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VIRGINIA'S CONTRIBUTION TO THE KYANITE-MULLITE INDUSTRY

Stanley S. Johnson

Virginia is fortunate in being North America's leading producer of kyanite (Al_2SiO_5), a non-metallic high-aluminum silicate mineral that is utilized for super-duty refractory purposes by modern industry. The largest known kyanite reserves in the United States occur in Virginia. There are only three active kyanite producers in the United States; they are Kyanite Mining Corporation, with mines near Farmville and Dillwyn, Virginia; Commercialores, Inc., with mines near Clover, South Carolina; and Aluminum Silicates, Inc., with a mine near Lincolnton, Georgia. Since 1950 the total domestic production of kyanite concentrates has been from these mines, with commercial production beginning in Georgia in the latter part of 1962. Figure 1 shows the trends of domestic production of kyanite and imports of kyanite and related minerals for the years 1954 through 1965. The domestic price of kyanite was stable at \$29 per ton from 1955 through 1958. In 1959 the domestic price showed a marked increase to a range of \$42-\$44. Since 1959 the price has continued to rise to a high of \$47 in 1965. All prices are for 35 mesh material, in bulk car-load lots, and f.o.b. at point of shipment. The import price per ton for kyanite and related minerals in bags, c. i. f. Atlantic ports, 60 percent grade, was variable with a low of \$75 and a high of \$80 in 1955 and an annual range of \$76-\$81 for the years 1957 through 1964, and \$79-\$84 in 1965.

Kyanite occurs in high-grade metamorphic rocks or as a hydrothermal mineral in pegmatite.

The present commercial deposits of kyanite are in metamorphic rocks such as quartzite, gneiss, and schist. A relatively high percentage of alumina, either primary or secondary, is required for the formation of kyanite. Kyanite is generally believed to crystallize in high-alumina metamorphic rocks either at low pressure when water is present as an essential agent, or under high temperature and pressure conditions in a relatively water-free system. As a hydrothermal mineral, kyanite crystallizes from fluids and gases that act as agents for selective mineral crystallization. When formed by this process, the individual crystals occur in veins with other minerals, in vugs, or in other open spaces in the enclosing rocks. Hydrothermal deposition is generally associated with igneous intrusions, especially around marginal zones.

Kyanite is very important as an industrial mineral in the ceramic industry. The properties of kyanite change when the mineral is calcined at a temperature of 1100°-1480°C. Synthetic mullite prepared in this manner has been used extensively in the manufacture of high-alumina, super-duty refractories. The choice of a refractory material for use in industry depends on the ability of the material to pass numerous tests in order to meet specifications for use in a particular product. Refractory material must be able to withstand high temperatures while subjected to numerous destructive conditions that exist in furnaces and kilns; the refractory surfaces are attacked by corrosion from chemicals generated and

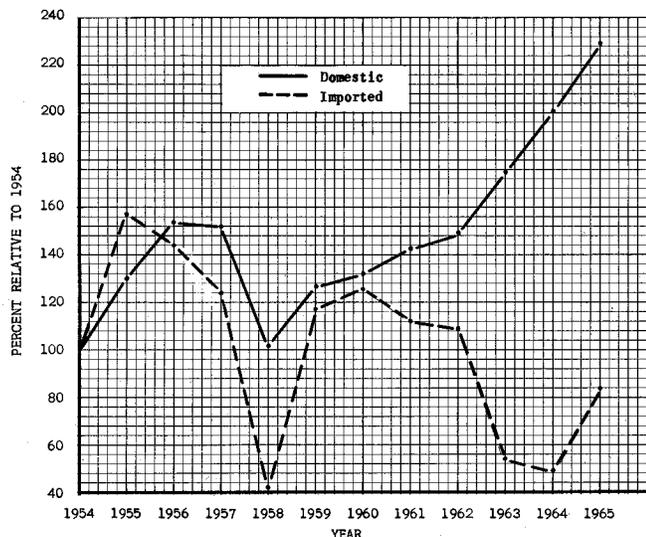


Figure 1. Domestic kyanite concentrate production (35 mesh) and total imports of kyanite and related minerals for the years 1954 through 1965, relative to 1954 production and imports. (Data from U. S. Bureau of Mines Minerals Yearbooks).

released by fluxes and slags, and may be worn away by the abrasive action of moving solids. At high temperatures, fusion is common between the refractory surface and the charge being heated in the furnace or kiln.

Kyanite is a source of high-alumina refractory material. Very little of the total tonnage mined, about 10 percent, is used in the raw state. This small tonnage is utilized in high-temperature mortars and cements, in ramming mixes, as a source of alumina in glass, porcelain, and pyrometer tubes, and as an additive to increase the alumina content of many fire clays. Kyanite undergoes a considerable increase in volume (approximately 12 percent) when heated, and this characteristic limits its use in the raw state. The degree of expansion is dependent upon grain size and temperature. The expansion is used very effectively in improving the workability of clays, increasing their strength, and compensating for their firing shrinkage. The other 90 percent of the raw kyanite is calcined into mullite, a material that exhibits no further expansion upon heating, except for normal thermal expansion.

Mullite was first noted in artificial, high-temperature melts and ceramic porcelains. The mineral was later found to occur naturally as inclusions in lavas on the Island of Mull near Scotland and takes its name from that locality. Today, years after its first identification, mullite has become one of the most important refractory materials used in the ceramic industry. Approxi-

mately 90 percent of the mullite (produced mostly from kyanite) consumed annually is used as refractory lining in metallurgical and glass-manufacturing furnaces; the remaining 10 percent is used in kilns, kiln furniture, saggars, boilers, and similar products. Mullite has many desirable properties that adapt it to these uses. The material is stable and has a low coefficient of thermal expansion and a high disintegration point. Mullite increases the fired strength of ceramic products and improves their dielectric properties, thermal resistivity, and resistance to deformation under load; it decreases the coefficient of expansion and the tendency to spall. Products made of mullite have a low reheat shrinkage and heat conductivity, and excellent resistance to slagging. Refractory products made from mullite are expensive, thus making cost a deciding factor in their use. The selection of mullite as a basic refractory material depends on a balance of operating conditions and economics. These factors determine the type of refractory that will give the longest and most economical life. The alternate materials that may be used in place of mullite are super-duty fire clays and high-alumina and pure-alumina refractories. These alternate materials are not suitable in all respects; the initial cost, service life, loss of production due to downtime, and quality of products must be considered before a decision is made between mullite and these alternate materials.

In the early 1920's the ceramic industry began to experiment with naturally occurring minerals as a source of mullite. The first experiments were with dumortierite and andalusite, obtained from small deposits in Nevada and California. Experimental studies were extended to kyanite, sillimanite, and topaz. It was found that all of these minerals would yield aggregates of small mullite crystals. Important physical and chemical properties of these minerals are listed in Table 1. Sillimanite is the most stable of the five aluminum-silicate minerals studied and undergoes very little expansion when heated. Because of this factor, many refractory brick have been sawed from the raw, quarried sillimanite rock and placed directly into use as furnace linings.

Synthetic mullite for commercial use is currently produced largely by the calcining of high-alumina silicate minerals. Mullite is also obtained by sintering a mix of uniformly ground kaolin and alumina particles at very high temperatures. This sintering process was the first method used for obtaining synthetic mullite and yields impure,

Table 1. — Physical and chemical properties of kyanite and related minerals.

	Kyanite	Mullite	Sillimanite	Andalusite	Dumortierite	Topaz
Chemical formula	Al_2SiO_5	$\text{Al}_6\text{Si}_2\text{O}_{13}$	Al_2SiO_5	Al_2SiO_5	$\text{Al}_8\text{BSi}_3\text{O}_{19}(\text{OH})$	$\text{Al}_2\text{SiO}_4(\text{F}, \text{OH})_2$
Composition	Al_2O_3 63.2% SiO_2 36.8%	Al_2O_3 71.8% SiO_2 28.2%	Al_2O_3 63.2% SiO_2 36.8%	Al_2O_3 63.2% SiO_2 36.8%	Al_2O_3 64.6% B_2O_3 5.5% SiO_2 28.5% H_2O 1.4%	Al^{+3} 29.3-30.0% Si^{+4} 15.6-15.5% F^{-1} 20.6- 0.0% OH^{-1} 0.0-19.0% O^{-2} 34.8-35.5%
Type	Aluminum silicate	Aluminum silicate	Aluminum silicate	Aluminum silicate	Aluminum borosilicate	Aluminum fluosilicate
Crystal system	Triclinic	Orthorhombic	Orthorhombic	Orthorhombic	Orthorhombic	Orthorhombic
Specific gravity (or density)	3.56 to 3.66	3.23	3.23	3.16 to 3.20	3.26 to 3.36	3.4 to 3.6
Hardness	5 to 7	6 to 7	6 to 7	7.5	7	8
Temp. at which mullite is formed	1100° to 1480°C	—	1550° to 1650°C	1450° to 1500°C	1000° to 1250°C	1000° to 1480°C
Volume change after calcining	Sizable increase	Negligible	Slight increase	Very slight increase	Slight increase	Slight increase
Density after calcining at 2633°F (1445°C)*	3.05	—	3.10	3.04	2.89	3.02 (at 2192°F or 1200°C)

* From Klinefelter and Cooper (1961, p. 4).

small crystal aggregates. Today, a high-quality synthetic mullite is obtained by fusing a mixture of bauxite or Bayer-process alumina and clay (generally kaolin) or silica in an electric furnace. The raw materials used in this process must be of the purest quality. The alumina is obtained from the large deposits of bauxite in the Caribbean area and South America, and silica is obtained from high-quality silica sources. This fused synthetic mullite has excellent, strong, large crystal aggregates; for this reason it is classified as a strategic material and is kept in the national stockpile for emergency use. Of all the minerals mentioned, only kyanite has had any importance in the production of mullite; this may be in part due to its greater abundance in large, known deposits.

The kyanite reserves presently being exploited in the United States are reported as about 100 million tons of kyanite-bearing quartzose rock that contains approximately 10 to 30 percent kyanite (Cooper, 1965, p. 484). This estimated tonnage occurs in disseminated-type deposits in Virginia, North Carolina, South Carolina, and Georgia. Other states have medium- to low-grade kyanite and kyanite-related resources. The occurrences outside of the Southeastern States are not presently commercial. All of the raw material

and mullite now used in the ceramic industry is shipped from the southeastern deposits. Two of the important marginal occurrences in the western part of the United States that may have potential economic possibilities are the kyanite-andalusite schists at Goat Mountain in Idaho and the kyanite occurrence in the Petaca district of New Mexico. Florida also has millions of tons of kyanite and sillimanite in heavy-mineral sand deposits. Recovery from these sources is not considered economical under present-day conditions, but may have good potential in the future.

On a worldwide basis, the important production of kyanite has been centered in India, Africa, and the United States. The largest known deposits of kyanite and sillimanite are in India and Africa where the minerals occur mainly as masses of small interlocked crystals in large surface boulders that are easily and cheaply mined. This material is preferred by industry because when mullitized it yields large, strong aggregates of mullite crystals, whereas the domestic kyanite from disseminated-type deposits yields smaller, finer grained aggregates. Since the early 1950's, however, the domestic kyanite has been favored over imported kyanite for the production of synthetic mullite. Klinefelter and Cooper (1961, p. 2) stated that the decline in imports after the early

1950's (Figure 1) was caused by the excessive prices asked by Indian exporters and the depletion of the massive material in Africa. The decrease in imported material was offset by an increase in production of synthetic mullite from domestic kyanite sources. Industry has some specialized uses for a small amount of the Indian-type kyanite, and for this reason Indian kyanite is stockpiled by the Federal Government for emergency use.

Support by the Federal Government of incentive programs involving research, procurement, and taxes has been instrumental in the development of the domestic kyanite-mullite industry. In 1965 producers were given a depletion allowance of 23 percent of domestic production, and no special taxes were imposed on the industry. In 1959, kyanite-mullite minerals were restored to the list of strategic and critical materials, thus enabling them to be stockpiled. The Office of Minerals Exploration will grant loans of up to 50 percent of approved costs for exploration for kyanite deposits. Cooper (1965, p. 487) forecasts that the domestic kyanite industry will continue to increase at a rate of 8 to 10 percent per year until 1970; he also states that the total free-world requirements for kyanite-mullite materials are increasing at about 5 percent per year. The trend

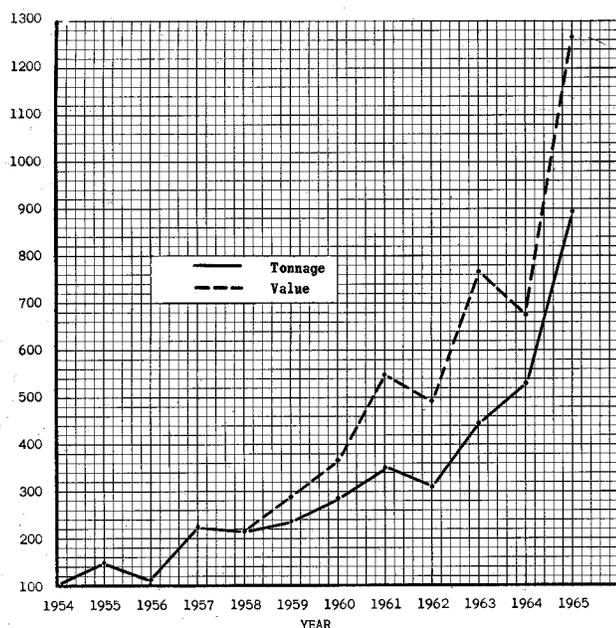


Figure 2. United States exports of kyanite and value of these exports for the years 1954 through 1965, relative to 1954 exports and values. Percentage trends for value and tonnage for the years 1954 through 1958 are so close that both are represented by the tonnage line. (Data from U. S. Bureau of Mines Minerals Yearbooks).

of kyanite exports from the United States for the years 1954 through 1965 is shown in Figure 2.

Although mullite derived from kyanite was first used in super-duty refractories, new uses of mullite in nonrefractory products are steadily increasing. One of the newest uses has been in ceramic bodies not subjected to heat after initial firing in manufacture, such as sanitary porcelain, wall tile, precision casting molds, and other similar products. The use of mullite in these products is due to the added strength that the interlocking mullite crystals give to a ceramic composition. In the United States space program, raw kyanite is being utilized as an insulating material. The kyanite is heated to a molten state, and air is then blown into the molten material causing kyanite fibers to form. These fibers are pressed into a blanket-type form and utilized in space capsules, unmanned probes, jet aircraft engines, and many other similar uses. Experimental uses of mullite refractories in the critical sections of blast furnaces and in the leading wing-edges of hypersonic aircraft may result in an increased demand for kyanite-mullite refractories.

In Virginia kyanite has been reported from a number of localities in the Blue Ridge and Piedmont physiographic provinces, but known commercial and possible commercial deposits are confined to an area of metamorphic rocks approximately 25 to 30 miles in length and 15 to 20 miles in width in the east-central portion of the Piedmont that includes parts of Buckingham, Prince Edward, and Charlotte counties. The kyanite-bearing rocks include varieties of mica schist and gneiss, hornblende gneiss, and quartzite, all of probable Precambrian age. The rocks in this part of the Piedmont are deeply weathered, and those that crop out are composed principally of the more resistant minerals that are only slightly decomposed. Kyanite quartzite, one of the most resistant rocks to weathering, forms several prominent knobs and ridges.

The only actively developed deposits of kyanite in the Farmville district are at Willis Mountain in Buckingham County and at Baker Mountain in Prince Edward County. Other rather large occurrences in the district are at Wood Mountain in Buckingham County, Leigh Mountain in Prince Edward County, and near Madisonville in Charlotte County. Other kyanite occurrences are near Meadville in Halifax County, near Sheppards in Buckingham County, and near Prospect and Briery in Prince Edward County. Small amounts of kyanite also occur in metamorphic rocks,

quartz veins, and pegmatites; some of these occurrences are in Carroll and Grayson counties (Jonas, 1932, p. 15), in the Axton pegmatite area in Henry and Pittsylvania counties, in the Philpott-Martinsville pegmatite area in Henry County, and in the Anna River pegmatite area, which includes portions of Spotsylvania, Caroline, Hanover, and Louisa counties (Jahns and Griffiths, 1953, p. 171, 192, 194).

There have been many theories concerning the origin of kyanite in the Southeastern States. Some deposits have a hydrothermal origin; others, a regional metamorphic origin, and still others a combination of hydrothermal and metamorphic processes. The following discussion concerning the origin of the Virginia kyanite deposits was summarized from a report by Espenshade and Potter (1960, p. 51-53). The Virginia kyanite deposits are believed to have been formed by regional metamorphism of alumina-rich sedimentary rocks. The kyanite-bearing rocks are believed to have been sedimentary in origin because they appear to have a definite, restricted stratigraphic position, and appear to have been a clay-bearing sandstone and high-alumina shale. The clay in the sandstone could possibly have been derived from a weathered basalt or other volcanic rock. On the other hand, if the alumina in the sandstone and shale were derived from hydrothermal solutions during metamorphism, the solutions could have come from an igneous source or from the possible leaching of the surrounding country rock. The scarcity of kyanite in quartz veins, the absence in many pegmatites, and the unlikelihood that the alumina would have been introduced only into the sandstone and adjacent shale beds in the district seem to make the origin of the deposits by hydrothermal solutions improbable.

The first commercial production of kyanite in the Southeastern United States was probably in Virginia at Baker Mountain, Prince Edward County, in the early 1920's. Activity at this locality, started by the McLanahan-Watkins Company, was the first attempt in this country to beneficiate kyanite-bearing rock. At that time a grinding and tabling process (gravity) was used to separate the kyanite from the quartzite rock. From 1926 through 1936 the deposit appears to have been idle as no production was reported. In 1936 the Phosphate Recovery Corporation acquired the operation from the Baker Mountain Corporation and resumed production. Flotation equipment was installed at this time to concentrate the

kyanite. In 1940 the Phosphate Recovery Corporation was reorganized and the name changed to Kyanite Products Corporation. The present operator, Kyanite Mining Corporation, was established in 1945.

Baker Mountain is a low, rounded knob that rises approximately 100 feet above the surrounding area. Espenshade and Potter (1960, p. 50) reported that the kyanite-bearing rock at this locality is probably on the lower limb, or is the compressed crest, of a large recumbent anticline. The kyanite (Figure 3) occurs in a schistose quartzite as blue-green to gray-blue, medium- to coarse-grained crystals; minor groups of small, fine, needle-like, radiating crystals are found. The accessory minerals are magnetite, muscovite, rutile, pyrite, chalcopyrite, and clay.

Willis Mountain, rising as a monadnock over 500 feet above the surrounding countryside, is one of the most prominent features in Buckingham County. Mining was begun on this deposit in 1957 by the Kyanite Mining Corporation. The kyanite-quartzite rock that is mined is on the nearly vertical west limb of the Whispering Creek anticline. The kyanite occurs in the quartzite as pale blue-gray to colorless crystals that differ in shape from long, narrow blades to small, needle-like forms. Accessory minerals are muscovite, pyrite, rutile, topaz, magnetite, and feldspar.

The kyanite-bearing rocks of the Baker Mountain and Willis Mountain deposits are mined by power shovel in open-pit operations. The mined rock is taken to concentrating operations near the quarries where it is crushed, ground, screened, classified, and washed. After washing, the clean, fine-grained material is prepared for selec-



Figure 3. Kyanite ore from Baker Mountain.



Figure 4. Willis Mountain kyanite deposit.

tive flotation processes. The pyrite in the flotation concentrate is primarily separated in the initial stages of flotation. Magnetite, and other iron compounds that have been converted to magnetic iron oxide (Fe_3O_4) by roasting and cooling in a reducing atmosphere, are removed by electromagnets and stockpiled. The beneficiated kyanite is marketed in the raw state or is converted into mullite. The materials are available in 35, 48, 100, 200, and 325 Tyler mesh screen sizes. Chemical analyses, supplied by the company, for the marketed raw kyanite concentrate and mullite (calcined kyanite) are as follows:

	Kyanite		Mullite
Alumina	59.05-61.80	%	59.17-61.80 %
Silica	38.65		38.73
Iron oxide	0.16- 0.94		0.16- 0.94
Titania	0.67		0.67
Lime	0.03		0.03
Magnesia	0.01		0.01
Alkalies	0.42		0.42
Ignition loss	0.21		—
	<u>99.98</u>		<u>99.97</u>

The Kyanite Mining Corporation owns and operates two processing plants for each of their two mines. Part of the raw kyanite from the Willis Mountain deposit (Figure 4) is ground and bagged for shipment at a plant (Figure 5) at the mine site; the rest of the raw kyanite is trucked

8 miles to a company plant at Dillwyn where it is calcined, ground, and shipped. Kyanite mined at Baker Mountain (Figure 6) is calcined, ground, bagged, and shipped from a plant (Figure 7) adjacent to the mine or is trucked 6 miles to a grinding and bagging plant at Pamplin City (Figure 8). Bulk material is available from all four plants. A fine-grained quartz sand with a minor percentage of fine bladed kyanite is produced from the milling process at each plant. This sand is marketed through the Dixon Sand Company and is utilized mainly as a cleaning, blasting, engine, foundry, and ballast sand. The magnetic iron oxide, muscovite, and pyrite derived from the beneficiation and milling processes may also find a market in the future.

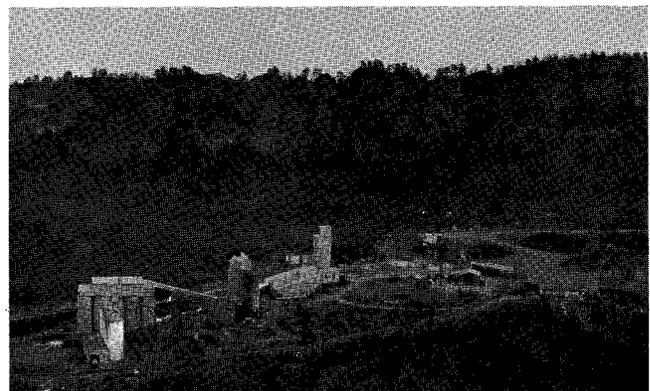


Figure 5. Processing plant at the Willis Mountain kyanite mine.

THE MINERAL INDUSTRY IN VIRGINIA IN 1966¹

PRELIMINARY DATA

The value of mineral production in Virginia in 1966 was \$267 million, only slightly less than last year's record high, according to estimates by the Bureau of Mines, United States Department of the Interior. New highs were established in production of coal, sand and gravel, lime, and clays. The production of bituminous coal, the leading commodity in terms of both tonnage and value, increased for the fourth consecutive year and was 2 percent higher than in 1965, the previous record year. Natural gas and a small quantity of petroleum were also produced in the State.

Slackened construction activity, particularly in residential housing and certain phases of highway construction, was reflected in decreased production of stone, cement, and gypsum. The production of all varieties of crushed stone, with the exception of sandstone, decreased in 1966. Output of crushed limestone, the leading stone type, was about 2 million tons less than in 1965. Most of the dimension-stone products also declined in

¹ Prepared by David J. Kusler, U. S. Bureau of Mines, Pittsburgh, Pennsylvania.

output and value. Although stone output declined 9 percent, it still was the second highest year on record. Combined shipments of portland and masonry cement were 8 percent less than those of 1965; however, higher prices received per barrel kept the value of shipments near the 1965 levels.

Sand and gravel production increased 4 percent, and that for clay, 5 percent. Lime production increased for the fourth consecutive year primarily because of increased demand by the chemical industry. The production of aplite and soapstone increased.

Although the operation of mines was continuous throughout the year, output of crude ore was at a lower monthly rate; consequently production of both lead and zinc was less than in the previous year. The production and value of titanium-ore concentrates (ilmenite and rutile) rose moderately. The increases in both output and value were due entirely to a gain in the production of ilmenite; rutile output and value were less than in 1965. The production of iron-oxide pigments decreased moderately.

Table 1. — Mineral production in Virginia.¹

Mineral	1965		Preliminary 1966	
	Quantity	Value (thousands)	Quantity	Value (thousands)
Clays..... thousand short tons....	1,415	\$ 1,657	1,482	\$ 1,780
Coal (bituminous).....do.....	34,053	139,291	34,715	(²)
Gem stones.....	(³)	7	(³)	7
Lead (recoverable content of ores, etc.)..... short tons....	3,651	1,139	3,100	930
Lime..... thousand short tons....	847	10,584	906	11,320
Natural gas..... million cubic feet....	3,152	942	2,900	870
Petroleum (crude)..... thousand 42-gal. barrels....	4	(²)	5	(²)
Sand and gravel..... thousand short tons....	15,322	18,019	15,934	18,920
Soapstone..... short tons....	3,549	9	3,800	10
Stone..... thousand short tons....	36,350	59,397	33,245	55,091
Zinc ⁴ (recoverable content of ores, etc.)..... short tons....	20,491	5,942	17,296	5,016
Value of items that cannot be disclosed: Aplite, portland cement, masonry cement, feldspar, gypsum, iron ore (pigment material), kyanite, salt, titanium concentrate (ilmenite and rutile), and values indicated by footnote 2.....	—	30,990	—	173,176
Total.....	—	\$267,977	—	\$267,120

¹ Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

² Withheld to avoid disclosing individual company confidential data.

³ Not available.

⁴ Recoverable zinc valued at the yearly average price of prime western slab zinc, East St. Louis market. Value established after transportation, smelting, and manufacturing charges have been added to the value of ore at the mine.

GROUND-WATER LEVEL FLUCTUATIONS

Thomas M. Gathright and William W. Winters

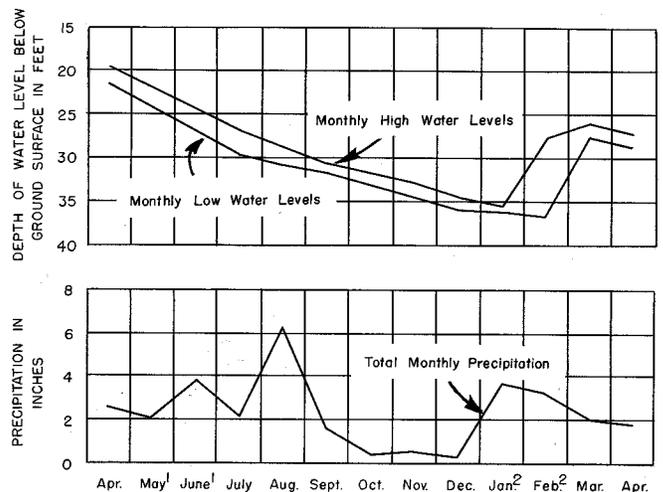
During the past several years, considerable work with public and industrial water-well site location and well development has emphasized the need for quantitative ground-water data in Virginia. Among the data urgently needed are accurate records of water-level fluctuations in wells located in the various geographic, topographic, and geologic environments in the State. These data, coupled with accurate precipitation records, are considerable help in evaluating ground-water potential.

As a result of this need, in 1963 the Division of Mineral Resources began the installation of a network of automatic water-level recorders in observation wells drilled at selected sites in the State. These recorders continuously measure and record the fluctuations in elevation of the water level in wells that penetrate confined and unconfined aquifers. Water levels in wells fluctuate in response to many different factors: recharge of ground water from precipitation, discharge of ground water into streams and springs, loss of ground water through evapo-transpiration, changes in barometric pressure, moon and sun tides, earthquakes, and artificially induced conditions such as large withdrawals of ground water from several wells located in a relatively small area. The amount of fluctuation depends on the magnitude and number of forces acting upon the aquifer, and the period of fluctuation may be seasonal, daily, hourly, or momentary. Presently, water levels are being recorded in eight observation wells at sites in the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain physiographic provinces.

The following information is presented as an example of the type of water-level data currently being collected by the Division of Mineral Resources. One of the observation wells is located on the west side of U. S. Highway 15, approximately 2 miles north of Gordonsville, near the boundary between the Blue Ridge and Piedmont provinces. This well is at an elevation of 480 feet above sea level on a low hill less than 0.25 mile east of Merry Mountain, and between two intermittent streams that are 50 to 60 feet below the elevation of the well. The 97-foot drill hole encountered bedrock at 10 feet, is cased to a depth of 11

feet, and obtains water from openings in the vertical phyllites and thin interbedded quartzites. Because this well is more than 1500 feet from the nearest producing well, it should not be influenced by local ground-water withdrawals.

Water-level data from this well have been plotted on the accompanying graph to show the high and low water levels for each month during the period from April 1965 through April 1966. Also shown are the total monthly precipitation data for the same period. These data were obtained from published records of the U. S. Department of Commerce weather-recording station in Gordonsville, which is located approximately 6 miles from the observation well. It has been observed that water levels in wells are usually highest in early spring, and records from the Gordonsville well are in accord with this general observation. During the months of maximum plant growth (spring and summer) little precipitation reaches the zone of saturation, whereas during the months of plant dormancy (fall and winter) precipitation recharges the aquifers. The fact that total recovery of the water level was not achieved is probably the result of subnormal precipitation and recharge during this period and the preceding year.



¹ Only partial data available.

² Water equivalent of snowfall estimated, using a ratio of 1 inch water equivalent to 10 inches of new snowfall.

Relationship between water levels and precipitation in the Gordonsville well from April 1965 through April 1966.

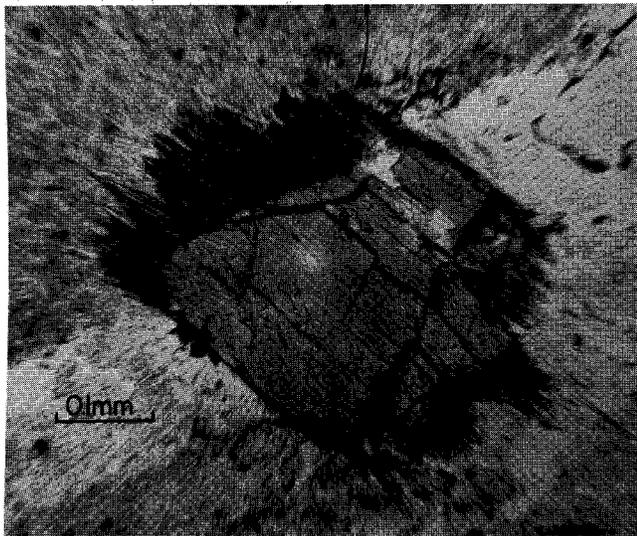


RIEBECKITE OCCURRENCE IN SOUTHERN VIRGINIA

Gary C. Allen

Riebeckite, which has not previously been reported in Virginia, was found 9/14/66 during an examination of Triassic-age rocks from southern Pittsylvania County. The mineral, a relatively common member of the amphibole group, occurs in sedimentary rocks of undetermined origin which crop out along the Virginia-North Carolina boundary west of Danville. It forms a thin grayish-blue coating along fracture surfaces and is a minor constituent of the host rock. Fibrous dark-blue riebeckite surrounds grains of detrital hornblende, as shown in the accompanying photomicrograph. Commonly the *c* crystallographic axes of the riebeckite needles are in parallel orientation to the *c*-axes of the enclosed hornblende. However, where the mineral is not associated with a hornblende grain, it tends to grow in radiating aggregates.

Riebeckite is usually found in soda-rich syenites, granites, and granite pegmatites. It is



Photomicrograph of Triassic sedimentary rock from southern Pittsylvania County showing detrital green hornblende surrounded by authigenic blue riebeckite (plain light).

normally deep blue in color and occurs as poorly formed prismatic crystals or as fibrous aggregates. The theoretical chemical composition is $\text{Na}_2\text{Fe}_3^{+2}\text{Fe}_2^{+3}\text{Si}_8\text{O}_{22}(\text{OH}, \text{F})_2$. The occurrence of authigenic riebeckite in sedimentary rocks is rare (Milton and Eugster, 1959, p. 141-143) and possibly represents the presence of mineralizing solutions after deposition of the original sediment.

Reference

Milton, C., and Eugster, H. P., 1959, Mineral assemblages of the Green River formation, in *Researches in geochemistry*: New York, John Wiley and Sons, Inc., p. 118-150.

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NEW PUBLICATIONS

Mineral Resources Report 7. BASE- AND PRECIOUS-METAL AND RELATED ORE DEPOSITS OF VIRGINIA, by Gwendolyn W. Luttrell; 167 p., 1 map. Price: \$2.00

Gold, pyrite, pyrrhotite, copper, zinc, lead, arsenic, nickel, tin, tungsten, and barite have been mined in Virginia. Gold occurs in vein deposits and in pyritized shear zones in the metamorphic rocks of the Piedmont province, and in placers derived from these deposits. Copper is mainly in massive pyrrhotite-pyrite deposits, but also occurs in vein deposits with a quartz gangue, in pyritized shear zones in the Piedmont province, as native copper in greenstone in the Blue Ridge and Piedmont, and in small amounts in Triassic shales. Lead occurs with copper and zinc in a few veins and replacements of shear zones in the metamorphic rocks, and with zinc in vein and replacement deposits in Paleozoic rocks in the Valley and Ridge province. Zinc occurs in small amounts in many of the base-metal deposits in metamorphic rocks, but it forms large deposits by replacement and cavity-filling in Paleozoic limestone and dolomite of the Valley and Ridge province.

Small arsenic and nickel deposits occur in metamorphosed rocks in the Blue Ridge upland, and a tin deposit is present in intrusive rocks in the Blue Ridge. A tungsten deposit in quartz veins occurs in granite in the Piedmont province. Barite deposits are associated with zinc and lead in Paleozoic rocks in the Valley and Ridge province, and in the Piedmont province barite occurs in rocks ranging in age from Precambrian to Triassic.

In this report 496 mines and prospects are described, and their locations are shown on an index map. Most of the deposits were explored and mined many years ago, and the source material used in this compilation dates back to 1837.

Virginia Division of Mineral Resources

Box 3667

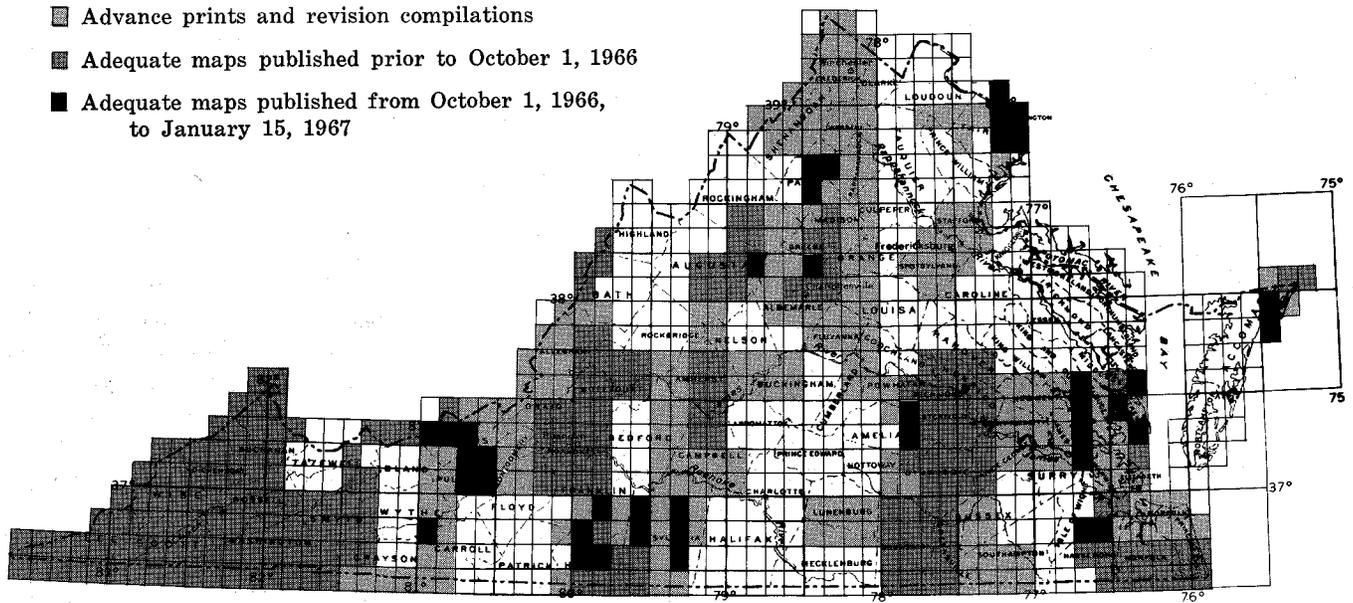
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Austinville	Crimora	Hog Island	Pearisburg	Thornton Gap
Bassett	Deltaville	Luray	Radford North	Wallops Island
Big Meadows	Dublin	Mannboro	Radford South	Ware Neck
Blairs	Earlsville	Martinsville East	Rockville	Washington West
Callands	Falls Church	Martinsville West	Sandy Level	Williamsburg
Chincoteague West	Glade Hill	Narrows	Shackelfords	Windsor

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PUBLISHED MAPS

State index is available free. Published maps are available at 50 cents each from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903.