

THE RUTILE DEPOSITS OF THE EASTERN UNITED STATES.

By THOMAS L. WATSON.

INTRODUCTION.

The titanium-bearing minerals comprise more than 60 distinct species, grouped under a variety of mineral and chemical forms, chiefly as oxides, titanates, titano-silicates, silicates, columbates, and tantalates. These minerals are widely distributed in a variety of associations and in such quantity as to make titanium a relatively abundant element. Clarke¹ estimates the amount of titanium in the solid crust of the earth to be 0.44 per cent, equivalent in oxide to 0.73 per cent, the element thus standing in the ninth place in the scale of abundance, next to potassium.

Most of the titanium-bearing minerals, however, are rare and are only of scientific interest. The largest concentrations of the element are as oxide (rutile), as iron titanate (ilmenite), and in iron ferrate (magnetite) as intergrown ilmenite. Of these three forms the principal source of the element at present is rutile. The known workable deposits of rutile, however, are extremely few and widely separated, and as the demand for titanium has greatly increased in the last few years it has been necessary for some uses to turn to ilmenite or highly titaniferous magnetites.

This paper briefly summarizes present knowledge of the geology of the rutile deposits in the eastern United States and for the sake of comparison discusses several foreign deposits, each of which has produced some rutile. Of the known deposits in the United States only those in Virginia are of commercial importance. These have been made the subject of a special report² by the Virginia Geological Survey, which was preceded by a preliminary paper on the rutile deposits of Amherst and Nelson counties.³

¹ Clarke, F. W., U. S. Geol. Survey Bull. 491, pp. 32, 33, 1911.

² Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3-A, 308 pp., 1913.

³ Watson, T. L., and Taber, Stephen, The Virginia rutile deposits: U. S. Geol. Survey Bull. 430, pp. 200-213, 1910.

In the preparation of this paper the writer has drawn freely on all available publications relating to the individual areas described.

MODE OF OCCURRENCE.

Rutile is found in each of the major groups of rocks—igneous, metamorphic, and sedimentary. It occurs (1) as small prismatic forms and acicular hairlike bodies, chiefly as microscopic inclusions in the rock-forming silicate minerals; and (2) as separate formless grains and masses of variable size. The first mode of occurrence is common but nowhere of economic importance; the deposits of the second group are less widespread and constitute the source of the mineral in the few known localities from which it is obtained in commercially valuable quantities.

Rutile is formed as a constituent of (1) igneous rocks, (2) pegmatite dikes, (3) contact-metamorphic deposits, (4) veins, and (5) regionally metamorphosed rocks. Of these several occurrences Nos. 1 and 2, rarely 3 and 5, constitute important sources of rutile.

ROCK ASSOCIATIONS.

Rutile occurs in both plutonic and volcanic igneous rocks and has been observed in most of the principal types (acidic, basic, and intermediate in composition), but with very few exceptions the rocks contain it only as a very minor constituent. It is usually in grains and crystals of microscopic size, though in some places it is found in masses visible to the unaided eye.

Most of the known deposits of rutile that are of commercial importance are associated with gabbro (including anorthosite), chiefly as deposits formed by magmatic differentiation. The region of Amherst and Nelson counties in Virginia, the Bay St. Paul area in Quebec, Canada, and the Kragero area in southern Norway belong to this type. A second important type of rutile deposit is found in Amherst and Nelson counties, Va., in dikelike bodies of the ultrabasic igneous rock nelsonite,¹ which is composed chiefly of the minerals ilmenite and apatite but which in places has rutile as the dominant mineral.

Rutile has been found in most classes of metamorphic crystalline rocks, such as gneiss, schist, phyllite, quartzite, and granular limestone and dolomite. It occurs in simple and geniculated forms in quartz veins and stringers in the metamorphic crystalline rocks of the Piedmont province of the southern Appalachians. Rutile has

¹ Watson, T. L., Mineral resources of Virginia, p. 300, 1907; Watson, T. L., and Taber, Stephen, U. S. Geol. Survey Bull. 430, pp. 206-207, 1910; Watson, T. L., and Taber, Stephen, Virginia Geol. Survey Bull. 3-A, pp. 100-155, 1913.

been reported as an important constituent in parts of the apatite veins of Norway and Sweden, which, according to Vogt,¹ are pneumatolytic in character and connected with gabbro. In these veins the mineral is associated with the titanium minerals ilmenite and titanite, and is so abundant in some places as to be mined.

Rutile and ilmenite occur as primary constituents of pegmatite dikes² of granitic composition in Goochland and Hanover counties, Va., described on pages 401-404. The rutile is present in considerable quantity at this locality, and is of potential commercial value. Hess³ has described the occurrence of rutile in association with minerals of the rare-earth metals in the pegmatite body at Baringer Hill, Llano County, Tex.

Because of its resistance to atmospheric agencies, rutile is a common mineral in beds of sand and gravel and in the residual material derived from the weathering of crystalline rocks in which it originally occurred. It is to be found in many gold-bearing sands and gravels, in the monazite sands of the Carolinas, and in similar sands composed of heavy resistant minerals at numerous other localities.

MINERAL ASSOCIATIONS.

The minerals associated with rutile include a wide range of species. As a product of crystallization from rock magmas, it is associated with most of the common rock-forming silicate minerals, including quartz. Where formed in metamorphic rocks by regional metamorphism, its associates, in addition to the common rock-forming silicate minerals, are usually a group of heavy minerals found in metamorphic rocks, such as kyanite, magnetite, and ilmenite. Where it occurs as a vein mineral, the commonest associate of rutile is of course quartz, but with these are other titanium minerals, especially ilmenite, and iron oxides. In some veins and pegmatites the associated minerals comprise some usually regarded as having been formed by pneumatolysis, such as those of the apatite veins of Norway, Sweden, and Canada. In alluvial and water-sorted sands rutile is associated with the heavy resistant minerals, such as ilmenite, magnetite, chromite, monazite, garnet, zircon, spinel, and locally gold.

DISTRIBUTION.

Rutile has a very broad distribution, but it is rarely found in large quantity and the known deposits of commercial value are few and are widely separated, being limited to three localities in North

¹ Vogt, J. H. L., *Genesis of ore deposits*: Am. Inst. Min. Eng. Trans., p. 646, 1901.

² Hess, F. L., *Min. World*, vol. 33, pp. 35-37, 1910; Watson, T. L., and Taber, Stephen, *Virginia Geol. Survey Bull.* 3-A, pp. 252-253, 1913.

³ Hess, F. L., *U. S. Geol. Survey Bull.* 340, pp. 287-294, 1908.

America and one each in Europe and Australia. The commercial localities include (1) the Amherst-Nelson and Hanover-Goochland areas in Virginia; (2) Bay St. Paul, in northern Quebec, Canada; (3) Kragero, in Norway; and (4) an area near Mount Crawford, 25 miles northeast of Adelaide, South Australia.

Each of these localities, except the Hanover-Goochland area, has produced some rutile, but the Amherst-Nelson area has yielded the largest quantity.

RUTILE IN THE EASTERN STATES.

The deposits of rutile in the eastern United States extend from New England to Alabama, but all except those of Virginia are of scientific interest only, as they are not known to be of commercial value. There is great variation over the region in the mode of occurrence of rutile, both as to kind of rock and as to mineral associations. Of most of the deposits very little can be said beyond the statement of location, for they have not been the subject of special study in the field, and knowledge of them is yet imperfect. The principal localities are indicated on the map forming figure 93.

NEW ENGLAND.

Rutile has been reported from one or more localities in each of the New England States except Rhode Island, but so far as known the mineral has nowhere been noted in commercial quantity. The occurrences in the different localities show marked differences in the associated rocks and minerals.

MIDDLE NORTHERN STATES.

Minor deposits of rutile have been reported in New Jersey and New York. Pennsylvania was a small producer of rutile prior to 1901, when exploitation of the Virginia deposits was begun.

The occurrence of rutile in Pennsylvania is limited, so far as known, to the central portion of Chester County, in the extreme southeastern part of the State. (See 1, fig. 93.) The mineral was picked up from plowed fields during cultivation and sold for collections and to the dental trade.¹ It was reported to be well crystallized, in comparatively large crystals, and very pure. Kunz² reports double geniculated twins of rutile forming complete circles found near Parkesburg, some of which weighed more than a pound. The State has produced only a few pounds of rutile since 1901.

¹ Hess, F. L., U. S. Geol. Survey Mineral Resources, 1906, p. 530, 1907; idem, 1908, pt. 1, p. 744, 1909.

² Kunz, G. F., *Gems and precious stones*, p. 193, New York, 1890.

Prof. Florence Bascom,¹ who has completed the geologic mapping of Chester County, has kindly furnished the following statement:

The formations in which the rutile occurs are highly metamorphosed sediments. The chief deposits of the mineral in Chester County, and these can hardly

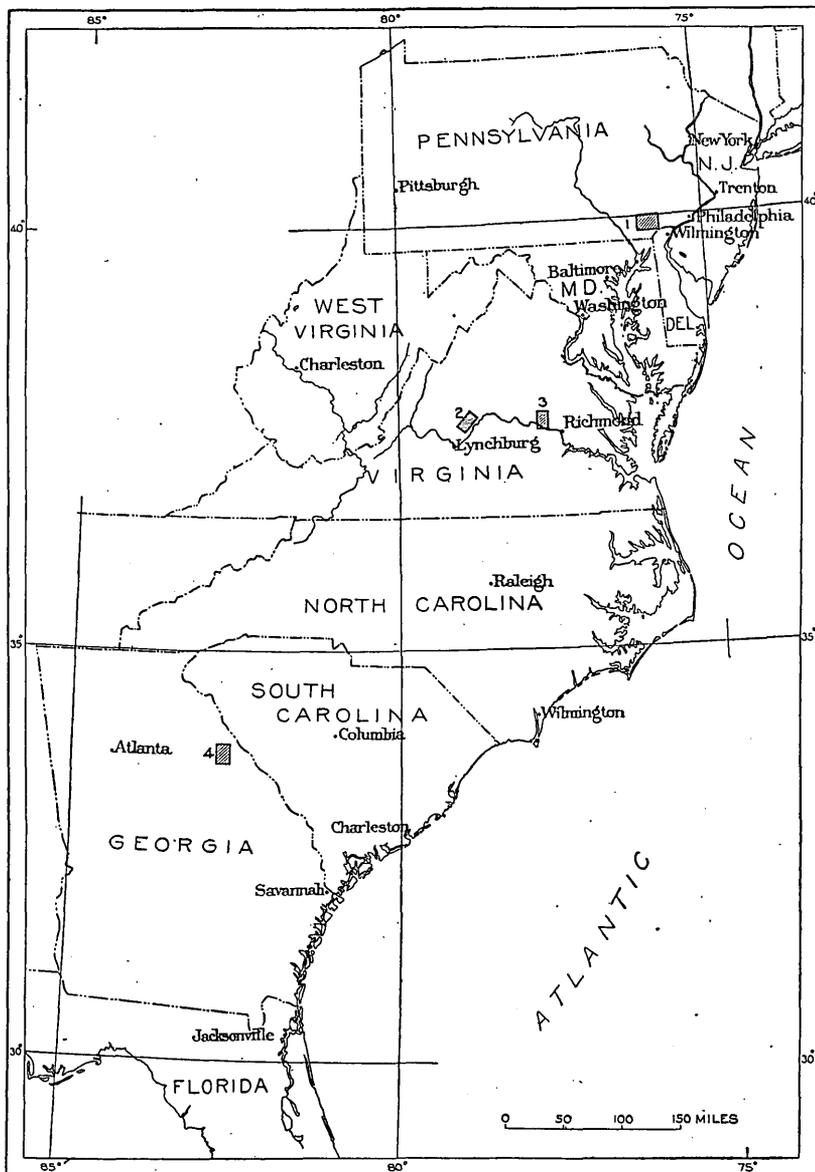


FIGURE 93.—Outline map showing principal localities where rutile is found in the eastern United States.

be of commercial importance, are as follows: (a) It is weathered out from the Cambrian (Chickies) quartzite on slopes of the North Valley Hills in the

¹ Personal communication.

neighborhood of Parkesburg and in railway cuts northeast of Pomeroy and west of Atglen. (b) Along the Valley road southeast of Coatesville it is weathered out from Cambrian and Ordovician (Shenandoah) limestone. Chester Valley and hills are parts of an overturned syncline of Paleozoic (Cambrian and Ordovician) sediments.¹ (c) Rutile occurs in Cambrian and Ordovician limestone in the Doe Run region, south of Coatesville and Chester Valley. This limestone lies on a folded thrust plane with pre-Cambrian gneiss above and below it. (d) It is found in similar limestone at the county poorhouse quarry in West Bradford, south of Chester Valley; also in East Bradford.

SOUTHEASTERN ATLANTIC STATES.

Rutile is found in most of the southeastern Atlantic States, but prior to the opening of the deposits in Nelson County, Va., in 1900, it was not known that the mineral occurred at any place within these States in sufficient quantity to be of commercial value, although rutile of gem grade had been found at a number of localities. Before 1900 the most noted rutile locality in the South was Graves Mountain, Ga., the production from which has been confined to cabinet specimens and a small quantity for the gem trade.

THE CAROLINAS.

Prior to 1906 a small production of rutile was reported from the Carolinas as a by-product obtained in washing sands for monazite, principally at Ellenboro, Rutherford County, N. C., and near Gaffney, Cherokee County, S. C. The workable deposits of monazite, containing some rutile in places, are confined largely to stream sands and gravels derived by weathering from granites, gneisses, and schists of the Carolina gneiss, which is mapped by the United States Geological Survey as Archean.

Rutile in various mineral associations has been reported from more than 20 counties in North Carolina, but so far as known it does not occur anywhere in large quantity. Many of the North Carolina localities, however, have furnished rutile of gem grade, and the State has probably yielded more rutilated quartz of unexcelled beauty for gems than all the other American localities combined.

Rutile occurs in South Carolina principally in the form of loose grains and crystals in the monazite sands near Gaffney, Cherokee County. Rutilated quartz is reported from the monazite belt and rutile crystals are found in the vicinity of Prosperity, Newberry County. Crystals which show some wear are found in Kershaw County.

¹ See, on region to the east, U. S. Geol. Survey Geol. Atlas, Philadelphia folio (No. 162), 1909.

GEORGIA.¹

Graves Mountain lies in the extreme western part of Lincoln County, Ga., within less than a mile of the Wilkes County boundary, 10 miles nearly east of Washington, the county seat of Wilkes County, and about 40 miles northwest of Augusta. (See 4, fig. 93, and fig. 94.) It is within the Piedmont Plateau province, near the eastern border, a short distance north of the fall line.

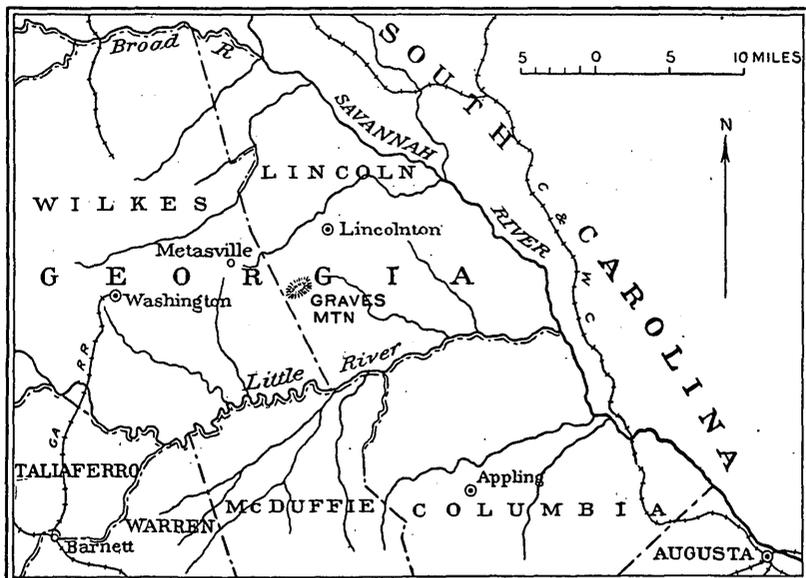


FIGURE 94.—Map showing location of Graves Mountain, Ga.

Graves Mountain, a conspicuous ridge (monadnock) of partly reduced hard rock, has an elevation of several hundred feet above the surrounding Piedmont Plain, is 2 miles in length along an approximate northeast line, and is less than half a mile wide. It is less steep on the northwest side, which corresponds with the direction of dip, and its upper portion is greatly roughened from weathering.

The rock composing the ridge is a fine-grained quartzite, which is in part schistose, rather thinly foliated, and in part essentially massive in structure. The hill also contains a kyanite-hematite rock. Igneous rocks have not been observed at Graves Mountain, but they occur at several localities in the vicinity. In the basal portion of the ridge and for some distance up the northwest slope the quartzite is crushed to a schist, containing considerable sericite and accessory

¹ Watson, T. L., and Watson, J. W., A contribution to the geology and mineralogy of Graves Mountain, Ga.: Virginia Univ. Philos. Soc. Bull., Sci. Sec., vol. 1, No. 7, pp. 201-221, 1912.

kyanite, small grains of rutile, and black oxide of iron. A partial chemical analysis of the rock gave SiO_2 , 79.18 per cent; Al_2O_3 , 14.14 per cent; Fe_2O_3 , 3.17 per cent. Microscopic study shows that rutile occurs in grains and crystals formed along the boundaries of the quartz grains and as inclusions in the quartz and kyanite.

On the crest of the ridge and for an undetermined distance down the slopes the rock is a fine-grained quartzite, which has essentially the same composition as the quartzite schist. It is composed largely of fine sugary quartz but contains some muscovite and in places abundant kyanite that is pale green when fresh, crystals of blue lazulite, and small grains of red rutile. Pyrophyllite is rather common. Kyanite, lazulite, and rutile are as a rule intimately associated. The kyanite and lazulite are commonly embedded one in the other, and the rutile occurs as separate grains and as inclusions in the other minerals. A partial chemical analysis of the massive quartzite gave SiO_2 , 69.74 per cent; Al_2O_3 , 24.86 per cent; Fe_2O_3 , 0.53 per cent.

On top of the ridge the quartzite is cut by quartz veins, some of the larger of which measure several feet in width. These are apparently barren, but smaller quartz veins only a few inches wide carry rutile and iron oxide.

The rutile of Graves Mountain was first described and worked by Prof. C. U. Shepard,¹ who obtained it from the central depression on top of the ridge and along the northwest slope. The openings are old and at the time of the writer's visit in 1911 were largely obscured from caving. No coarse rutile was observed, but the mineral was noted in every specimen collected, chiefly as microscopic inclusions in other minerals and as small crystals and grains visible to the naked eye.

Coarse rutile crystals from this locality found in many mineral collections in this country are lustrous black to reddish brown and red, with brilliant orange-red in thin sections. They vary in size, some being as much as 5 inches in length, and occur both as single and twin forms. Kunz reports that fine single crystals weighing 4 pounds have been found. The single crystals are usually of prismatic habit and commonly show pyramidal terminations. Careful examination of the dumps at the openings and on the northwest slope of the ridge from which the mineral was mined, and inspection of thin rock slices, which showed rutile in microscopic particles, clearly indicate that the large rutile crystals must have come from a heavy dark-colored rock, composed of an aggregate of long-bladed and coarsely columnar crystals of kyanite, massive granular hematite, and quartz. In many places the rock carries hematite in excess of kyanite; elsewhere kyanite may predominate.

¹ Am. Jour. Sci., 2d ser., vol. 27, p. 36, 1859; idem, vol. 28, p. 141, 1859.

ALABAMA.

Very little is known of the occurrence of rutile in Alabama. It has been noted at several localities in the crystalline area, but in none is it of commercial importance. In 1874 the Alabama Geological Survey observed its occurrence in mica schist in close proximity to a pegmatite dike in Chilton County. Occurrences in pegmatite bodies cutting mica schist have been noted in Coosa and Randolph counties.¹

VIRGINIA.²

Thus far commercial deposits of rutile in the United States are limited to Virginia, from which the entire domestic production has been derived since 1902. The mineral is found in considerable quantity and of excellent quality in two rather widely separated localities in the crystalline region of the State. These are the area in Amherst and Nelson counties (2, fig. 93), located near the northwest edge of the Piedmont Plateau, and the area in Goochland and Hanover counties (3, fig. 93), lying near the central-eastern margin of the same province. (See fig. 95.) The geology and mode of occurrence of rutile in the two areas show striking differences, as is indicated in the descriptions below. Thus far the production has been derived entirely from Nelson County.

AMHERST AND NELSON COUNTIES.

LOCATION AND TOPOGRAPHY.

The principal rutile-area lies in the west-central part of Virginia and occupies the south-central and southwestern parts of Nelson County and the contiguous northeastern part of Amherst County. Much the larger part of the area and probably all that will prove of economic value lies in Nelson County, and all the developments thus far made are included in this county. The area lies along the northwestern margin of the Piedmont Plateau, in the foothills of the Blue Ridge and near the base of the main ridge, 5 to 7 miles from the main line of the Southern Railway. Arrington and Tye River are the two nearest railway stations.

As mapped by the Virginia Geological Survey, the belt of rutile-bearing rocks extends in a general northeasterly direction for about

¹ Personal communication from Dr. Eugene A. Smith, State geologist.

² Abstracted from Watson, T. L., and Taber, Stephen, *Geology of the titanium and apatite deposits of Virginia*: Virginia Geol. Survey Bull. 3-A, 308 pp., 1913. See also U. S. Geol. Survey Bull. 430, pp. 200-213, 1910.

16 miles and has a maximum width not exceeding $2\frac{1}{2}$ miles. (See fig. 96.) It forms an area of comparatively low relief, with an average elevation of about 800 feet. Elevations of 1,400 to 2,000 feet are reached immediately on the west, north, and northeast sides

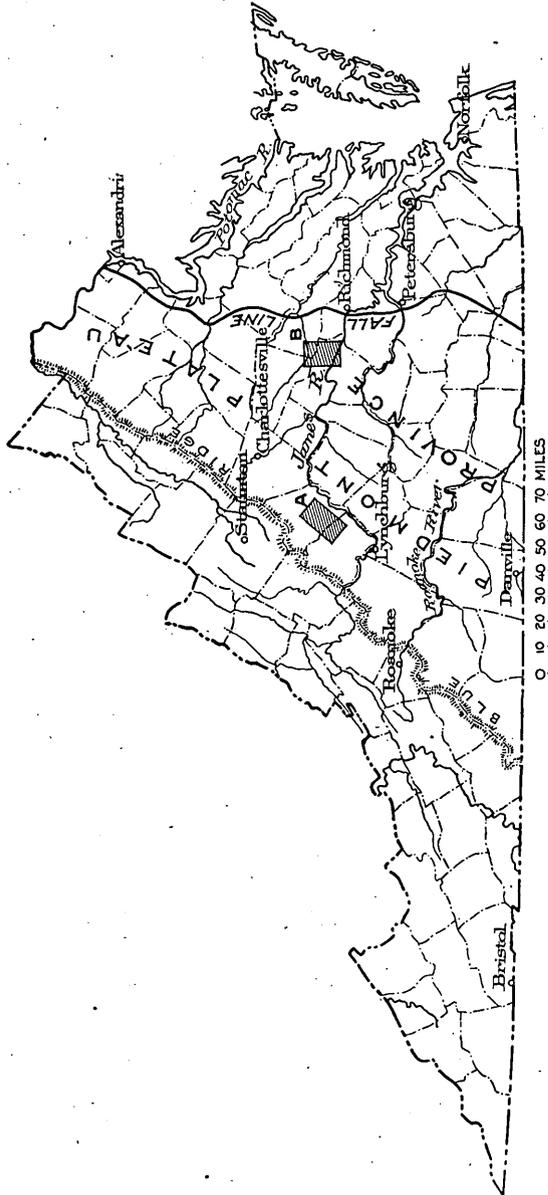


FIGURE 95.—Outline map of Virginia showing rutille districts. A, District in Amherst and Nelson counties; B, district in Goochland and Hanover counties.

of the belt. The streams of this area drain toward the southeast into James River through Tye, Piney, and Buffalo rivers and their tributaries. The map (fig. 96) gives a general idea of the topography of the area.

GEOLOGY.

The rocks of the Amherst-Nelson rutile area are igneous in origin and show in their mineral and chemical composition derivation from

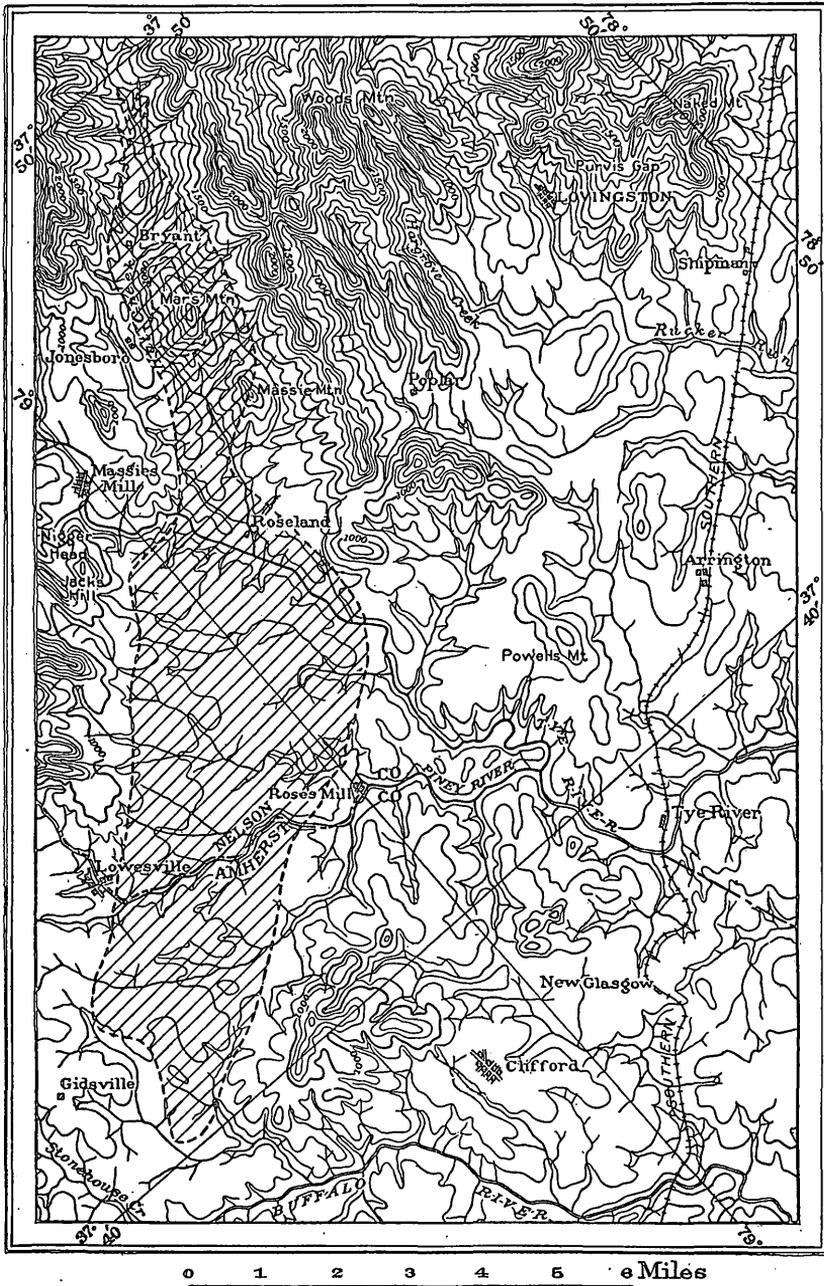


FIGURE 96.—Topographic map of the rutile area in Amherst and Nelson counties, Va. Ruling indicates area of rutile-bearing formation. Contour interval 100 feet.

a common parent magma. They are characterized by prominence of apatite and the titanium minerals ilmenite, rutile, and in a few

places "titaniferous" magnetite; opalescent-blue quartz; pyroxene (hypersthene) or secondary hornblende derived from pyroxene as the dominant ferromagnesian mineral; and in most of the feldspar-bearing types by andesine, usually intergrown with orthoclase (microcline), as the dominant feldspar variety.

As a rule the rocks are considerably weathered and are covered to a variable depth by a mantle of their residual decayed product, which grades downward into the fresh hard rocks. They are mostly of even-grained texture, though in places porphyritic, and range from coarse grained in portions of the syenite to very fine grained in some of the nelsonite and diabase. They have been intensely but unequally metamorphosed, and in most of them complete or partial schistose structure has been developed. The effects of metamorphism are likewise shown in thin sections of the rocks under the microscope. The formation of secondary minerals from the original ones involved the production of hornblende from pyroxene, leucoxene from ilmenite and rutile, osteolite from apatite, and sericite from feldspar. Other alteration products noted in thin sections in some of the rocks are biotite, chlorite, epidote, and zoisite.

ROCK TYPES.

The principal rock types that have been mapped by the Virginia Geological Survey include (1) biotite-quartz monzonite gneiss with variant schists, (2) syenite, referred to as pegmatite in all publications previous to Bulletin 3-A of the Virginia Geological Survey, (3) gabbro, (4) nelsonite, and (5) diabase. Intermediate gradations are observed between most of these types, and usually the dominant minerals in one type form the subordinate or accessory minerals in the others. Of the five rock types enumerated, syenite and nelsonite are of most importance, as they are the rutile-bearing rocks.

Biotite-quartz monzonite gneiss.—The gneiss with accompanying schists forms the country rock of the deposits and has wide general distribution beyond the limits of the rutile area. It is a foliated gneiss which exhibits considerable textural and mineral variations, but the predominant phase is a medium dark-gray rock varying in texture from fine to medium coarse and from even grained to porphyritic. The principal minerals are the usual ones in this type of rock. A notable feature in its composition is the large content of plagioclase feldspar, and the two analyses made show that the rock is sodipotassic in composition. The chemical composition of the rock is given in the table of analyses on page 399. The gneiss is intruded in places by dikes of acidic (granite and pegmatite) and basic (diabase) rocks, and in places it contains segregations of diverse size and outline composed chiefly of biotite.

Syenite (andesine anorthosite).—Syenite is the most widespread and with reference to the occurrence of rutile the most important

rock type in the rutile district. It occupies a narrow belt having a general northeasterly extension, the greatest breadth of which does not exceed $2\frac{1}{2}$ miles and which covers an area of about 20 square miles. It is, as a rule, coarsely crystalline in texture and in places gneissoid or even schistose in structure. Along its southeast border, at the American Rutile Co.'s quarries, the rock exhibits abnormally coarse texture, and individual masses of hornblende, quartz, and feldspar measure several inches across.

The rock is composed chiefly of feldspar and blue quartz but contains also, in places near the margin, pyroxene (hypersthene, usually altered to hornblende), rutile, and lesser amounts of ilmenite and apatite. The ratio of these minerals varies greatly in different parts of the rock mass, but feldspar is the dominant mineral, except in portions of the border zone. Two facies of the rock mass which apparently grade into each other are recognized—a feldspathic variety, which includes the central and larger part of the rock mass, and for which the name piedmontose has been suggested; and a hornblendic variety, which is developed chiefly as a border zone and corresponds to tonalose. The central portion of the mass consists almost exclusively of feldspar, with only scattered grains of blue quartz and scarcely any visible rutile or other minerals. Rutile and in smaller quantity ilmenite are developed more abundantly along the southeast border of the mass, their occurrence being strikingly shown in the quarries of the American Rutile Co. on Tye River near Roseland. The general character and mode of occurrence of the rutile in this rock are described on pages 400-401.

The principal feldspar in the rock is a calcic soda variety (andesine) corresponding to about $Ab_{65}An_{35}$ and containing intergrowths of microcline oriented parallel to the twin lamellæ. In the feldspathic facies of the rock normative orthoclase (microcline) ranges from 16.68 to 23.35 per cent. Opalescent-blue quartz and hypersthene or its alteration product, hornblende, are the next most abundant silicate minerals.

Gabbro.—The principal exposures of gabbro occur near the contact with the outside gneiss, some of them forming irregular areas between the gneiss and syenite. On the American Rutile Co.'s property at Roseland the gabbro grades into the syenite. Gabbro also occurs as dikelike masses, cutting the syenite with sharp contacts in the Roseland district, and as dikes cutting gneiss in the Lovingson district.

The gabbros are light to dark gray rocks, generally of fairly even-grained texture, though in places porphyritic, and slightly to strongly schistose in structure, the latter phase yielding a uralitized gabbro gneiss. The principal minerals are feldspar (andesine) and pyroxene (hypersthene), partly or completely altered to hornblende. Subordinate ilmenite, rutile, and apatite occur, and pyrrhotite and graphite are generally present, the graphite occurring in considerable quan-

tity in some localities. By increase of the ore minerals and decrease of the silicate minerals the gabbro passes through gabbro-nelsonite into nelsonite. The chemical composition of the gabbro is shown in the table of analyses on page 399.

Nelsonite.¹—Nelsonite is the name given to a group of titanium and phosphorus bearing rocks of igneous origin, occurring in dike-like bodies of varying size and irregular shape in the rutile area of Amherst and Nelson counties and to a less extent farther southwest in Roanoke County, Va. The nelsonite bodies usually occur along the border portion of the syenite mass, and most of them are confined to the syenite area, but some are in the outside gneiss.

Nelsonites are holocrystalline, even-grained, dark rocks composed chiefly of apatite with ilmenite or rutile, or both, and in some places magnetite. Here and there it has a porphyritic texture, with apatite forming the phenocrysts. Subordinate silicate minerals may or may not occur, and pyrite (perhaps secondary) is an almost constant minor constituent. Variation in mineral composition gives rise to the varietal forms ilmenite nelsonite, rutile nelsonite, magnetite nelsonite, biotite nelsonite, hornblende nelsonite, and gabbro-nelsonite. Of these only the variety rutile nelsonite is of importance in the present discussion.

The rutile nelsonites show all gradations in the ratio of rutile and ilmenite, from those bodies composed of dominant rutile and apatite with little or no ilmenite to those composed of apatite and ilmenite with or without rutile. Gradations both vertically and laterally between these two extremes may be noted in the same body. Two analyses of rutile nelsonite are given in the table on page 399.

The bodies of rutile nelsonite are less widely distributed than the normal ilmenite nelsonite, being limited to the syenite area. They are found at several places southwest of Rose Union, on the Warwick tract, on the Bourne farm, and on the Giles tract half a mile northwest of Roseland. Each of these deposits has been prospected to a minor though unequal extent. The development work on the Giles tract has not been sufficient to reveal the size of the ore bodies, but that done on the Warwick farm by the General Electric Co. resulted in opening two dikes to a depth of 100 feet and for a distance of nearly 200 feet on the strike, while one of them was proved at the surface by pits and trenches for a distance of about 500 yards.

Though the nelsonite bodies are dikelike in general form the writer believes that they represent segregations in the igneous rocks inclosing them, being somewhat similar in mode of genesis to the well-known titaniferous magnetite ore bodies in gabbros and anorthosites.

¹ Watson, T. L., Mineral resources of Virginia, pp. 300-302, 1907; Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3-A, pp. 100-155, 1913.

Gabbro-nelsonites.—The type of rock termed gabbro-nelsonite, like nelsonite proper, is a new one. It occurs in dikes and is intermediate in mineral composition between normal gabbro and nelsonite. It is much less widespread in occurrence than either gabbro or nelsonite but has been especially noted along the eastern border of the syenite. It consists of silicate (hypersthene and secondary hornblende with variant feldspar) and nonsilicate (apatite, ilmenite, and magnetite) minerals in unequal amounts, the silicates predominating. In texture the rock is usually porphyritic, though here and there it is even grained. An analysis is given below. The name *roselandose* has been proposed for the rock.

Diabase.—The rocks grouped under the term diabase occur as dikes and range texturally from typical diabase to basalt. They are the youngest of the intruded rocks, as they may be found cutting all others in the area. The dikes vary in width from a fraction of an inch to more than 25 feet. They are confined chiefly to the rutile-bearing rocks of the syenite area but in places penetrate the surrounding gneiss. They present no unusual features in mineral composition. A chemical analysis of the typical specimen is given below.

CHEMICAL ANALYSES.

The composition of the various rock types briefly described above is shown in the following table:

Analyses of rocks from rutile area of Amherst and Nelson counties, Va.

[William M. Thornton, jr., analyst.]

	1	2	3	4	5	6	7	8	9
SiO ₂	64.93	60.44	57.06	53.65	50.95	33.83	0.95	0.70	0.67
Al ₂ O ₃	15.44	23.62	14.54	15.51	13.53	5.19			
Fe ₂ O ₃	1.94	.29	1.49	1.86	3.59	11.38	3.65	11.12	2.87
FeO.....	3.50	.19	4.52	8.33	9.67	15.08	7.95	27.93	5.04
MgO.....	1.22	.21	4.10	4.27	5.19	8.57	.25	.72	.15
CaO.....	3.43	5.59	4.37	6.26	8.99	8.22	11.13	8.34	12.16
Na ₂ O.....	3.08	4.94	3.13	3.06	2.53	1.28			
K ₂ O.....	4.02	3.37	1.96	1.80	1.41	.50			
H ₂ O.....	.06	.08	.09	.11	.26	.45	.21	.15	.09
H ₂ O+.....	.78	.32	1.32	1.02	1.43	.75	.35	.58	.11
TiO ₂	1.08	1.11	7.10	3.62	2.63	10.00	65.90	42.84	69.67
P ₂ O ₅.....	.42	.15	.24	.75	.54	4.84	8.14	6.89	9.41
MnO.....	.06	Trace.	.04	.06	.09	.26	.26	.18	
CO ₂	Trace.	Trace.	.09	Trace.	Trace.	Trace.	Trace.	Trace.	
S.....	Trace.	Trace.	Trace.	Trace.	.09	.25	1.61		.34
Cl.....						.04	None.	.01	Trace.
F.....						.55	.34	.21	.70
Less O.....	99.96	100.31	100.05	100.30	100.90	101.39 .30	100.74 .54	99.67 .09	101.21 .39
						101.09	100.20	99.58	100.82

1. Average of two analyses of biotite-quartz monzonite gneiss.
2. Average of four analyses of feldspathic facies of syenite.
3. Average of three analyses of hornblende facies of syenite.
4. Average of four analyses of gabbro.
5. Average of four analyses of diabase.
6. Analysis of gabbro-nelsonite.
7. Analysis of rutile nelsonite, Giles tract, near Roseland.
8. Analysis of ilmenite nelsonite, Shelton farm, 1 mile northwest of Roseland.
9. Analysis of rutile nelsonite, General Electric Co.'s mine, near Roses Mill.

WORKABLE DEPOSITS.

The general character and mode of occurrence of rutile in the Amherst and Nelson area have been fully described in previous publications,¹ especially in the State Survey report, to which the reader is referred. Two distinct types of rutile occur in the area and each has been mined. They are (1) syenite (formerly called pegmatite) rutile, in which the rutile occurs chiefly as disseminated grains of various sizes and as segregations in the form of wavy lines representing masses which have been modified by dynamic metamorphism in the coarse-grained syenite; and (2) nelsonite rutile, in which the rutile occurs as a constituent of a variety of the rock nelsonite having a dikelike character and composed normally of apatite and ilmenite.

In the first type rutile occurs as an original constituent irregularly distributed through the syenite, chiefly within the southeastern portion of the rock mass. The mineral ranges from sparsely disseminated grains to segregations, which locally may make up 30 per cent or more of the rock mass, with a probable average of 4 or 5 per cent for the quarries of the American Rutile Co. near Roseland.

The quarries of the American Rutile Co. are opened in both the feldspathic and the hornblendic facies of the syenite, each of which is quarried and milled for rutile. Ilmenite is associated with rutile in each facies of the rock but apparently is in larger amount in the hornblendic facies, and this is confirmed by the milling operations, which usually show for the same amount of material milled a much larger percentage of ilmenite in the hornblendic facies of the rock, locally known as black rock, than in the feldspathic facies or white rock. The ratio is variable, but in the hornblendic rock ilmenite may equal or even exceed the rutile. Locally apatite is associated with the rutile, especially in the larger segregations of rutile.

Analyses of rutile from Nelson County, Va

[William M. Thornton, jr., analyst.]

	Syenite rutile.	Nelsonite rutile.
TiO ₂	95.71	98.80
FeO.....	2.35	1.68
SiO ₂.....	.92	.26
Cr ₂ O ₃.....	.02	.07
V ₂ O ₅.....	.15	.20
Specific gravity.....	99.15 4.196	101.01 4.21

Nelsonite rutile is limited in occurrence to the rutile variety of the rock nelsonite, the normal type of which is composed of ilmenite and

¹ Watson, T. L., and Taber, Stephen, U. S. Geol. Survey Bull. 430, pp. 200-213, 1910; Virginia Geol. Survey Bull. 3-A, pp. 193-197, 1913.

apatite. The ratio of rutile and ilmenite in the rutile-bearing bodies varies, as is clearly shown in the percentages of the three principal minerals calculated from analyses of ilmenite-bearing rutile nelsonite and rutile-bearing ilmenite nelsonite:

	Rutile.	Ilmenite.	Apatite.
Rutile nelsonite.....	64.56	9.73	22.18
Ilmenite nelsonite.....	5.76	60.65	29.57

The nelsonite rutile occurs in anhedral grains not exceeding, as a rule, 3 millimeters in size, although segregations of coarse rutile which grade into nelsonite are observed. The nelsonite rutile is uniformly darker in color than the syenite rutile.

The rutile mined in the Nelson County area at present is exclusively the syenite type quarried and milled by the American Rutile Co. at Roseland. Since the completion by this company of its concentrating mill at Roseland in 1902, a large total production of rutile has been made, which not only supplies the markets of this country but much of the European demand. Nelsonite rutile was formerly mined by the General Electric Co. on the Warwick tract near Roses Mill, but operations were discontinued in 1909, when, it is said, 100 tons of material containing 50 per cent TiO₂ was shipped to a Pennsylvania company for concentrating.

The production, price, and uses of rutile in Virginia, the only producing State in the United States, have been fully discussed in previous publications of the Federal and State surveys,¹ to which the reader is referred.

GOOCHLAND AND HANOVER COUNTIES.²

LOCATION AND TOPOGRAPHY.

The discovery of a second area of commercial deposits of rutile in Virginia was announced in 1910. The deposits are located near the central-eastern margin of the Piedmont province, in the northwest corner of Goochland County and the adjacent extreme southwestern part of Hanover County, 17 to 25 miles northwest of Richmond. (See fig. 95.) They lie near Peers, Waldelock, and Gouldin, between the main line of the Chesapeake & Ohio Railway on the north and the James River division of the same railway on the south, and may be reached from Beaver Dam station on the main line or from Maiden and Sabot on the James River division.

¹ U. S. Geol. Survey Mineral Resources; Bull. 430, pp. 200-213, 1910; Virginia Geol. Survey Bull. 3-A, 308 pp., 1913.

² Hess, F. L., New rutile deposits near Richmond, Va.: Min. World, vol. 33, pp. 305-307, 1910.

Watson, T. L., and Taber, Stephen, Geology of the titanium and apatite deposits of Virginia: Virginia Geol. Survey Bull. 3-A, pp. 248-261, 1913.

Topographically (see fig. 97) the area forms a part of the moderately dissected eastern margin of the Piedmont province without marked elevations above the general area, which averages about 300 feet above sea level and is drained by South Anna and James rivers and their tributaries.

GEOLOGY.

The area is composed of crystalline metamorphic rocks in an advanced stage of decay. The moderately fresh rocks are covered by a mantle of decayed rock varying in thickness, and exposures of hard rock are rare except along stream courses. The country rock of the region comprises a granitic gneiss of variable composition, cut in many places by pegmatite dikes, and basic igneous rocks, including diorite, diabase, and pyroxenite. The gneiss contains much biotite and hornblende and the usual large amounts of feldspar and quartz, the proportion of which varies considerably. It is penetrated by numerous pegmatite dikes, which usually lie in the foliation planes and some of which are rutile-bearing.

The pegmatites range from several inches to 4 feet or more in width, are of granitic composition, and, like the inclosing rock (gneiss), have been mashed and are more or less highly schistose. They are very feldspathic and contain both potash and soda-lime feldspars, some quartz, and less mica (muscovite and biotite), and some of them contain rutile and ilmenite. Like the gneiss, the pegmatites are decomposed for a considerable depth below the surface. Rutile is an original constituent of the pegmatites and occurs in grains and masses that reach many pounds in weight.

WORKABLE DEPOSITS.

The rutile occurring in the several areas in Goochland and Hanover counties is of excellent grade and somewhat resembles in physical character that occurring in the syenite of Nelson County, but much of it is redder and brighter. It ranges in size from small grains to large masses. Hess mentions one mass found on the Nuckols farm that weighed 200 or 300 pounds.

The rutile is associated with some ilmenite, and a little apatite has been observed. Rutile occurs (1) as loose grains and masses on the surface and in the soil derived from the pegmatites through their disintegration and (2) as a constituent of the pegmatite dikes.

The several rutile areas have been prospected to a slight extent by pits and shafts, the deepest of which (not exceeding 75 feet) have hardly penetrated below the zone of rock decay. Prospecting has been confined chiefly to the Bowe farm, near Gouldin, in Hanover

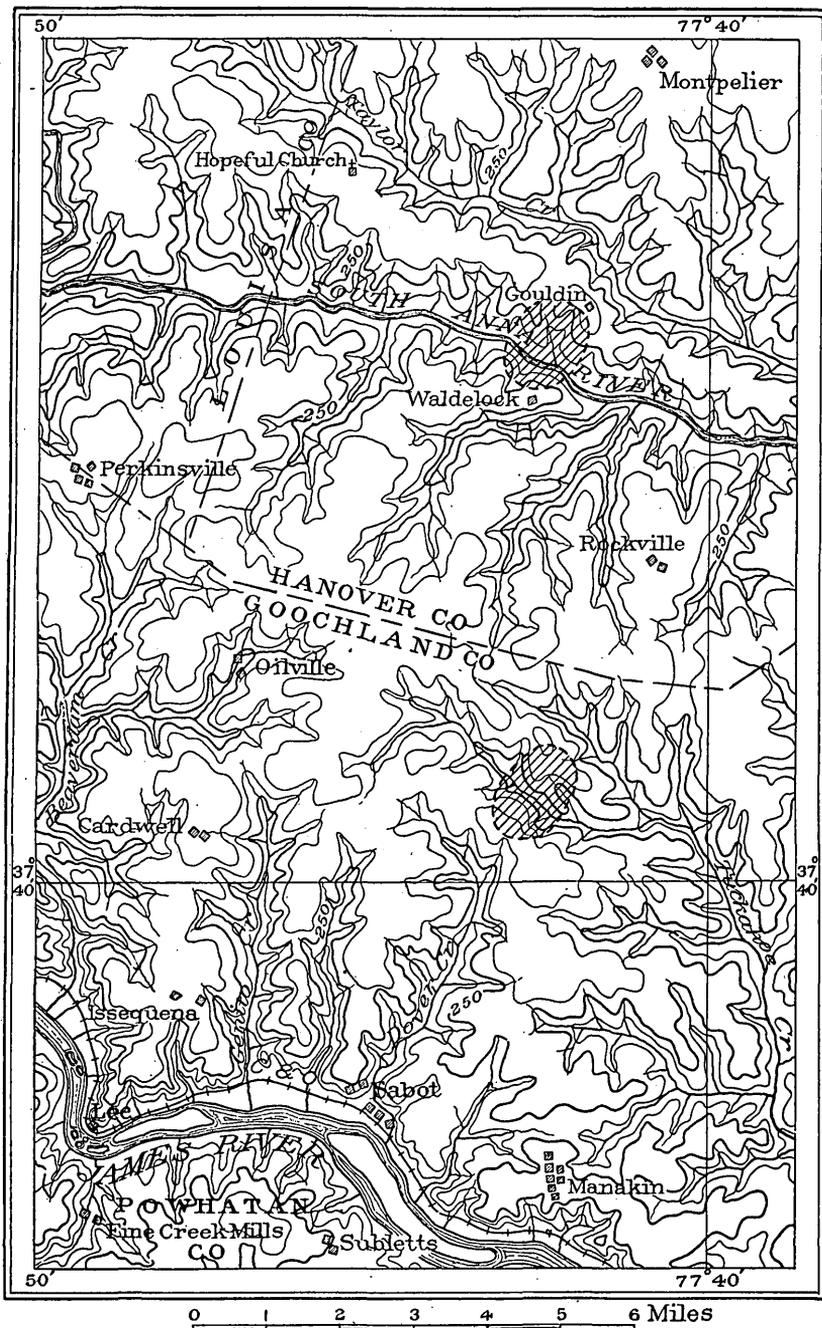


FIGURE 97.—Topographic map of the rutile areas in Goochland and Hanover counties, Va. Ruling indicates areas of rutile-bearing rocks. Contour interval 50 feet.

County, and the Nuckols farm, near Peers, in Goochland County. Irregularity in both quantity and distribution of the rutile in the pegmatite bodies is indicated by the results obtained. Large quantities of the mineral, ranging from fine sand to masses weighing many pounds, are found loose on the surface and in the soil over areas aggregating many acres, which could be worked at a relatively small cost.

SOME FOREIGN DEPOSITS OF RUTILE.

Rutile has been produced in recent years in Quebec, Canada; South Australia; and Kragero, Norway. The geology of these areas, so far as the writer has information, is separately discussed below.

ST. URBAIN, QUEBEC.

The principal known occurrence of rutile in Canada and the only one that has been productive is about 2 miles west of the village of St. Urbain, which is about 10 miles north of Bay St. Paul, on River Gouffre, and about 60 miles east of Quebec. It was first noted by T. Sterry Hunt, who briefly described it in 1863, but for the details of the geology of the rutile deposits at this locality we are indebted to the recent investigations of Charles H. Warren.¹

The ilmenite-rutile deposits near St. Urbain, like many other occurrences of ilmenite, are contained in anorthosite, the feldspars of which are chiefly andesine. The rock is poor in femic minerals and locally shows some crushing.

The larger ilmenite bodies exhibit as a rule the form of elongated masses, some of which have dikelike outlines that conform in direction to an indistinct gneissoid structure in the anorthosite. The contacts between the ore bodies and the inclosing anorthosite are usually sharp, although gradation occurs in places. A narrow band of dark-brown mica is developed locally along the contacts.

Most of the ilmenite bodies are free from rutile, but rounded grains of feldspar (andesine), biotite, and spinel are noted as accessories in the rutile-free bodies. Quantitative estimates of the accessory minerals contained in one of the principal bodies show a general average of 5 to 6 per cent, with considerable portions containing not more than 2.5 per cent. The ilmenite may be massive, but it usually occurs in grains which range in size from 3 to 12 millimeters in cross section, with a probable average of 6 or 7 millimeters. Warren's study of polished surfaces shows that the individual grains of ilmenite are not homogeneous in composition, although identical in

¹ Warren, C. H., The ilmenite rocks near St. Urbain, Quebec; a new occurrence of rutile and sapphirine: *Am. Jour. Sci.*, 4th ser., vol. 33, pp. 263-277, 1912.

character, but are made up of very fine lamellar intergrowths of two kinds of material, and he states that the facts point to the conclusion that the material intergrown with ilmenite is hematite.

A second and, so far as the present discussion is concerned, the most interesting as well as the commercially most important type of ilmenite body is a rutile and sapphirine bearing ilmenite which has been exposed for a length of about 300 feet, a width of 50 feet, and a maximum depth of 15 feet. Warren describes the deposit as follows:

Its contacts with the anorthosite, where exposed, have a roughly east and west trend and are nearly vertical. In the ore are several streaks of anorthosite which have also a nearly vertical extension and a more or less marked schistosity following much the same direction. There is also in the ore in places a feebly marked banding with the same trend. Farther west and southwest of this deposit several small dikelike masses of ilmenite are exposed with the same orientation, but these carry no rutile, etc.

The mineralogical character of the greater part of the ilmenite rock in this mass is essentially the same as that previously described. The grain, however, appears on the average to be a little finer. A portion of the deposit differs from the rest and from other known bodies of ilmenite associated with anorthosite rocks in containing a notable percentage of rutile and a smaller amount of the rare mineral sapphirine.

The rutile-bearing portion was first observed as a streak 2 feet wide, with a nearly vertical dip and an indistinctly marked banding parallel to the walls, which ran east and west. The passage of this streak into the rutile-free ilmenite on both sides was very sudden. Toward the west the rutile-bearing portion widened and was somewhat less sharply defined, and there is evidence which points to the occurrence of rutile-bearing bands and patches. It appears, however, to always change quite sharply into the rutile-free rock. It was traced for several hundred feet.

Cutting the ore body in the rutile-bearing portion is a streak of anorthosite rock which itself carries more or less rutile. The rutile makes up from 2 to 3 per cent of this rock, as nearly as it was possible to estimate it. It is associated with ilmenite and a considerable amount of biotite. These minerals are arranged along distinct lines of schistosity. No sapphirine has been noted in this rock.

The rutile-bearing rock is of a brownish-black color and consists of a rather finely granular ilmenite thickly sprinkled with grains of an orange-red rutile, a smaller amount of feldspar, biotite, sapphirine, or their decomposition products, and spinel. The sapphirine can not be distinguished without the aid of a good lens, and then only upon very close inspection, about the feldspar and ilmenite grains in the form of very dark greenish-black grains. The less altered ore is firm, but weathered portions are somewhat friable. All of the material collected shows more or less limonite along cracks and joints. In a limited portion of the rutile-bearing rock fairly numerous plagioclase grains or groups of grains, often larger than the average in size, are present. These feldspars sometimes reach a length of 2 or 3 centimeters and 1 centimeter in width and are characteristically associated with a strong development of biotite plates.

Microscopic thin sections of the rutile-bearing rock disclose a highly xenomorphic texture for all of the constituent minerals with the one exception of the spinel inclusions in some of the feldspar grains. The ilmenite forms an almost continuous background in which the other minerals lie. Its grains,

although irregular in outline, are roughly equidimensional and are fairly uniform in size, their average cross section being about 3 millimeters. They consist of the same lamellar intergrowths as previously described, but the two sets of lamellæ are narrower than in the former case, conforming to the smaller average size of the grains. The rutile is in the form of simple crystal grains or clusters of such and is of a beautiful orange or golden-brown color with a barely perceptible pleochroism. The cleavages are prominently developed. Twinning is rare. Individual grains attain a diameter of 3.5 millimeters. From this size they run down to mere specks, the average being in the neighborhood of 0.6 millimeter. It is distributed quite uniformly through the ilmenite and occurs also with the other minerals, being sometimes inclosed in their grains. The spinel is rather sparingly present and forms grains comparable in size to those of the rutile. In the feldspar-rich portions of the rutile-bearing rock it also occurs included in the feldspars in the form of exceedingly minute crystals. These inclusions deserve a brief description. Many of the feldspars are crowded with them. They are of a pale dull-green color and as a rule are definitely oriented with reference to the inclosing crystal. Just what the orientation is has not been made out. Many of the spinels have a highly perfect octahedral habit, the whole crystal coming into view with slight changes of focus. Other crystals show the characteristic cross sections of distorted octahedrons or form flat triangular plates. These attain a diameter of 0.015 millimeter, though usually smaller. Again, the spinels have the habit of relatively greatly elongated rods or somewhat flattened blades arranged in lines across the feldspars. The inclusions are isotropic, although, being wholly inclosed in the feldspar, which often exhibits a slight disturbance in its optical properties about the inclusions, they often seem to be slightly doubly refracting themselves. Minute inclusions of sapphirine have also been noted occasionally associated with the spinels, but these have a different color and are irregular in outline.

The feldspars are an andesine-like that of the anorthosite. They are as a rule quite evenly distributed and of fairly uniform size comparable with the ilmenite, but occasionally, as noted, they become more numerous and of larger size and form groups of grains. Many of them show evidences of strains and slight bending. In even the fresher material collected the feldspar is usually partly replaced by secondary products, particularly where biotite and sapphirine were present with it, and in more highly altered specimens it is entirely gone.

The biotite is sometimes quite abundant and has the same characteristics as previously described. It is most intimately associated with the plagioclase, and where sapphirine is present it appears to have developed later than this mineral. Its position about the margins of the feldspar or replacing part of it is here, as elsewhere, strongly suggestive of a later secondary origin. Its alteration is to chloritic products.

An occasional grain of apatite has been noted, but it is hardly present as more than a trace.

The sapphirine, which is of especial interest here, it being not only a new occurrence of this rare mineral but also in a new association, seems to be confined to portions of the ilmenite rock which carry rutile. Even when alteration has destroyed both plagioclase and sapphirine, the characteristic alteration products enable it to be seen that the sapphirine has been quite a constant associate of the feldspar in the rutile-bearing portion. That there is some intimate relation between the feldspar and the sapphirine is shown by the fact that the latter generally lies between the feldspar and the ilmenite. It is often seen as a narrow band extending around the feldspar. The band may widen

out into a larger mass. Again the feldspar may be surrounded by sapphire of nearly or quite equal area. About a single feldspar grain the sapphire usually has, throughout the greater portion of its extent, a uniform orientation. The mineral also includes ilmenite and rutile grains, and in one instance at least has been noted in contact with spinel. Where the feldspar is more abundant the sapphire is also more strongly developed, and its grains have in some instances fairly continuous distribution through the section, and often lie, with and without included ilmenite and rutile, between the feldspar crystals, or even included in them. In such sections as much as 20 per cent has been observed, with about an equal amount of feldspar and rutile, a little spinel, and the remainder ilmenite. Here the larger grains frequently attain a diameter of 3 millimeters, the average being somewhat smaller (0.4 or 0.7 millimeter). Quantitative estimates of the amount present indicate something like 3 to 5 per cent for the general run of the rutile-bearing rock.

Warren made two quantitative estimates, by the Rosiwal method, of the mineral composition of the rutile-bearing rock in thin sections—one from a rutile-rich sample, the other from a rutile-poor sample—with the following results:

Mineral composition of rutile and sapphire bearing ilmenite from St. Urbain, Quebec.

Rutile -----	20.4	11.3
Ilmenite-hematite -----	73.2	84.5
Sapphire -----	3.2	.7
Undetermined -----	3.2	3.2

A chemical analysis of a sample of the rutile-rich type yielded the following result:

Analysis of rutile and sapphire bearing ilmenite from St. Urbain, Quebec.

[R. S. Anderson, analyst.]

SiO ₂ -----	2.24
TiO ₂ -----	53.35
Al ₂ O ₃ -----	1.65
Fe ₂ O ₃ -----	13.61
FeO -----	24.49
MnO -----	.30
MgO -----	4.04
CaO -----	.30
	99.98

The rutile-bearing rock is regarded as a magmatic differentiation product in which there was an excess of titanite oxide and a smaller excess of magnesia and alumina. It represents an extreme and new ultrabasic type of igneous rock, for which Warren has proposed the name urbainite. No attempt has been made to classify it in the quantitative system, but it falls into a new position in the perthite class (V), possibly close to the rutile nelsonites of Nelson County, Va.

Late in the seventies an English company mined a few thousand tons of the ilmenite for iron. In 1910 the deposits were leased and worked by the General Electric Co. for rutile, and it is said that a considerable quantity of the material was mined from an open cut and shipped to Schenectady, N. Y. The property has not been operated since 1910.

SOUTH AUSTRALIA.¹

The known occurrences of rutile in South Australia are near Mount Crawford, in sec. 119, hundred of Para Wirra, and secs. 6 and 9, hundred of Talunga, 6 miles north of Blumberg, about 25 miles northeast of Adelaide, and 16 miles from Gawler station. Practically nothing has been published on the geology of these occurrences.

Gee² has made the following brief statement in regard to the occurrence of rutile in secs. 8 and 9, hundred of Talunga, 6 miles north of Blumberg:

From time to time for many years past work has been carried on by various parties, but apparently in no instance has there been much enterprise or energy. The workings, which continue for about 150 yards in length, are principally a number of small shafts, cross trenches, and surface openings, from 3 feet to 30 feet in depth, disclosing a soft clay kaolinized dike formation, from 10 feet to 12 feet wide, striking slightly east of south. Through this material rutile crystals in various forms, both coarse and fine, can be seen, in some places dispersed throughout the matrix, in others in pockets and seams, and can be extracted by dishwashing. For some distance on each side of the formation fine rutile can be obtained on the surface, but the most valuable is in a small seam of gravel resting on a clay bed about 12 inches below the surface, and which yielded very good prospects indeed, much better than had been anticipated, judging from the debris on the surface and its position not being on the line. The better-class material is at each end of the workings. From each of those several samples were taken, also from the surface and shallow pits, which, when bulked, gave an average return of 1¼ per cent.

Hand specimens of the material obtained by Frank L. Hess, of the United States Geological Survey, from the leases of Francis J. Spence, have been studied by the writer, and the important features are summarized below. The specimens show chiefly a granular mixture of dark-red rutile and light-colored silicate minerals, mainly sericite, sillimanite, feldspar, and quartz. Pressure effects are visible in fractures in the rutile and quartz and in the orientation of the shreds of sericite that extend inward from the outer laminae of the rutile. The marginal portions of the specimens show interleaving of rutile with mica.

A thin section examined under the microscope shows formless grains of deep-red rutile having slight pleochroism, good cleavage, and in most cases twinning. Inclusions of a black, opaque metallic

¹ Watson, T. L., and Taber, Stephen, Virginia Geol. Survey Bull. 3-A, pp. 35-37, 1913.

² Gee, L. C., Record of the mines of South Australia, 4th ed., pp. 356-357, 1908.

mineral, probably ilmenite, occur in the rutile. The rutile grains are broken by fractures, along which there is some alteration to leucoxene. Small grains of quartz occur, and here and there shreds of colorless mica (sericite) are disseminated through the rutile or fill fractures, in which the sericite is probably of secondary origin.

A second specimen showed rutile associated with much sillimanite in feltlike aggregates, less quartz, and little sericite. The specimen is considerably mashed. Microscopic study of a thin section cut from this specimen shows the chief mineral constituent to be rutile, which is accompanied by sillimanite, quartz, and feldspar (mostly plagioclase), together with accessory minerals as inclusions in the quartz and feldspar. The rutile is red to red-brown in color. It exhibits cleavage and, in places, twinning, and some particles show appreciable pleochroism. It occurs chiefly in granular masses and in aggregates of granules and microscopic crystals having good outward crystal form. It is free from inclusions but contains inclosures of the silicate minerals, especially quartz. Much sillimanite occurs in aggregates of fibers, showing a partial radiate arrangement and penetrating the quartz and feldspar. Pressure effects are evident in broken fibers of sillimanite, fractured rutile and quartz, and slight optical disturbance and partial granulation of the quartz.

In the mineralogic collections of the University of Virginia are several specimens of rutile labeled Blumberg, South Australia, which are similar in associations and general character to the specimens described above. These specimens also show marked evidence of mashing. One of them is composed chiefly of kaolinized feldspar with greenish scales of sericite and large and small grains of red rutile, more or less segregated as very minute stringers that lie for the most part in the foliation of the rock.

The mode of occurrence of the South Australia rutile is unknown, but from the brief statement of Gee as to the field relations and from the results of the writer's examination of hand specimens and thin sections it seems probable that the rutile occurs in pegmatite.

KRAGERO, NORWAY.¹

Rutile has been noted at a number of localities in Norway,² but the deposit of greatest commercial importance is in the neighborhood of Kragero, on the southeast coast.

¹ Watson, T. L., Kragerite, a rutile-bearing rock from Krageroe, Norway: *Am. Jour. Sci.*, 4th ser., vol. 34, pp. 509-514, 1912.

² Vogt, J. H. L., Problems in the geology of ore deposits: *Am. Inst. Min. Eng. Trans.*, vol. 30, pp. 646-647, 1901; see also references to Vogt's work in *Zeitschr. prakt. Geologie*, 1894-1897. Brögger, W. C., and Reusch, H. H., *Verkommen des Apatit in Norwegen*: *Deutsche geol. Gesell. Zeitschr.*, vol. 27, pp. 646-702, 1875.

According to Vogt rutile occurs in the apatite veins of Norway and northern Sweden in sufficient quantity at numerous places to be profitably mined. The veins are connected with gabbro and were formed soon after the intrusion of the rock, which shows characteristic pneumatolytic action. Chlorine is present in the vein minerals scapolite and chlorapatite, and, besides rutile, the veins contain the titanium minerals ilmenite and titanite. Many of the veins carry some pyrite and exceptionally a little tourmaline.

According to Brögger,¹ the occurrence of rutile in the neighborhood of Kragero is confined to a large aplite dike situated 200 to 300 meters from the sea and about 100 meters above sea level. The rock is called a rutile aplite and is an even-granular white rock practically free from dark silicate minerals. Brögger says that the middle part of the dike contains rutile uniformly distributed through the rock in grains 0.5 to 2 millimeters in size and estimated roughly to amount to about 5 to 10 per cent by weight.

A second, and commercially the most important, occurrence of rutile in the aplite is referred to as schlieren of local enrichments of the mineral. Most of the schlieren consist almost exclusively of rutile, and these portions of the rock crumble easily to a grainy rutile powder. The rutile schlieren are unequally distributed through the dike, the richest ones being concentrated in a few zones, the largest of which is situated about in the middle of the dike.

In 1904 Brögger discussed the rock as a new member of the aplite series and named it kragerite. Concerning this rock Vogt² says:

Brögger discussed a new rock, kragerite, a new member of the aplite series. The rock is of practical interest on account of its content of rutile. In theoretic connection the speaker considered this rock, which consists almost exclusively of albite and rutile, as a differentiation product of a gabbro magma, analogous to the appearance of lestiwarite, an aplitic differentiation product of a nepheline syenite magma, etc. In addition, mention was made, by analogy, of routivarite, anorthosite, and oligoclase. The content of titanitic acid in the kragerite was attributed to pneumatolytic processes during formation.

In a personal communication to the writer Vogt states that the rock has been found only at a single place in the neighborhood of Kragero and has small areal extent. It has been worked in later years for rutile, the percentage of which is variable.

The rutile-bearing rock, when submitted to analysis, is found to be medium grained, of light color, and granitic texture. Its most prominent megascopic constituents are light-gray and pinkish feldspars and much black rutile, with a little quartz. Several small areas of a green ferromagnesian mineral, probably pyroxene, partly altered and

¹ The statements which follow have been taken partly from a report made by W. C. Brögger, Oct. 5, 1904.

² Vogt, J. H. L., Vidensk.-Selsk. Christiania Forh., Oversigt over Videnskabs-Selskabets Møder i 1904, p. 30, 1905.

associated with rutile, were noted. The feldspar and quartz grains measure 1 to 2 millimeters in thickness; few of the rutile grains are more than 1 millimeter and many of them are less than 0.5 millimeter thick. Under the pocket lens most of the feldspar shows fine albitic twinning on cleavage surfaces. The rutile is partly disseminated as small grains through the rock, but most of it appears to be segregated along roughly parallel lines, suggesting the appearance of imperfect foliation, which Brögger refers to schlieren of local enrichments of the mineral.

A thin section of the less rich rutile-bearing portion of the rock was examined under the microscope and found to consist essentially of feldspar, much rutile, some quartz, and a little ilmenite. No mafic minerals were observed. Feldspar is the most abundant constituent and is composed chiefly of a soda plagioclase (albite-oligoclase), together with some microcline and orthoclase, the latter intergrown with a second feldspar (albite) as microperthite. Some of the feldspar anhedral show partial micropoikilitic structure developed from inclosures of other feldspar, quartz, and rutile. The feldspars are generally fresh, though here and there small areas of colorless mica due to alteration occur. The feldspar and quartz show some granulation about the borders, and a slight bending of the lamellæ of several plagioclase individuals was noted.

When calculated in the usual way from the chemical analysis of the rock (given below) the composition of the feldspar content is as follows:

Composition of feldspar in rutile-bearing rock from Kragero, Norway.

Orthoclase.....	6.12
Albite.....	52.40
Anorthite.....	5.56
Ab _n An _m ratio.....	9.4:1
Orthoclase-Ab _n An _m ratio.....	1:9.5
Total plagioclase.....	57.96
Total feldspar.....	64.08

Rutile, the next most abundant mineral to feldspar, occurs in forms ranging from irregular massive grains to small idiomorphic crystals. Some of the larger grains show partial crystal outline. It is deep red-brown and distinctly pleochroic, and much of it shows cleavage and twinning. Some ilmenite is associated with the rutile and in part exhibits slight alteration to leucoxene. The rutile occurs entirely enveloped by feldspar or along the sutures of feldspar individuals and of feldspar and quartz and penetrates for a greater or less distance into their substance. The relations of the rutile to the rock minerals suggest that it crystallized from the magma, like the feldspar and quartz, in the usual order of crystallization.

A thin section of the rutile-rich portion of the rock, representing probably the schlieren of Brögger, was studied microscopically. It is composed essentially of rutile, together with biotite partly altered to chlorite, some anhedral grains of apatite, and an altered light-colored silicate mineral, probably a potash feldspar.

In reflected light the rutile is dark brown to gray with faint greenish tinge; in transmitted light it is pleochroic, usually shows good cleavage and twinning, is marked by irregular fractures, and shows some alteration to leucoxene peripherally and along fractures.

Biotite, partly altered to chlorite, is developed in aggregates of shreds having in places a radial arrangement or grouping. Inclusions of the silicate minerals, chiefly biotite, are noted in the rutile, and rutile granules are distributed through the silicate minerals—a relation which apparently indicates contemporaneous crystallization of the rutile and silicate minerals.

An analysis of the rutile separated from the rock and freed as nearly as possible of silicate minerals yielded the following results:

Analysis of kragerite rutile from Kragero, Norway.

[William M. Thornton, jr., analyst.]

TiO ₂	97.68
SiO ₂	1.06
FeO.....	.81
Cr ₂ O ₃.....	.39
V ₂ O ₅.....	.55

100.49

Specific gravity (determined by J. W. Watson), 4.225.

The rock was analyzed in the laboratories of the University of Virginia, with the following result:

Analysis of kragerite (rutile aplite) from Kragero, Norway.

[J. W. Watson, analyst.]

SiO ₂	50.52
Al ₂ O ₃	13.98
Fe ₂ O ₃.....	.49
FeO.....	.16
MgO.....	.34
CaO.....	1.05
Na ₂ O.....	6.18
K ₂ O.....	1.00
H ₂ O—.....	.20
H ₂ O+.....	.30
TiO ₂	25.00
P ₂ O ₅	Trace.
V ₂ O ₅	Not determined.
MnO.....	None.
CO ₂	None.
S.....	.12

99.34