.
Muscovite	Common; abundant in greisen.
Plagioclases:	
An_0 to An_5	Abundant.
*An_5 to An_{40}	Scarce.
*Pyrite	Scarce.
Pyroxenes:	
*Diopside	Very scarce.
Spodumene	Common; locally abundant.
*Pyrrhotite	Very scarce.
Quartz	Abundant.
*Rutile, tin-bearing	Found as float; very scarce.
*Sphalerite	Scarce.
*Titanite	Very scarce.
*Tourmaline	Scarce.

Supergene

Halloysite	In seams.
Kaolinite and hydrous mica	Common locally.
Purpurite	Very scarce.
Vivianite	Very scarce.
Fine-grained mixtures of hydrous ferric and calcium-ferric phosphates with hydrous iron and manganese oxides; colors olive green, yellow, brown, black	Common.

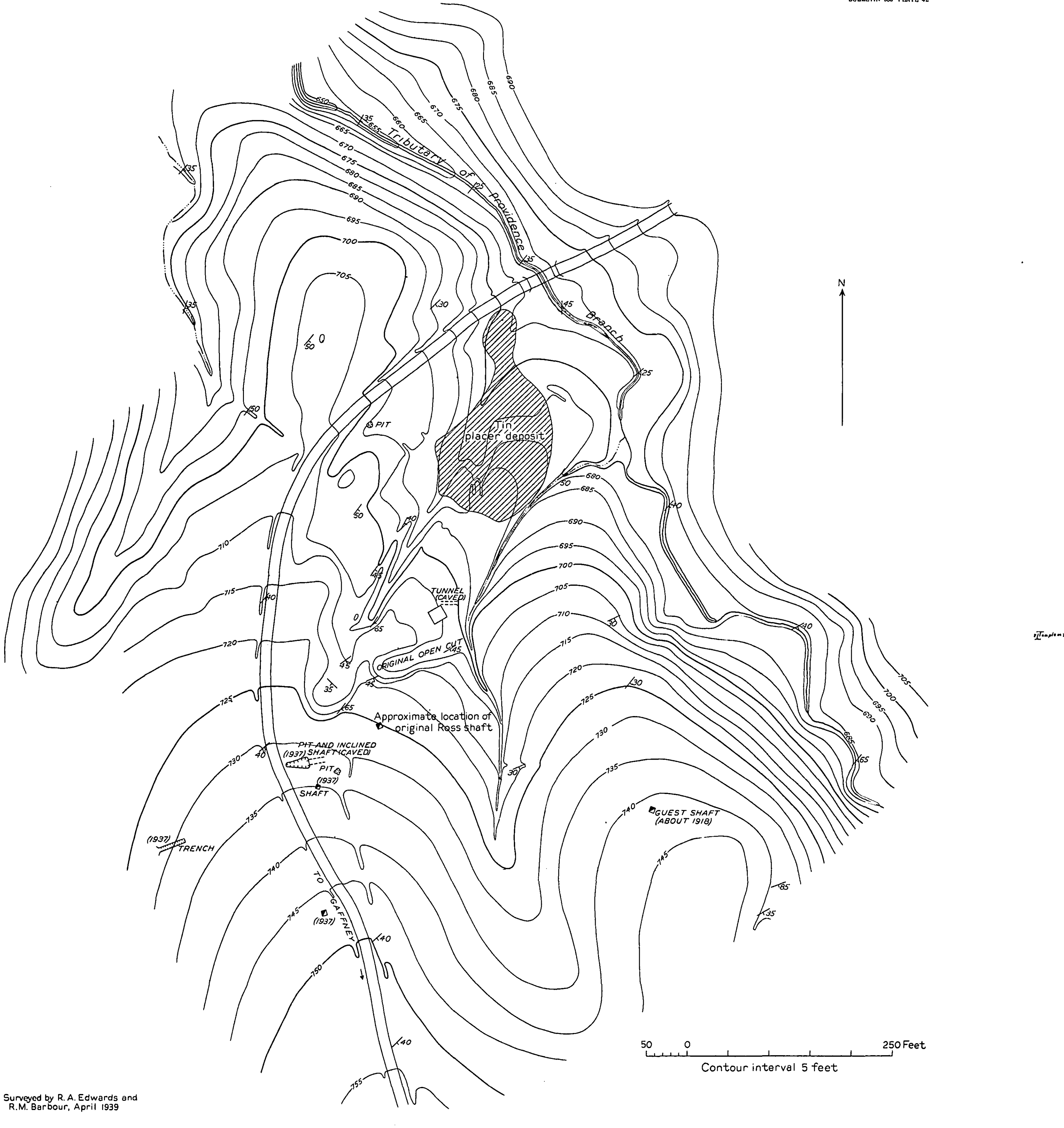
† Optical and qualitative chemical determinations indicate a composition near the montebrasite end of the amblygonite-montebrasite series.

Structural control of emplacement.--The pegmatite was emplaced in openings formed by minor rock movements that accompanied or followed the folding of the older rocks. The openings include joints that cross the layering (see pl. 40), openings that follow the layering (see pl. 39), and irregular openings (see pl. 41); those of the first two types are common, those of the last rather scarce.

In areas underlain by almost uniformly competent hornblende-biotite gneisses, pegmatite was emplaced in joints that cut at various angles across the strike of the rocks. One such area, which lies in the Beaverdam Creek drainage area, between Lincolnton and Kings Mountain, is shown in plate 40. The pegmatite bodies here are straight, tabular, and nearly uniform in thickness; some bend abruptly where prominent joints intersect. One body in this area is cut by a thick Triassic diabase dike, and an inclusion of pegmatite was found in the diabase. It seems probable that the diabase dikes were intruded into pre-pegmatite joints, however, for their prevailing trend, N. 40°-60° W., falls within the strike range of three sets of the joints.

In areas where country rocks of contrasting competence alternate in relatively thin layers, most of the pegmatite was emplaced parallel to the strike and dip of the layers. Such an area, immediately southwest of Kings Mountain, is shown in plate 39. The interlayered country rocks here are largely competent hornblende gneisses and incompetent muscovite schists.

Some of the pegmatite bodies on the property of the Ka-Mi-Tin Concentrating Co., 2 miles southeast of Lincolnton, are of the third type: they are extremely irregular in shape and attitude. The bodies prospected by power shovel in the western part of the area shown in plate 41 appear to have been emplaced in irregular fractures that commonly cut across the foliation of muscovite schist but are oriented at random.



PLAN OF THE ROSS MINE AND VICINITY

Origin.--The minerals of the pegmatite bodies were deposited in the order given below. The order of deposition, which is the same throughout the belt, is also the order of increasing abundance with the exception of the minerals of the first stage and the sulfides of the seventh. There is little or no evidence on which to date some of the minerals, and these are not included in the sequence. The relative ages of the minerals listed are apparent from relative degrees of deformation, and from veining and replacement of earlier by later members. Quartz apparently was deposited during all stages but most abundantly in ~~two.~~ three

Stage 1. Tourmaline, beryl, and apatite.
Stage 2. Cassiterite and columbite-tantalite.
Stage 3. Quartz (most of the greisen formed).
Stage 4. Spodumene.
Stage 5. Microcline.
Stage 6. Medium-grained albite (minor alteration of spodumene and microcline to muscovite).
Stage 7. Fine-grained albite and quartz (minor quantities of sulfides and apatite).

The minerals are believed to have been deposited by solutions, along channels that were reopened from time to time by intermittent rock movements. The inferred process of deposition may be outlined as follows:

The minerals of stages 1 and 2 developed in and adjacent to prominent joints and fissures forming deposits of three types: (a) Veins and lenticular masses of compact crystalline tourmaline in gneisses and schists; (b) lodes of disseminated tourmaline crystals in muscovite schist; (c) veins and lodes or disseminations of cassiterite, columbite-tantalite, and probably ilmenite, in muscovite schist, between layers of muscovite schist and hornblende gneiss, and in joints that cut obliquely across hornblende-biotite gneisses.

Many deposits of types a, b, and c were fractured and dislocated by wall-rock movements, and the new openings served as channels for the introduction of the quartz of stage 3, which veined the earlier minerals. Quartz also has partially replaced muscovite schist, into which it commonly grades. The muscovite left by partial replacement has been coarsened by recrystallization, but remains oriented for the most part parallel to the unsilicified schist. It is in the resulting aggregate of quartz and muscovite, called greisen, that cassiterite of possible commercial grade occurs most commonly. At many places, however, quartz was deposited in schist that contained no earlier cassiterite, and greisen is not uncommonly barren of tin. Rarer and possibly later types of greisen that, in places, contain earlier cassiterite were formed (1) locally in joints in hornblende gneiss, with the muscovite possibly derived from alteration of earlier pegmatite minerals, and (2) as zoned open-space fillings 6 inches or less in width, conformable with muscovite schist and containing muscovite crystals oriented perpendicular to the walls.

Some of the early deposits formed during stages 1, 2, and 3 were not greatly disturbed by later rock movements, and they remained unchanged, or but little changed, in mineral composition. Conversely, the minerals of one or more of the early stages are lacking in pegmatite bodies developed by the deposition of later minerals in channels opened after the early deposits were formed. Most of the pegmatite bodies, however, contain minerals of each stage of deposition, indicating that many lines of weakness were persistent.

Not only quartz but other pegmatite minerals were deposited in fissures and joints, and partially replaced adjacent bodies of country rock as much as 400 feet thick. The paragenetic relations are the same in both environments: each pegmatite mineral that replaced wall rocks did so at the same time that it was being deposited in open joints and fissures. The later pegmatite minerals replaced greater volumes of the country rocks than did those deposited earlier, and are more abundant. Replacement of wall rock occurred most commonly where hornblende gneiss and muscovite schist are interbedded, the muscovite schist being the more extensively replaced. Minerals that replaced wall rocks were less severely fractured by recurrent rock movements than those deposited in openings, and those in oblique joints somewhat less severely than those in fissures parallel to the bedding.

A relatively fine-grained aggregate of albite and quartz of stage 7 is by far the most abundant replacement product. A similar replacement of country rock by plagioclase has been described by C. S. Ross.[7/] Tourmaline, spodumene, microcline, and plagioclase as calcic as An_{40} also replaced the wall rocks. Replacement by these minerals, in various degrees, is abundantly exemplified in the belt. Spodumene and microcline, the coarsest-grained minerals, developed to greater size in open fissures, particularly those parallel to bedding, than in replaced wall rock.

From the order in which the pegmatite minerals were formed it is inferred that the composition of the solutions from which the minerals were deposited changed as the process went on but was comparatively simple at any given stage. The partial replacement of large bodies of country rock indicates that these solutions could not have been viscous; had they been so they could not so intimately have permeated the rocks. They are thought to have been aqueous.

TIN DEPOSITS

Deposits with greisen gangue

The cassiterite-bearing bodies of greisen, which are the simplest of the ore bodies in mineral composition, are believed to be relatively undisturbed relics of the early pegmatite

7/ Ross, C. S., Origin of the copper deposits of the Ducktown type in the southern Appalachian region: U. S. Geol. Survey Prof. Paper 179, pp. 24-25, 71, 1935.

stages. The maximum known thickness of the tin-bearing greisen bodies is 3.5 feet, but the average thickness of 35 of them is only 1 foot. No deposit of this type is exposed for its full length, but apparently none is more than 100 feet long and most of them are less than 50 feet long. The few ore bodies that have been prospected to depths greater than their observed lengths along the surface seem to be shootlike in form, but little is known about their dip or pitch lengths.

Deposits with feldspathic gangue

Tin deposits in which the gangue is dominantly feldspathic pegmatite are less numerous than the greisen deposits, but they generally are larger; the largest dimensions measured or reliably reported are: Thickness, 9 feet; strike length, 275 feet; pitch length, more than 200 feet. Three of the larger deposits of this type, the Jones, Faires, and Ross,[8/] have a well-defined pitch, which is probably true of most of the feldspathic as well as of the greisen deposits.

The cassiterite of these deposits apparently was emplaced along lines of weakness sufficiently pronounced to be reopened by subsequent movements of the wall rocks, with accompanying abundant deposition of later pegmatite minerals. Some of the tin deposits remain relatively intact, in and along the margins of pegmatite bodies thus enlarged, but others were so disrupted by the recurrent movements that only small and apparently disconnected parts of them are found in the feldspathic bodies. By a decrease in the abundance of cassiterite, these deposits grade into relatively barren feldspathic pegmatite that contains perhaps 1 to 25 grains of cassiterite in each cubic foot.

8/ See references cited in table 18 for descriptions of these mines when in operation prior to 1907.

Quantity and grade of ore

During the course of the present investigation, 55 tin deposits, most of them poorly exposed, were examined (pl. 38). The locations of 37 others, including some mentioned in published accounts of early mining operations, were established only by float ore; 32 that were reported could not be found. With few exceptions, the 92 known deposits are too widely separated to permit the mining of more than one in a single operation. The maximum thicknesses of deposits in which this dimension could be measured were from 1½ to 6 inches for 21 deposits, from 7 inches to 2 feet for 16 deposits, and from 3 to 4 feet for 4 deposits. Sloan [9] states that the Ross deposit was 9 feet thick near the surface prior to its removal by mining.

The cassiterite content of the ore bodies is very uneven. Assays and mill recoveries have shown that in adjacent deposits, or even within a single deposit, the metallic tin content ranges from a trace to more than 6 percent. Field estimates as high as 10 percent have been made for small parts of ore bodies. There are no geologic indications that the cassiterite content will change materially in grade or mode of occurrence with depth, and this is true also of the associated nonmetallic pegmatite minerals.

Accurate data from which to derive an estimate of ore reserves are lacking. On the basis of the approximate dimensions and general grade of the 55 ore bodies examined, and published information on previous mining (see references listed in table 18), the gross tin content of all the deposits in the area may be as much as 10 tons of metallic tin per foot of depth; this includes at least 7 of the larger deposits that have been mined to depths as great as 175 feet. Most of the deposits are

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9/ Sloan, Earle, op. cit., p. 39.

less than a foot thick, however, and are not minable under ordinary conditions.

Only 18 of the deposits are known to be 1 foot or more thick, and for these the limit of reasonably inexpensive mining is the depth of partly weathered rock above the level of ground water, which is about 50 feet. Seven of these deposits, as mentioned above, have been mined to or below this depth, and one (the Swamp shaft ore body of the Ka-Mi-Tin Concentrating Co., which was under water during the present survey) is in low, marshy ground. The remaining 10 bodies of ore 1 foot or more thick have an average grade of possibly 1.5 percent tin; an average thickness of 3 feet and an average length of 100 feet are assumed, giving a calculated reserve of 12,500 tons of ore, containing 188 tons of metallic tin, to a depth of 50 feet, an average of 0.375 ton of tin per foot of depth in each deposit. The 8 deposits of minable widths that have been mined to or below water level may contain ore of equal or even higher tin content, but the costs of mining would necessarily be much higher.

Placer deposits

The few known placer tin deposits in the belt occur in narrow valleys, near deposits in place; but most of them are less than 10 feet thick and contain only a negligible tonnage of cassiterite. Nothing is known regarding the possible occurrence of cassiterite in larger alluvial deposits farther downstream. Three of the most promising of the placers have been worked on a small scale.

The best known placer deposit is that at the Ross mine (locality 60 on pl. 38, and pl. 42), which yielded an unknown part of the mine's production of 130 tons of concentrates.[10] Of the original placer deposit, about 2,500 tons of cassiterite-

10/ Sloan, Earle, op. cit., p. 92.

bearing alluvium remains in an area of 25,000 square feet. The remainder of the deposit is probably of low grade. The margin of the deposit is shown in plate 42, which also shows the locations of the original open cut and 121-foot shaft, as well as more recent prospect openings.

A placer deposit, having a surface area of 60,000 square feet [11] adjacent to the Jones mine (locality 23, pl. 38) was prospected in 1903-04, but the results are unknown. Keith [12] states that the Blue Ridge Tin Corporation produced several thousand pounds of concentrates from part of an alluvial area of about 50,000 square feet in the narrow valley immediately south of locality 50, plates 38 and 39.

The three known placers, together with similar small bodies yet to be discovered, might add as much as 100 tons of metallic tin to the reserves. A little additional placer tin might be recovered from the tin-bearing soils, mostly less than 1 foot thick, which cover the weathered bedrock for distances rarely exceeding 300 feet down slope from outcrops of the tin deposits. These shallow soils, which could be removed by scraper, may contain about 50 tons of metallic tin. Very few of the deposits in place, however, are weathered sufficiently to be handled by scrapers.

Summary of deposits

The locations of all deposits examined or reported are shown in plate 38, and available information bearing on geologic and economic features are listed in table 18. Underground workings were not accessible at the time of the survey. A few of these have been described in earlier reports, and references to the descriptions are listed in the table.

11/ Pratt, J. H., and Sterrett, D. B., The tin deposits of the Carolinas: North Carolina Geol. Survey Bull. 19, p. 29, 1904.

12/ Keith, Arthur, and Sterrett, D. B., Tin resources of the Kings Mountain district, N. C. and S. C.: U. S. Geol. Survey Bull. 660, p. 141, 1917.

Atlas prospect shaft.--Early in 1941, at the completion of the present study of the tin deposits, the Atlas Collapsible Tube Co., of Chicago, began prospecting at the old Faires mine near the southern limit of the town of Kings Mountain. A shaft about 30 feet deep was sunk 125 feet northeast of the Faires shaft without encouraging results. Two churn-drill holes approximately 40 feet apart were then drilled about 200 feet N. 15° W. of the Faires shaft. Hole No. 1 was drilled to a depth of 122 feet, and hole No. 2 to a depth of 144 feet. Showings of tin ore were reported from each hole, but No. 2, in which the showings were said to be best at depths of 59, 89 to 104, and 144 feet, was considered the better; a shaft was then sunk adjacent to hole No. 2. The shaft had reached a depth of 125 feet in April 1942, when the management permitted an examination to be made.

The walls of the shaft were boarded up. Crosscuts had been driven from the bottom for 30 feet northwest and 12 feet southeast. Two pegmatite bodies and two layers of greisen, conformable with the foliation in muscovite schist, were exposed in the crosscuts, as shown in figure 28. The larger of the pegmatite bodies is 7 feet thick, and was exposed at the base of the shaft; it is said to have lensed out upward at a depth of 95 feet. The section of this body exposed in the northeast wall of the shaft shows the relative ages of some of the commoner pegmatite minerals. Relatively fine-grained albite and quartz, comprising a lenticular core about 2 feet thick, have invaded a distinctly earlier body composed largely of coarse-grained microcline with some spodumene, quartz, and cassiterite.

The cassiterite was seen only in the microcline-rich rock in the southwest wall of the shaft where the albitic rock has permeated the older mass irregularly, and is not confined to a core. It was obvious that the cassiterite-bearing rock at this point is of commercial grade, averaging possibly as much as 2 percent of tin, but no cassiterite was seen along the strike in the opposite wall. In order to determine whether or not all of the microcline-rich rock can be regarded as tin ore, a transverse channel sample was taken from the northwest side of the body, in the northeast face.

The pegmatite body exposed in the southeast crosscut is 2 to 4 feet thick, has a layered structure, and consists of fine-grained albite and quartz; a little coarse-grained microcline

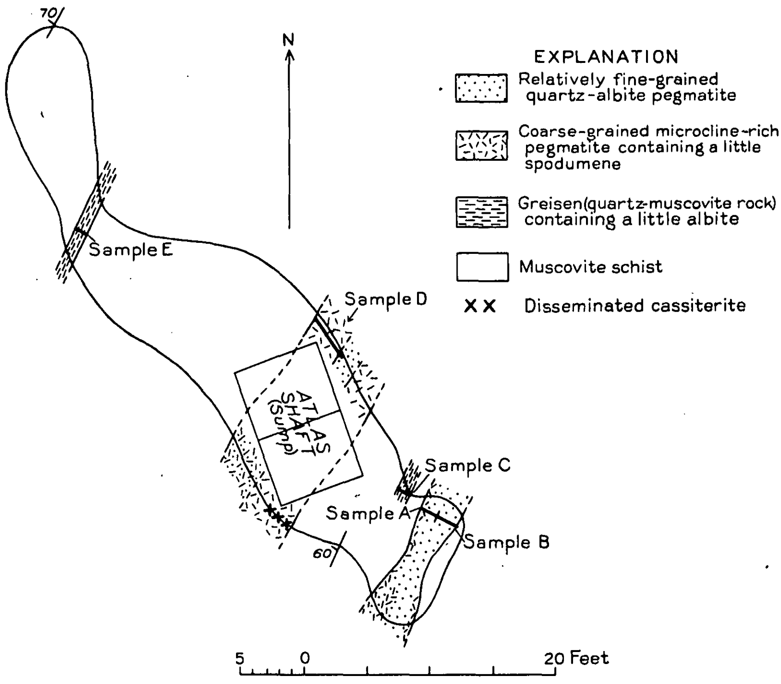

Figure 28.--Plan of crosscut and rocks exposed at base of Atlas shaft, April 1942.

occurs largely, but not entirely, adjacent to the enclosing schist. No cassiterite was visible in this body, but a transverse channel sample was taken from the northwest 14 inches of the body, and another from the southeast 18 inches.

Each of the greisen layers exposed, one in the southeast crosscut, the other in the northwest, is 12 inches thick. Each layer was sampled.

The five samples, assayed by J. G. Fairchild in the chemical laboratory of the Geological Survey, showed less than 0.03 percent of metallic tin in each. It is apparent, therefore, that the only ore of economic grade found in crosscutting four bodies of possible tin-bearing rock, which have an aggregate thickness of 11 feet 8 inches, is in the larger pegmatite, and is exposed only in the southwest wall of the shaft. The continuity of the ore to the southwest of the shaft can be determined only by drifting in that direction.

SPODUMENE RESERVES

The tin-spodumene belt contains an enormous reserve of spodumene, but a steady production in large quantities can be attained only by mining and milling comparatively rich pegmatite that may contain from 10 to 50 percent of spodumene. This might be feasible if a concentration procedure were developed that would yield spodumene as the chief but not the only product. Possible byproduct minerals, for which there are ready markets, include cassiterite, columbite-tantalite, beryl, fine-grained muscovite, feldspars, and possibly amblygonite. All of these except the feldspars are minor constituents where spodumene is most abundant.

In laboratory tests that showed the possibility of making a good separation of spodumene, Norman and Gieseke [13/] used rock from the tin-spodumene belt that contained from 33 to 50 percent spodumene. Hess [14/] states that hand-cobbed ore mined 1¼ miles southwest of Kings Mountain contained more than 50 percent spodumene. He estimates [15/] that the pegmatite bodies of the entire belt may contain an average of 15 percent spodumene. The available information concerning grade is derived, however, from ore

13/ Norman, James, and Gieseke, E. W., Beneficiation of spodumene rock by froth flotation: Am. Inst. Min. Met. Eng. Tech. Pub. 1161, p. 2, 1940.
14/ Hess, F. L., The spodumene pegmatites of North Carolina: Econ. Geology, vol. 35, p. 965, 1940.
15/ Idem.

that has been taken only from some of the richest outcrops; pegmatite bodies that contain only small, sporadic crystals have apparently escaped general notice. Because of the high proportion of fine-grained bodies that consist largely of albite and quartz, it is neither possible nor practicable to estimate the total amount of spodumene in the belt.

The most favorable showing of spodumene is exposed in a quarry 100 feet long, 12 feet wide, and 35 feet in maximum depth, located $1\frac{1}{4}$ miles southwest of Kings Mountain. The opening has been made in the east side of a pegmatite body 85 feet thick at this point, and at least 1,450 feet long, but the comparatively rich part exposed in the quarry averages only about 8 feet in thickness. The spodumene crystals here are among the largest in the belt; the maximum length observed was 38 inches. It is reasonable to expect a small quantity of hand-cobbed ore containing as much as 50 percent of spodumene from this quarry, but the large quantity of low-grade rock on the dump shows that only the richest part of the rock exposed is of such grade. The rest of the pegmatite body also contains spodumene, but the average grade is considerably lower than that of the rock in the quarry, and few of the crystals exceed 3 inches in length.

Some of the pegmatite bodies richest in spodumene occur in the two areas shown in plates 39 and 40. Although they constitute only a small portion of the belt, these two areas contain more than 700 pegmatite bodies 1 foot or more thick. The total number in the belt, therefore, must be very large. It is possible to make a rough estimate of the quantity of spodumene ore in these areas, although little is known about the average spodumene content of the pegmatite that could be applied to large tonnages. Comparatively small parts of bodies that may contain as much as 50 percent of spodumene are included because their limits are unknown, and separate estimates cannot be made.

The Beaverdam Creek area, shown in plate 40, contains 388 pegmatite bodies 1 foot or more thick. Spodumene was identified in 245, and about half of these may contain from 10 to 25 percent of spodumene, but probably not more than one-fourth are large enough to be workable. About 60 bodies, therefore, having an average thickness of about 10 feet and an average length of 250 feet, are estimated to contain rock of possible commercial grade. Assuming that not more than half of the material in these bodies would be rich enough to mill, and that this part would yield at least 15 percent of spodumene, it is estimated that the Beaverdam Creek area contains something on the order of 625,000 tons of possible ore, containing about 93,750 tons of recoverable spodumene, to a depth of 100 feet.

The area southwest of Kings Mountain, shown in plate 39, contains 376 pegmatite bodies 1 foot or more thick. Spodumene was identified in 256; it is safe to assume that at least half of these, or 128, include rock that contains from 10 to 25 percent of spodumene, and are thick enough to be quarried. The bodies in this area have a wider range of thickness and length than those in the Beaverdam Creek area, but spodumene is less evenly distributed, so that greater allowance must be made for rock that would not be milled, perhaps not even quarried. It is estimated that the average thickness of the 128 bodies is 35 feet and the average length 540 feet; probably not more than one-fifth of the rock they contain would be workable, and this entire amount probably contains at least 15 percent of spodumene. Using these figures, it is estimated that this sector of the belt contains no less than 3,700,000 tons of possible ore, containing about 555,000 tons of recoverable spodumene, to a depth of 100 feet.

The combined estimate for the two areas is a minimum of nearly 650,000 tons of spodumene in rock that may be minable to a depth of 100 feet. Boyd [16/] gives the following analysis of the spodumene obtained from a hand-sorted sample crushed to minus one-half inch, from which fragments containing visible impurities were rejected:

	Percent		Percent
SiO_2..................	63.84	K_2O..................	None
Al_2O_3..................	28.61	Na_2O..................	None
Fe_2O_3..................	.19	Li_2O..................	7.26
CaO..................	.04	Ignition loss.........	.16
MgO..................	Trace		

It has been found [17/] that the amounts of the minor constituents, particularly Fe_2O_3, vary considerably even in a single pegmatite body. Assuming an average of 7 percent LiO_2, the possibly recoverable spodumene estimated above would contain about 45,500 tons of lithia, or more than 20,000 tons of metallic lithium. The two areas to which this estimate applies have a combined length of only 6½ miles out of a total of 24½ miles for the belt. Further, the estimate applies only to the very large quantities of spodumene rock that might be minable for a composite mineral output, rather than to the relatively small bodies of rock that contain from 30 to 50 percent of spodumene.

16/ Boyd, J. E., Jr., Pyrometric properties of spodumene-feldspar mixtures: Am. Ceramic Soc. Jour., vol. 21, p. 386, 1938.

17/ Gabriel, Alton; Slavin, Morris; and Carl, H. F., op. cit., pp. 119-121, 124.