Uranium in Phillips Mine–Camp Smith Area, Putnam and Westchester Counties New York

By HARRY KLEMIC, JOHN H. ERIC, JAMES R. McNITT, *and* FRANK A. McKEOWN

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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URANIUM IN PHILLIPS MINE-CAMP SMITH AREA, PUTNAM AND WESTCHESTER COUNTIES, NEW YORK

By Harry Klemic, John H. Eric, James R. McNitt, and Frank A. McKeown

ABSTRACT

Uraniferous rock was discovered in the Phillips mine-Camp Smith area in 1953. Precambrian rocks of the Hudson Highlands of the New England physiographic province underlie the area. Hornblende pegmatite intrudes hornblende gneiss and diorite. The hornblende pegmatite and diorite are conformable with regional structures in the gneiss. Crosscutting bodies of oligoclase-quartz pegmatite intrude the diorite and hornblende gneiss.

Uraninite occurs in hornblende pegmatite and in adjacent hornblende gneiss and diorite in an elongate zone that is mineralized with magnetite and iron sulfides. The mineralized zone strikes northeast and dips steeply northwest. The Phillips pyrrhotite-pyrite ore body at the northeast end of this zone plunges northeast. The uraninite is in crystals and grains, most of which range from a millimeter to a centimeter in diameter. Subhedral uraninite crystallized from the pegmatite magma. The isotopic age of a crystal of uraninite from the hornblende pegmatite is about 920 million years.

Magnetite probably was emplaced during the latest stages of the consolidation of the hornblende pegmatite and is associated with secondary augite resulting from the alteration, possibly pneumatolytic, of hornblende in the pegmatite and adjacent rocks. The solutions that deposited magnetite and altered hornblende to augite embayed and rounded some of the uraninite crystals. Iron sulfides probably were deposited by hydrothermal solutions that followed the main channels through which the hornblende pegmatite magma and the magnetite solutions had been introduced. Later, oligoclase-quartz pegmatite intruded the area discordantly. The lead-alpha age of zircon from the oligoclase-quartz pegmatite is about 620 million years.

Results of exploration suggest that the deposits are submarginal under 1955 marketing conditions for uranium.

INTRODUCTION

The Phillips mine-Camp Smith area is in the Hudson Highlands, a hilly belt of igneous and metamorphic Precambrian rocks that forms part of the Reading prong of the New England physiographic province. The area is in the Peekskill 7½-minute quadrangle (fig. 8). About a mile and a half west of the Phillips mine, the Hudson River with its surface at sea level cuts through the highlands. Erratic boulders at altitudes of 800 feet and higher indicate that this part of the highlands was once covered by glacial ice. The area included in plate 11 lies between 560 and 900 feet above sea level. In valleys and near the bottoms of hillsides in the mapped area, as much as 4 feet of soil and overburden covers the bedrock. Although the overburden is thin on the upper parts of hills, outcrop of bedrock probably constitutes less than 25 percent of the area in these places.

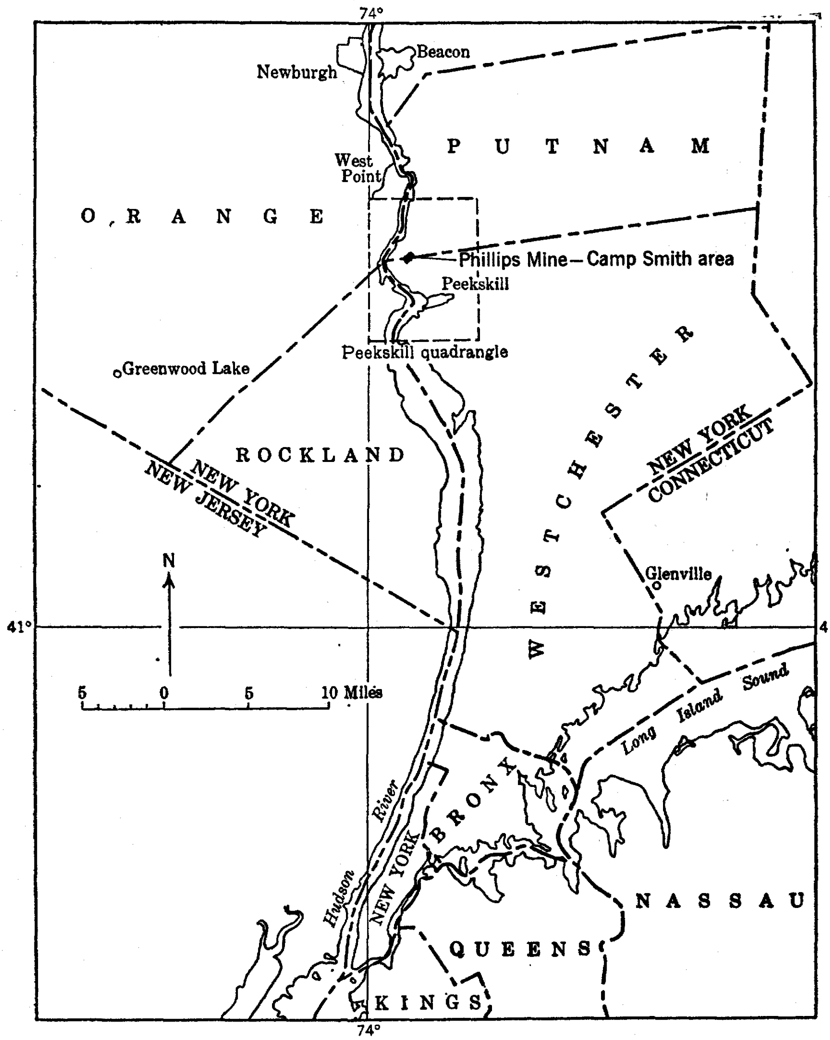

FIGURE 8.—Index map showing location of Phillips mine-Camp Smith area, New York.

The Phillips mine, owned by Mrs. Lucius Boomer of New York, is an old sulfide mine in Putnam County, about one and a half miles east of the Hudson River along the boundary between Putnam and Westchester Counties. Camp Smith, a military reservation owned by the State of New York, is in Westchester County just south of the county line.

The Phillips mine is accessible by a dirt road south from Manitou Road which connects U. S. Highway 9 with State Highway 9D about a mile and a half northeast of Bear Mountain Bridge. Camp Smith is reached from U. S. Highways 202 and 6. Peekskill is about 3 miles to the southeast.

The date of discovery of the Phillips sulfide ore body is not known to the authors, but the mine was opened shortly after the Civil War. Credner (1865) refers to deposits of magnetite with pyrite and pyrrhotite in this area, but does not refer specifically to the Phillips mine. Credner (1866) gives, in German, the following information: "A mine shaft on the north slope of Anthony's Nose is about 100 feet deep, and the operators intend to process the ore for sulfuric acid, copper, and nickel." This information suggests that the mine had been worked for only a short time before 1866.

Kemp (1894, p. 631) gives the first reference that specifically mentions the name Phillips mine and the time of its opening. He states:

> The ore-body was opened shortly after the war, and was known as the Phillips mine * * * It was operated for ten or fifteen years after this, but for sulphur fumes, and not for its metallic contents, which proved too low for profit.

Raymond (1894, p. 886, 887) in discussing the description of the Phillips mine by Kemp in 1894 stated:

> * * * I had occasion nearly thirty years ago, * * * to examine that deposit, to assist in certain experiments performed upon the ore and to join in the advice given to the Hudson River Copper Company which then owned the property * * * A small experimental furnace on Staten Island made some sulphuric acid from the ore, and, finally, the chemical works on the Hudson, to which Professor Kemp has alluded, employed it for a considerable period * * *

RECENT INVESTIGATIONS FOR URANIUM

Pitchblende was reported by Zodac (1939, p. 350) about a mile south of the Phillips mine-Camp Smith area. McKeown (1951, p. 11) defined a radioactive province in the Hudson and Housatonic Highlands. Uraniferous rock was found on the dump of the Phillips mine in Putnam County, and in adjacent areas in Camp Smith in Westchester County, N. Y. in 1953 by Edward J. Chalmers of Glenville, Conn. Walthier (1955, p. 546) mentions uranium in the Phillips mine-Camp Smith area, and in other places in the Hudson Highlands.

In 1953 Mr. Chalmers filed notices of discovery of uranium on the Camp Smith military reservation and in 1954 made arrangements with Mines, Inc., of New York, subsidiary of Ventures, Ltd. of Toronto, Canada, for the exploration of his claims. Mines, Inc. mapped the outcrops, trenched and stripped in selected areas, made a detailed Geiger-counter survey of their workings, sampled the radioactive rock, and prepared a plan for exploratory drilling. Mr. Chalmers presented this proposed plan to the Defense Minerals Exploration Administration and was granted an exploration contract under which 11 diamond-drill holes were put down early in 1955.

These investigations show that the uraninite occurs in hornblende pegmatite and adjacent hornblende gneiss and diorite in a zone that has been mineralized with magnetite and iron sulfides. The mineralized zone is elongate, strikes northeast, and dips steeply northwest. The Phillips pyrrhotite-pyrite ore body within this zone strikes and plunges northeast and dips northwest. The results of exploration suggest that the deposit is submarginal under 1955 marketing conditions for uranium.

PREVIOUS WORK

The geology of the sulfide deposit at the Phillips mine was described by Loveman (1911). Berkey and Rice (1921) in their comprehensive report on the geology of the West Point quadrangle summed up the earlier geologic information that had been compiled about this part of the Hudson Highlands and added much new information from their own studies. The magnetite deposits of southeastern New York were described by Colony (1923). Thompson (1936) described the geomorphology of the Hudson River gorge. Lowe (1950) described the petrography, petrology, and structure of the Storm King granite of Berkey (1907) in the Bear Mountain area to the west.

Preliminary examinations of the area to evaluate its potential for uranium were made in 1953 by the U. S. Geological Survey and the U. S. Atomic Energy Commission. In 1954 the U. S. Geological Survey, on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission, made a more detailed geologic study. A geologic and topographic map on a scale of 1:2,400 was made of an area about 4,500 feet by 1,800 feet. Samples of the radioactive rock were assayed and mineralogic studies were made in the U. S. Geological Survey laboratories. A radioactivity survey was made with a scintillation counter and a magnetic survey was made with a dip needle in part of the area.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of Mr. Edward J. Chalmers, who discovered the uranium and brought it to the attention of the Geological Survey.

Acknowledgment is made to Mrs. Lucius Boomer for permission to do field work on her property, and to the chief of staff of the State of New York and other State officials for permission to do field work on the Camp Smith military reservation. The authors are indebted to Capt. J. J. McLaughlin of Camp Smith, and to Messrs. G. Flaherty, R. K. Wheelock, and T. Sciacca of Mines, Inc., for their friendly cooperation and assistance.

The help of many members of the Geological Survey is also appreciated. Jerome Stone assisted in the petrographic studies; David Gottfried, Thomas Stern, and Lorin Stieff did the mineral age determinations; H. F. Phillips, L. D. Elmore, K. E. White, Glen Edgington, and R. A. Powell made chemical analyses; C. S. Annell made the spectrographic analysis; Nancy Pearre translated the reference material in the German publications; and R. G. Schmidt and A. V. Heyl critically reviewed the manuscript and suggested many improvements.

GEOLOGY

The Hudson Highlands are a northeastward-trending belt of Precambrian crystalline rocks bounded on the northwest and southeast by faults. A great variety of rock types is exposed in the highlands. The most abundant rocks in the area within the West Point quadrangle have been described by Berkey and Rice (1921), and include metamorphosed Precambrian sedimentary rocks, bodies of diorite and granite, mafic dikes, and mixed types consisting of intrusive and metamorphic rocks.

For mapping at a scale of 1:2,400, the rocks in the Phillips mine-Camp Smith area were divided into five lithologic units. The oldest unit is hornblende gneiss, which is intruded by diorite in the central part of the area and by biotite diorite along the northwestern and southeastern boundaries of the area. The youngest rocks are hornblende pegmatite and oligoclase-quartz pegmatite, which intrude the hornblende gneiss and diorite.

The hornblende gneiss is similar to the Pochuck gabbro gneiss, and the diorite and biotite diorite are probably the Pochuck diorite described by Berkey and Rice (1921).

Local variations in texture and composition occur within some lithologic units. Coarse-grained hornblende-rich facies of hornblende gneiss resemble hornblende pegmatite in hand specimens. The rock mapped as diorite has granodioritic and granitic facies.

In most of the area the diorite is massive, but in places where biotite is abundant it is distinctly gneissic. Likewise, there are facies changes in the pegmatites, but the gross features of each of these units as mapped are distinct.

The Phillips pyrrhotite-pyrite ore body is similar in some respects to some of the sulfide-rich magnetite bodies of southeastern New York as described by Colony (1923). In general these ore bodies are along northeastward trending zones, are roughly lenticular, dip steeply southeast, and plunge northeast. The Phillips ore body, however, dips steeply northwest. Some of the magnetite bodies contain practically no sulfides, whereas others are rich in sulfides.

HORNBLENDE GNEISS

Several layers of well-foliated hornblende gneiss underlie about one-third of the area mapped (pl. 11). Contact relations indicate that hornblende gneiss is the oldest unit, and that diorite and pegmatite were intruded into it.

DISTRIBUTION

Three parallel layers of hornblende gneiss strike about N. 40° E. (pl. 11). Three small, lenticular bodies of hornblende gneiss parallel these layers; one on the southwest margin of the map area, one near trench T–13, and the other south of the Phillips mine shaft. The hornblende gneiss bodies are interlayered with diorite and cut by pegmatite. In several places, especially along the northwest boundary of the area, partly assimilated bodies of hornblende gneiss with gradational contacts are enclosed in diorite. The foliated structure of the partly assimilated bodies, which were not mapped, is still preserved by thin layers of mafic minerals which are parallel to the thick layers of hornblende gneiss.

PETROGRAPHY

The hornblende gneiss is composed of alternating layers of light feldspathic material and dark hornblende-rich material. These layers are commonly ⅛ to 1 inch thick, but many are a foot thick and a few are as much as 4 feet. The boundary between the layers is sharp and the individual layers commonly retain the same thickness for 20 or 30 feet along their strike. Because platy minerals are absent, foliation is revealed only by the alternating layers of light and dark material. The alinement of minerals is planar but not linear.

The light layers of the hornblende gneiss are medium grained, have a granitic texture, and contain about 75 percent oligoclase, 10 percent quartz, 10 percent green hornblende, and 5 percent orthoclase. The feldspar crystals have a wavy extinction and traces of their twin planes are distorted. Minor sericitization has taken place along the edges and fractures of the feldspar crystals. The dark layers of hornblende gneiss are also medium grained and consist of about 65 percent green hornblende and 35 percent feldspar in crystalloblastic intergrowth. The feldspar in the dark layers has been so highly sericitized that its original composition could not readily be determined. The hornblende crystals are idioblastic and have been slightly altered to epidote. Some sections of the dark layers show subhedral grains of unaltered oligoclase embaying the hornblende crystals.

Where hornblende gneiss is associated with a pegmatite intrusion, the grain size of the hornblende gneiss is commonly increased from the normal diameter of 2 to 3 millimeters to as much as 6 millimeters. The composition of the dark layers in this coarse-grained phase approaches 100 percent hornblende and the gneiss becomes difficult to distinguish from the hornblende pegmatite unless it can be traced into the normal, medium-grained phase of the hornblende gneiss.

ORIGIN

Recent studies (Hotz, 1953 p. 161–172; Sims, 1953 p. 251–255) have shown the association, in the Precambrian Hudson Highlands, of amphibolite with skarn, marble, and other metasedimentary rocks. This association suggests that these amphibole-rich rocks are probably regionally metamorphosed calcareous sediments. The hornblende gneiss described in this report may have undergone even further modification, as suggested by the difference in texture and degree of alteration between the light and dark layers of hornblende gneiss. The dark amphibole-rich layers probably represent an originally calcareous sediment, and the light layers a dioritic magma that was injected into the metasedimentary rocks. In places, projections of diorite cut across and terminate hornblende-rich layers, and merge imperceptibly into the light layers, which suggests strongly that the hornblende gneiss is a mixed rock formed by lit-par-lit injection of the hornblende-rich rock by diorite. To what extent this dioritic magma is responsible for the metamorphism of the calcareous sediments is not known. The severe sericitization of the feldspar, the fact that sericite is not oriented parallel to rock foliation, and the seemingly later growth of oligoclase in the hornblende-rich layers may be due to the diorite injection rather than entirely to regional metamorphism. The rock resulting from this process is similar to the "injection gneiss" in the West Point quadrangle described by Berkey and Rice (1921, p. 59). The later intrusion of pegmatite into the hornblende gneiss is probably responsible for forming the coarse-grained facies in the dark, hornblende-rich layers because this facies and the pegmatite are spatially associated. The concentration of hornblende in the coarse-grained facies could have been accomplished by the mobilization and removal of the original feldspathic material during recrystallization.

DIORITIC ROCKS

Dioritic rocks, which underlie about two-thirds of the area mapped, are interlayered with the hornblende gneiss. These bodies of diorite range from small lenses 30 feet wide to a large continuous layer 500 feet wide. Diorite layers are generally conformable to the hornblende gneiss, but small-scale crosscutting features indicate the intrusive nature of the diorite.

Two types of diorite are represented in plate 11 as diorite and biotite diorite. This field distinction is based on a difference in mineralogy and on a weak gneissic structure caused by oriented biotite in the biotite diorite.

DIORITE

DISTRIBUTION

The largest body of diorite is a layer about 500 feet wide that crops out across the middle of the mapped area. Several isolated lenses of diorite, about 30 feet in width and 150 feet in length, intrude the hornblende gneiss on both sides of this main body. These lenses, like the largest diorite body, conform to the strike, and probably the dip, of the gneiss.

PETROGRAPHY

The diorite is a very light gray, massive rock with a medium-grained, equigranular texture. The diorite is coarse grained in places but in areas too small to be shown on plate 11. Although the nonbiotitic diorite is generally massive, weak foliation parallel to the regional structure is locally apparent.

Examination of thin sections reveals both granitic and granoblastic textures, and shows that the rock mapped as diorite grades from diorite through quartz diorite, granodiorite, quartz monzonite, to granite. The latter is rare. Diorite and quartz diorite are the most common facies, and consist of plagioclase (chiefly oligoclase and some andesine) 60–90 percent, quartz a trace to 20 percent, potash feldspar (which may be orthoclase or microcline or both) a trace to 10 percent, and amphibole a trace to 20 percent. The microcline and quartz are both interstitial to and included in the plagioclase. Some of the microcline inclusions appear to be exsolution products from the plagioclase. Most of the plagioclase and orthoclase has been moderately sericitized and the plagioclase has been intensely epidotized near zones of later mineralization. Biotite, zircon, and rutile are minor accessory minerals.

BIOTITE DIORITE

DISTRIBUTION

A body of biotite diorite, at least 400 feet wide, crops out along the northwest side of the mapped area. In includes a thin hornblende gneiss layer that pinches out to the southwest. Another mass of biotite diorite, about 100 feet thick, was mapped in two places along the southeast boundary of the area, but probably extends the full length of the area. Unlike the diorite, no small lenses of biotite diorite were found intruding the hornblende gneiss.

PETROGRAPHY

The biotite diorite is a light-gray, medium-grained rock which is massive except in the biotite-rich layers. The attitude of the foliation in the biotite-rich layers conforms, in general, to that of the surrounding gneiss.

Study of many hand specimens and one thin-section indicates that the rock has a granoblastic texture and the major mineral percentages in the biotite diorite are similar to those of the diorite. Quartz and feldspar are highly sutured and quartz fills fractures in the feldspar grains. The accessory mineral assemblage differs in several respects from that of the diorite. Biotite, which constitutes about 5 percent of the biotite diorite, forms well-defined layers and in places cuts the feldspar and quartz grains. Brown subhedral grains resembling sphene make up about 1 percent of the rock. Green hornblende occurs in fine-grained aggregates, and the feldspars have been extensively altered to sericite and epidote. Zircon is another minor accessory mineral.

RELATION BETWEEN HORNBLENDE GNEISS AND DIORITE

The area mapped is characterized by alternating layers of hornblende gneiss and diorite. The larger diorite bodies are continuous and have a fairly constant thickness. The narrower gneiss layers, however, pinch and swell, in places grading into diorite or biotite diorite for many feet along their strike. The wider layers and small lenses of both diorite bodies conform to the regional structure of the gneiss, but in detail a few crosscutting projections of diorite are visible. The diorite in large mappable bodies and small crosscutting projections is virtually the same rock as the light-colored layers of the hornblende gneiss.

In places the contacts between the diorite bodies and hornblende gneiss are transitional for several feet. The alternating layers of diorite and hornblende gneiss in this zone are each 2 or 3 feet wide. The diorite is virtually concordant with the structure of the gneiss except for a few crosscutting veinlets connecting two diorite stringers. At places where the layers are thinner, the contact is transitional for 1 or 2 feet in the dark layers of gneiss. Such contact features as drag folding, fracturing, inclusions, and chill zones were not observed at the contact between diorite and hornblende gneiss.

The relation between the diorite and biotite diorite could not be established in the mapped area because the two units were not found in contact.

ORIGIN OF DIORITE

The shape of the diorite masses, and their structure, microscopic texture, and contact relations suggest to the authors that the diorite probably crystallized directly from a magma that was intruded into the hornblende gneiss. The range in composition may be due, in part, to assimilation and in part to later addition of material during emplacement of pegmatite. There are few structural features in the diorite as compared to the gneiss. But the general conformity of the diorite bodies to the structure of the gneiss, as well as the absence of fracturing, inclusions, drag folding, and chill zones suggests that the intrusion took place during the closing stages of metamorphism. At that time the temperature and pressure may have been great enough to minimize discordant intrusion but insufficient to produce strongly gneissic structures in the diorite. Epidotization and sericitization of the feldspar, granoblastic textures and the late formation of oriented biotite and perhaps sphene in the diorite may have been due to concomitant metamorphism and igneous intrusion during the late stages of the tectonic activity that deformed the hornblende gneiss. An alternative interpretation—that the diorite may represent metamorphosed sedimentary rock—is supported by general conformity of diorite to regional structure of the gneiss, gradational contacts in places between diorite and gneiss, and weak foliation of biotite diorite.

PEGMATITE

Several bodies of pegmatite, the youngest rock mapped in the area, intrude the gneiss and diorite. These bodies have the typical mode of occurrence and large crystals of common pegmatite, but their composition is more dioritic than granitic. Two types of pegmatite have been mapped: hornblende pegmatite and oligoclase-quartz pegmatite. Hornblende pegmatite, as mapped (pl. 11), contains a facies of oligoclase-quartz pegmatite. Oligoclase-quartz pegmatite also forms separately mappable units that are probably younger than the oligoclase-quartz facies of the hornblende pegmatite. Hornblende pegmatite is the principal host rock for uraninite.

HORNBLENDE PEGMATITE

DISTRIBUTION

Hornblende pegmatite crops out in isolated, elongate bodies that range from about 50 to 750 feet in length in a zone 3,200 feet long. This zone strikes roughly northeast and cuts across a gneiss-diorite contact at a very low angle (pl. 11). The elongation of the hornblende pegmatite bodies generally is parallel to the regional structure.

The largest body of hornblende pegmatite mapped in the area is at least 500 feet long and 100 feet wide. It is bounded by gneiss in most places on the northwest and northeast sides, and by diorite on the southeast; the southwest side is covered by the Phillips mine dump. Two hundred feet farther southwest, stringers of hornblende pegmatite are exposed in the walls of the Phillips mine shaft and in the small inclined shaft close by. The strike of these hornblende pegmatite stringers suggests that they are probably extensions of the southwest end of the large pegmatite body. The large quantity of hornblende pegmatite found on the mine dump also supports this conjecture. If the pegmatites exposed in the shaft openings, as interpreted on plate 11, are connected with the main body, the total length of hornblende pegmatite northeast of the Phillips mine is 750 feet.

Several sheets of hornblende pegmatite, about 5 feet wide, crop out on the diorite hill just southwest of the Phillips mine shaft. Their extent and outline were inferred from exposures in old pits P–1 and P–3, from float blocks, and from small isolated outcrops, as well as from a few shallow pits dug by the authors and by Mines, Inc. The dumps of pits P–2 and P–5 contain many pieces of hornblende pegmatite.

A hornblende pegmatite body apparently crosses from diorite into gneiss about 200 feet southwest of the junction of Mine Road and Iron Mountain Road. From this point southwestward to the end of the pegmatite zone the remaining bodies are confined to the hornblende gneiss belt. Because both the gneiss and the hornblende pegmatite are highly susceptible to weathering and decomposition, natural exposures of these pegmatite bodies along Mine Road are scarce. Recent trenching in the area, however, has made possible the accurate location of parts of these bodies.

One small body of hornblende pegmatite is associated with oligoclase-quartz pegmatite on Riquier Trail, but the contact is not exposed and the relations between the two types of pegmatite at this locality were not established.

PETROGRAPHY

The coarse grain size and peculiar structure of the hornblende pegmatite make accurate laboratory grain counts impractical for determining its percentage composition. Estimates during field study show that the unit as a whole contains about 40 percent hornblende, 40 percent oligoclase, and 20 percent quartz. Probably there is very little rock with this composition, however, for the hornblende pegmatite bodies are not homogeneous throughout but are made up of a hornblende-rich facies and an oligoclase-quartz-rich facies.

The hornblende facies consists of about 90 percent dark-green hornblende crystals that average 2 inches in length but in places range from ½ to 8 inches in length. In a few places hornblende crystals are 2 feet long. The chemical composition of the hornblende is given in table 1.

TABLE 1.—*Chemical analysis of coarse-grained hornblende and coarse-grained augite*

[Analysts, H. F. Phillips, L. D. Elmore, and K. E. White]

	Hornblende JM-5 [1]	Augite AL-1 [1]
SiO_2	50.2	51.4
Al_2O_3	5.4	1.7
Fe_2O_3	3.0	4.5
FeO	10.0	6.6
MgO	14.8	12.3
CaO	11.6	20.3
Na_2O	1.6	1.5
K_2O	.65	.06
TiO_2	.76	.09
P_2O_5	.07	.06
MnO	.14	.06
H_2O	1.2	.59
CO_2	$<$.05	$<$.05
	99.47	99.21

[1] Lot No. 1967: Lab. No. 139246, field No. JM-5; lab. No. 139247, field No. AL-1.

About 10 percent of the hornblende facies is made up of quartz and oligoclase crystals about 1 inch in diameter. The quartz and feldspar are irregularly distributed between hornblende crystals and in places form discontinuous stringers.

Except for the larger size of its crystals, the oligoclase-quartz facies of the hornblende pegmatite is similar in composition and texture to the separately mappable oligoclase-quartz pegmatite described in the next section, and to the quartz and feldspar that occur as stringers in the hornblende gneiss.

In some outcrops irregular masses of the hornblende facies of the hornblende pegmatite, ranging from 3 to 25 feet in diameter, are surrounded by the oligoclase-quartz facies. In other outcrops equally large masses of oligoclase-quartz facies are surrounded by hornblende facies. The contact of one facies with the other is marked by mutually interpenetrating and crosscutting stringers of hornblende, and quartz and feldspar. Although the relations between these facies are not entirely clear, the mutual interpenetration and constant association of these units suggest that they were intruded as one igneous body, and they were mapped as one geologic unit.

Northeast of the Phillips mine, the hornblende pegmatite is unaltered. In and southwest of the Phillips mine, epidote and augite have formed in the hornblende pegmatite, especially near concentrations of magnetite and sulfides, where the pegmatite is abnormally radioactive because of its uraninite content. The epidote and augite are probably alteration products connected with introduction of magnetite and sulfides.

AGE

Age determinations of a sample of uraninite from a specimen of hornblende pegmatite on the dump of the Phillips mine, made by L. R. Stieff and T. W. Stern (written communication, 1955), indicate a Pb206/U238 age of about 920 million years.

OLIGOCLASE-QUARTZ PEGMATITE

DISTRIBUTION

Nine bodies of oligoclase-quartz pegmatite were mapped in the area; 7 of these bodies are in gneiss, 1 is in diorite, and 1 cuts across a contact between gneiss and diorite. The pegmatite forms lenses, sheets, and irregular bodies, ranging in length from 50 to 300 feet, and in width from 10 to 70 feet.

Where the oligoclase-quartz pegmatite is surrounded by gneiss, it weathers in small rounded knobs. Where surrounded by diorite, which is much more massive than the gneiss, the pegmatite weathers at about the same rate as its country rock. This may account partly for more pegmatite having been mapped in the gneiss than in the diorite. The structure of the gneiss had little effect on the intruding pegmatite, for in plan, the long dimensions of most of the oligoclase-quartz pegmatite bodies are not parallel to the foliation of the gneiss (pl. 11).

485162—59——3

PETROGRAPHY

The oligoclase-quartz pegmatite is light gray to pinkish. In the oligoclase-quartz facies of the hornblende pegmatite the crystals average about an inch in diameter; in the separately mappable units the crystal size is smaller. About 90 percent of the pegmatite is composed of subhedral crystals of oligoclase and the remaining 10 percent is made up of quartz, both in irregular grains and as graphic intergrowths in the feldspar. Local concentrations of magnetite occur as subhedral to euhedral crystals ¼ to 1 inch in diameter. Hornblende in small amounts, probably less than 1 percent, is commonly a primary accessory mineral, although it may be an incorporation from the surrounding hornblende gneiss. No elements of foliation or lineation are visible in the oligoclase-quartz pegmatite, and no recognizable inclusions of country rock were seen. Scintillation-counter surveys of the oligoclase-quartz pegmatite indicate that at least three of the nine bodies contain radioactive minerals; they are the two bodies on Iron Mountain Road and the long thin body that crosses the diorite-gneiss contact in the northeast part of the mapped area (pl. 12). Inasmuch as the oligoclase-quartz pegmatite is weakly radioactive and locally distributed compared to the hornblende pegmatite, the minerals causing this radioactivity, other than zircon, were not identified.

AGE

The oligoclase-quartz pegmatite in separately mappable units is probably the youngest rock in the area. It is unmetamorphosed and intrudes diorite and gneiss discordantly. A grab sample of coarse-grained rock, probably oligoclase-quartz pegmatite, containing zircon was taken from a slightly radioactive outcrop on Mine Mountain. Some of the zircon was separated, and its lead-alpha age, as determined by David Gottfried, is about 620 million years. This age may possibly be too young, however, because age determinations on Precambrian minerals by the lead-alpha method commonly are low compared to age determinations by isotopic methods; only rarely are they too high (David Gottfried, written communication, 1956).

RELATION OF PEGMATITES TO DIORITE AND GNEISS

The elongation of the hornblende pegmatite bodies, unlike that of the oligoclase-quartz pegmatite, is chiefly parallel or subparallel to the structure of the gneiss. Even where hornblende pegmatite bodies are surrounded by the almost structureless diorite, their strike parallels the regional strike of the gneiss. In places small stringers of hornblende pegmatite cut gneiss at the contact zone, follow the foliation of the gneiss, and only rarely cut across foliation from one layer to another. The contacts between hornblende pegmatite and diorite normally are abrupt, but in a few places small stringers or veinlets of hornblende pegmatite cut diorite for several feet.

No country-rock inclusions were found in the oligoclase-quartz pegmatite, but two of the hornblende pegmatite bodies contain xenoliths. The oval-shaped hornblende pegmatite body near the northeast end of Iron Mountain Road contains a xenolith about 3 feet in diameter which has a foliation similar to that of the hornblende gneiss. Many coarse crystals of tourmaline in the xenolith parallel the planes of foliation and may be the products of reaction between the xenolith and the pegmatite magma.

Pit P–12 exposes xenoliths in another hornblende pegmatite body. These xenoliths consist of coarse-grained calcite. The largest block is about 10 feet long by 3 to 4 feet wide. Several small, rounded bodies of coarse-grained calcite are embedded in the hornblende pegmatite only a few feet from this large xenolith. These smaller calcite bodies are surrounded by a weathered zone about an inch thick, rich in mica, which, like the tourmaline may be a product of reaction between the xenoliths and the pegmatite magma. The calcite contains a minor amount of coarse, subhedral magnetite crystals and finer grained sulfides.

The oligoclase-quartz pegmatite is generally discordant with the structure of the gneiss. An example of this discordance may be seen on Riquier Trail (pl. 11), about 150 feet south of the diorite-hornblende gneiss contact. The body of oligoclase-quartz pegmatite exposed here can be followed from a point about 80 feet west of Riquier Trail, eastward across the trail to a point where it swings northward for another 70 feet. The pegmatite exposed on the west side of Riquier Trail is thin and almost conformable with the surrounding gneiss which dips about 77° NW. On the east side of Riquier Trail, where the same pegmatite begins to swing northward, its dip changes from NW to SE and decreases abruptly to 30°. Fifty feet north of here, also on the east side of Riquier Trail, the bottom surface of the oligoclase-quartz pegmatite is exposed. This contact forms a gentle arch—the base of the pegmatite cuts directly across the underlying steeply dipping foliation of the gneiss. There is no evidence of disturbance in the gneiss such as drag folding or fracturing and the contact is sharp. The oligoclase-quartz pegmatite-diorite contact on the northeast end of this body, on the other hand, is gradational for several feet.

ORIGIN OF PEGMATITES

The texture, grain size, and mode of occurrence of the pegmatites in the Phillips mine—Camp Smith area suggest late-stage crystallization from magmatic solutions high in volatiles. The solutions must have been dioritic or quartz dioritic in composition, but they were more mafic than the magma that formed the diorite.

The relation between the hornblende facies and the oligoclase-quartz facies in the hornblende pegmatite is perplexing. The pegmatite is not zoned by layers of different composition; instead, masses of hornblende facies and oligoclase-quartz facies are interspersed in a manner that suggests simultaneous crystallization, with some injection of liquid phases of each facies into crystallizing masses. Similar mixtures of material of different composition might be obtained by crystal settling in a cooling magma. The speculation that settling of hornblende did occur is suggested by the fact that the largest crystals of hornblende are congregated at the northeast end of the pegmatite zone, which may thus be the exposed bottom of a southwestward-plunging pegmatite body. The southwest end of the pegmatite zone, which may be the top of the pegmatite body, is largely granodioritic (oligoclase-quartz) in composition along the diorite contact. That the pegmatite (and other structures) may plunge to the southwest is also suggested by the apparent southwestward-plunging major fold axis near the northeast end of the main body of pegmatite, and by the southwestward-plunging minor fold near Mine Road (see sections on "Lineation" and "Folds").

The absence of deformational features in the pegmatites indicates that they were emplaced after the major deformation in the area.

In an attempt to explain some of the relations between the hornblende facies and the oligoclase-quartz facies, an alternative explanation of the origin of the unit mapped as hornblende pegmatite was considered. This explanation, that the hornblende facies may have formed by contact metamorphism of calcareous rocks, represented by hornblende gneiss, intruded by oligoclase-quartz pegmatite, is considered unlikely for the following reasons:

1. Bodies of pegmatite consisting of interspersed masses of hornblende facies and oligoclase-quartz facies with highly irregular contacts between facies parallel the foliation in gneiss and form units that seem to have intruded the gneiss.

2. Much of the uraninite is in the hornblende facies of the pegmatite. The uraninite is crystalline and contains thorium. Uraninite in pegmatites generally contains thorium.

3. If the hornblende facies of the hornblende pegmatite had resulted from contact metamorphism of hornblende gneiss by intrusion of oligoclase-quartz pegmatite, the resulting pegmatite and adjoining gneiss should be more felsic than the original gneiss. Such enrichment in felsic material has not occurred; on the contrary, parts of

the gneiss adjacent to hornblende pegmatite have been enriched in mafic constituents.

STRUCTURAL FEATURES

FOLIATION

The hornblende gneiss is well foliated, but the biotite diorite shows weakly developed planar structures consisting of the parallel arrangement of biotite-rich layers. Foliation in the gneiss consists of alternating hornblende-rich and feldspar-rich layers. The attitude of this foliation is everywhere parallel to the trend of the rock unit which, in this area, averages about N. 40° E. and dips about 70° NW., although in other parts of the Hudson Highlands southeast dips are common. The granitic texture and fresh appearance of the feldspar-rich layers as contrasted with the granoblastic texture and altered feldspars in the hornblende-rich layers suggest that the gneiss is a migmatite, resulting from the lit-par-lit injection of a dioritic magma into a calcareous rock.

LINEATION

The only linear element that was measured in the area mapped is a small drag fold that plunges 45° SW. This fold is in hornblende gneiss west of Mine Road near the west end of trench T–9. This linear feature may indicate the plunge of local structures in the mapped area. The ore body at the Phillips mine, on the other hand, plunges northeast.

FOLDS

Although the area mapped is so small that any major folds cannot be demonstrated with confidence, the manner in which the hornblende gneiss projects into the diorite band at the northeast end of the mapped area (pl. 11) suggests the presence of a fold axis. The abrupt change in strike of the gneiss from northeast to east and the change in dip from an average of 70° W. to 76° SE., to 30° S. at this same point suggest that if there is a major fold axis here, the embayed area is the northeast end of a southwestward-plunging syncline.

The symmetrical arrangement of lithologic types as shown in plate 11 (diorite in the center, followed outward by hornblende gneiss, biotite diorite, and more gneiss) suggests possible repetition due to folding.

FAULTS

Evidence for faulting in the Phillips mine area is meager, but near the mineralized rock a few feet from the Phillips mine shaft slickensides were found, as well as highly fractured pegmatite. Pit P–3 also exposes fractured diorite and gneiss, but it is not known if these two localities of fractured rock actually represent shear zones.

According to Lowe (1950, p. 172–173) a major northeastward-trending southeastward-dipping thrust fault passes about a fifth of a mile northwest of the Phillips mine area. Possibly this fault extends under the area.

JOINTS

Joints are absent in gneiss and pegmatite and only a few were seen in diorite. Strike directions are not consistent enough to classify joints in diorite into sets. The majority of joints dip between 70° and 80°. In a few localities vein quartz, 2 to 3 inches thick, fills these joints.

MINERAL DEPOSITS

Pyrrhotite, pyrite, chalcopyrite, magnetite, and uraninite are distributed in an elongate zone in the Phillips mine-Camp Smith area. Hornblende pegmatite is the principal host rock for these minerals, but diorite and hornblende gneiss adjacent to the pegmatite also have been mineralized. The greatest concentration of sulfides in the area is at the northeast end of the mineralized zone where the Phillips massive pyrrhotite-pyrite body has been mined. Sulfides are disseminated throughout the mineralized zone in smaller amounts, whereas magnetite is abundant there and also forms small concentrations of ore grade in pit P–2 and at the Phillips mine. Unexposed ore-grade concentrations of magnetite are suggested in areas of anomalous magnetism shown on plate 12. No large body of magnetite-rich rock of ore grade is known within the area.

Uraninite also is widely distributed in the hornblende pegmatite and adjacent rocks. The largest bodies of uraniferous rock are in the sites selected for core drilling in the southwestern part of the area, but strongly radioactive rock crops out in widely separated places in the mineralized zone, as shown by radioactivity anomalies on plate 12, and is also found on the dump of the Phillips mine.

MINERALOGY AND PARAGENESIS

URANINITE

Uraninite in the Phillips mine-Camp Smith area occurs as subhedral crystals, as highly embayed and irregular grains, and as small rounded to spherical disseminated grains. Of the three types of occurrence, the large subhedral crystal type is the least common. The crystals are restricted to hornblende pegmatite and do not seem to be associated with areas of magnetite or sulfide mineralization. Aggregates of two or three subhedral crystals are common. The diameters of the individual crystals commonly range from 2 to 10 millimeters. Some crystals are much smaller, and a few as large as 2.5 centimeters were seen.

The embayed grains and smaller disseminated grains of uraninite occur in both hornblende pegmatite and its adjacent wall rock. Magnetite commonly is associated with occurrences of these types. Many of the embayed grains have an overall rectangular outline in thin section, which suggests that originally they may have been subhedral or euhedral. The embayed grains of uraninite average about 2 millimeters in diameter. The spherical grains are about 0.1 millimeter in diameter.

The embayed uraninite grains are the most common type found in the area, and the uraninite which occurs in hornblende gneiss wall rock at pit P–2 is of this type. The most common mineral filling the embayments is augite, but feldspar and magnetite also fill some of the embayments. Wherever augite is in contact with uraninite a small brown reaction rim has formed in the augite, which is the only mineral that shows this reaction rim. Whether this rim is due to chemical reaction between uraninite and augite or to a physical breakdown of augite by radiation is not known.

Uraninite in hornblende pegmatite is older than magnetite and consequently older than the sufides. Uraninite in hornblende gneiss is older than the sufides, and probably older than magnetite, but a paragenetic relation between uraninite and magnetite in this environment could not be established.

The approximate isotopic ages of a uraninite crystal from hornblende pegmatite from the dump of the Phillips mine, as reported by L. R. Stieff and T. W. Stern (written communication, 1955) are given in table 2.

TABLE 2.—*Isotopic age of uraninite (in millions of years).*

Pb^{206}/U^{238}	920
Pb^{207}/U^{235}	928
Pb^{207}/Pb^{206}	970
Pb^{208}/Th^{232}	960

In connection with the age-determination work, some physical and chemical determinations were made of the uraninite.

The uraninite has a specific gravity of 8.9+. X-ray analysis of the uraninite by D. D. Riska, U. S. Geological Survey, showed a unit cell size of 5.46±0.02 A.

Chemical analysis of the uraninite, in percent

[Analysts, Glen Edgington and R. A. Powell]

Pb	8.50
U	59.18
Th	5.49

Semiquantitative spectrographic analysis of the uraninite, in percent

[Analyst, C. S. Annell]

U, Pb	>10	Ce, Y, Nd, Al, Gd	0. 1–0. 5
None	5–10	Dy	0. 05–0. 1
Fe, Ca, Th	1–5	Mn, Er, Yb, Lu	0. 01–0. 05
Mg, Si	0. 5–1		

An isotopic analysis of the lead in the uraninite, in percent

[As reported to Stieff and Stern by the Mass Assay Laboratory, Y–12 plant, Union Carbide Nuclear Co., Oak Ridge, Tenn.]

Pb^{204}	Not detected
Pb^{206}	90. 73
Pb^{207}	6. 45
Pb^{208}	2. 81

Stieff and Stern (written communication, 1955) make the following observations on the uraninite crystal.

The uraninite was hand picked and crushed. The magnetite was removed with a hand magnet. Galena was not noticed during preparation. The sample was assumed to be in radioactive equilibrium because of the absence of secondary uranium minerals or other evidence of alteration. The absence of Pb^{204} in the lead of the uraninite made corrections for common lead unnecessary. No corrections were made for original radiogenic lead. The uraninite was fresh and the sample was excellent for age determination.

The Pb^{206}/U^{238} age of approximately 920 million years for the uraninite from the Phillips mine is considered to be the most reliable of the Pb/U, Pb/Th, and Pb^{207}/Pb^{206} ages. The higher Pb^{207}/Pb^{206} age probably is the result of several factors, such as instrumental errors, minor losses of radon, and the presence of minor amounts of original radiogenic lead for which corrections have not been made. The Pb^{208}/Th^{232} age may reflect minor errors in the analysis of thorium. Pb^{208}/Th^{232} ages usually are lower than Pb/U ages.

MAGNETITE

Magnetite occurs as irregular masses or small grains in mineralized hornblende pegmatite and adjacent wall rock in the Phillips mine-Camp Smith area. These masses or grains are interstitial and tend to conform to the structure of the host rock. In pegmatite they range from ½ to 6 inches in diameter and conform to the boundary of the hornblende or feldspar crystal that they replace. In diorite they average about 2 millimeters in diameter and show no preferred orientation. In hornblende gneiss they also average about 2 millimeters in diameter but are elongate parallel to the foliation of the gneiss. Coalescence of these masses in the gneiss may result in massive blocks of magnetite as large as a foot in diameter. Some of the magnetite has euhedral outlines, especially in hornblende pegmatite; but smooth-bordered, irregular grains are the most common. Less commonly, magnetite is in veinlets and stringers in the host rock.

Magnetite replaces hornblende, feldspar, and augite, which is the most abundant gangue mineral. Magnetite is definitely older than the sulfides and is probably younger than uraninite, although the time of emplacement of some of the magnetite and uraninite may overlap. Some magnetite may have been in the gneiss prior to the pegmatite intrusion.

PYRRHOTITE, PYRITE, AND CHALCOPYRITE

Pyrrhotite is the most abundant sulfide occurring in the mineralized zone, but minor amounts of pyrite and chalcopyrite are associated with the pyrrhotite.

The ore body of the Phillips mine is composed chiefly of massive pyrrhotite, which replaced large hornblende crystals of the hornblende pegmatite. Several stages of this replacement may be seen in blocks of ore from the mine dump. In the early stage pyrrhotite replaced hornblende crystals along border and cleavage planes and filled fractures across the crystals. As replacement progressed further, the structure of the hornblende crystals was nearly obliterated. Fine lines visible on some of the massive sulfide blocks appear to mark the cleavage trace of original hornblende but may be imprints from adjacent hornblende crystals. The chalcopyrite and pyrite associated with the massive pyrrhotite body occur more commonly as veinlets and stringers in hornblende pegmatite rather than as massive replacements of hornblende crystals. Pyrrhotite seemingly is the youngest of the sulfide minerals deposited in the mineralized zone, for it embays, engulfs, and fills fractures in the other sulfides and in magnetite and uraninite.

Pyrite and chalcopyrite in massive ore at the Phillips mine constitute a minor amount compared to the total volume of pyrrhotite, but elsewhere in the mineralized zone, where sulfides are disseminated in wall rock adjacent to hornblende pegmatite bodies, they are more abundant than pyrrhotite. Sulfide grains in the wall rock average about 2 millimeters in diameter; but, where the wall rock is gneiss, sulfide grains may coalesce into masses that are parallel to the gneissic structure and are 5 to 10 millimeters long. Pyrite is more abundant than chalcopyrite and commonly forms euhedral to subhedral crystals whereas chalcopyrite occurs only as small anhedral grains.

Pyrite is younger than magnetite and older that pyrrhotite. Chalcopyrite is definitely younger than pyrite and is probably older than pyrrhotite but this relation was not definitely established.

AUGITE AND OTHER MINERALS

Unreplaced hornblende, plagioclase, and quartz are the chief gangue minerals and have been discussed in descriptions of the rock units. Other minerals that are associated with uraninite, magnetite, and sulfides are, in the approximate order of abundance, augite, epidote, apatite, sphene, calcite, biotite, and molybdenite.

Augite is most abundant near the mineralized zones in hornblende pegmatite and in mineralized gneiss and diorite wall rock, but is also found in small amounts throughout the hornblende pegmatite bodies. Prominent parting planes in the augite indicate that it is a diallage variety. Some crystals are as much as 2 feet across. The chemical composition of the augite is given in table 1.

Augite in the hornblende pegmatite bodies is invariably closely associated with hornblende. According to John J. Prucha of the New York State Science Service (oral communication, 1954), augite in the Hudson Highlands tends to be light green, whereas hornblende usually is dark green; this color difference proved to be very useful in distinguishing the minerals megascopically. Augite commonly is in medium- to fine-grained aggregates fingering into hornblende crystals along their cleavage planes. Small stringers of augite cut the hornblende parallel to its cleavage and a short distance from the main augite-hornblende contact. Small islands of hornblende that have optical continuity, also are in the augite near these contacts. A narrow, "bleached" rim of hornblende is found along the contact of these two minerals. Another relation seen in the pegmatite bodies is a vermicular intergrowth between the hornblende and augite. In this relation the hornblende and augite have optical continuity; and, although the texture is difficult to interpret, hornblende seems to be the host mineral. Crystals of augite, as much as 2 inches across, which have the crystal habit and cleavage traces (but not the actual cleavage) of hornblende were also found in the pegmatite bodies.

Only the magnetite-bearing parts of the hornblende gneiss contain augite. It occurs as anhedral grains averaging 2 millimeters in diameter. Aggregates of these grains are elongate parallel to the foliation of the gneiss. The gneissic rock exposed at pit P–2 consists chiefly of augite, magnetite, and feldspar, it is believed that the augite is secondary and has completely replaced the original hornblende of the gneiss. Such thorough replacement of hornblende in gneiss has not occurred throughout the mineralized area. At a hornblende pegmatite-hornblende gneiss contact exposed in pit P–8, the hornblende of the gneiss has been replaced by augite in a zone not more than an inch wide that parallels the border of the pegmatite.

The augite in diorite adjacent to mineralized hornblende pegmatite also seems to be a secondary mineral and has replaced quartz and feldspar and filled grain interstices. As in hornblende gneiss, augite in diorite occurs only in areas of magnetite mineralization.

Some specimens of augite-rich rock show minor uralitization along partings, fractures, and cleavages of augite. Uralite was seen only near pit P–8, where the rock is highly weathered.

According to the evidence outlined above the authors believe that augite is associated with magnetite mineralization. Pneumatolitic fluids, probably related to but slightly younger than the hornblende pegmatite, have altered the hornblende to augite. Augite has not been found as a primary mineral in the rocks of the area, but only in mineralized parts of the rocks, and therefore its presence cannot be explained as a recrystallization of augite already existing.

The pneumatolytic solutions, which deposited magnetite and altered hornblende to augite, were moderately oxidizing. The ratio of ferric to ferrous iron is greater in augite than in hornblende, as shown in table 1. Under oxidizing conditions small subhedral uraninite crystals might be partly dissolved, resulting in the observed spherical grains and anhedral grains of uraninite embayed by augite and magnetite.

The paragenesis of the minerals is shown in figure 9.

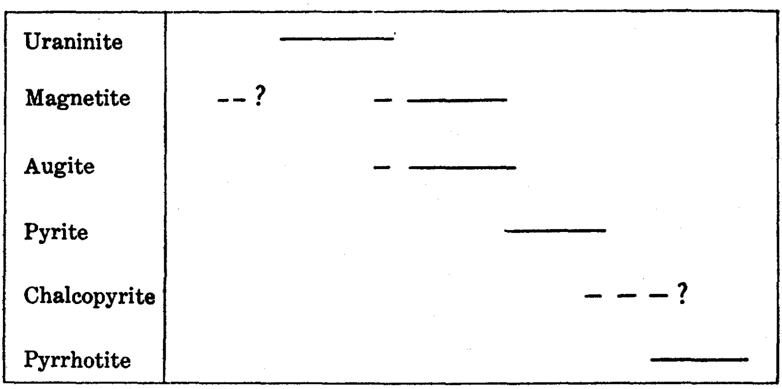

FIGURE 9.—Paragenetic sequence.

DISTRIBUTION OF URANINITE

Radioactive rock is found on the dump of the Phillips mine and in most of the old test pits that were dug in limonite-stained rock southwest of and approximately along strike with the Phillips mine. The zones of radioactivity are in hornblende pegmatite and in mineralized parts of the rock adjacent to pegmatite, as shown in plate 12.

In areas where background radioactivity is less than 0.03 milliroentgens per hour, and in some areas where background is between 0.03 and 0.10 milliroentgens per hour much of the radioactivity may be attributed to minerals other than uraninite such as zircon, sphene, allanite, and apatite. These minerals may contain both uranium and thorium. Assays of most samples of the weakly radioactive rocks show that the uranium content is insufficient to account for all the radioactivity. The excess radioactivity in these samples is probably due to thorium. Thorite has been identified by D. D. Riska in one sample taken from the upper adit of the Phillips mine (pl. 11).

Most of the radioactivity of the more strongly radioactive rock is due to uranium. Uraninite is the only uranium-bearing mineral found in significant quantity in these rocks. Uraninite occurs at the surface of bedrock and, except for some loss of luster, has been virtually unaffected by thousands of years of post-glacial weathering under humid conditions. A possible explanation for the preservation of uraninite is that a mantle of humus maintained reducing conditions at the surface of bedrock (R. G. Schmidt, written communication, 1956). A yellow mineral that resembles uranophane has been found in exceedingly small amounts in weathered uraninite-bearing rock.

Apparently a close spatial relation exists between uraninite and magnetite, but in some of the rocks these minerals occur separately.

The greatest concentrations of uranium in the Phillips mine-Camp Smith area are in rock rich in hornblende and magnetite. Selected specimens of such rock contain as much as 2.6 percent uranium. Magnetite-rich rock, similar in appearance to magnetite ores from other mines in southeastern New York and northern New Jersey, but with a noticeable amount of sulfides, averages about 0.08 percent uranium in three samples taken from the dump of pit P–2 (pl. 11). A veinlet of magnetite, about 2 millimeters wide, cuts uraninite-bearing hornblende pegmatite in this pit. Magnetite has penetrated and engulfed crystals of uraninite.

Coarse crystals of uraninite, as much as 2.5 centimeters in diameter, were found in hornblende pegmatite and in coarse-grained amphibole-rich layers on blocks of hornblende gneiss on the dump of the Phillips mine. Although sulfides were found in almost all samples that contain uraninite, no uraninite was found with very coarse grained pyrrhotite, 2 to 3 centimeters in diameter, that may be typical of the massive sulfide ore of the Phillips mine.

The largest exposure of strongly radioactive rock is in the stripped area about 1,400 feet southwest of the Phillips mine. The rock is altered hornblende pegmatite, consisting of epidotized pale tan oligoclase-quartz facies and pyroxenized greenish hornblende facies, and inclusions of hornblende gneiss. A 3-foot channel sample cut across a mafic part of this rock and a 5-foot continuation of this channel cut across the epidotized feldspathic pegmatite assayed 0.14 percent and 0.024 percent uranium respectively. A 3.3-foot channel sample cut across epidotized feldspathic pegmatite a few feet from and parallel to the sample of the mafic part assayed 0.058 percent uranium. Small grains of uraninite can be seen in some of this rock with the aid of a hand lens. Magnetic anomalies occur along both the northeast and southwest sides of this zone of uraniferous rock.

Another exposure of strongly radioactive rock is in the stripped area (pl. 11) about 800 feet northeast of the site where the channel samples were cut and about 600 feet southwest of the Phillips mine at the junction of Mine Road and Iron Mountain Road.

PHILLIPS ORE BODY

The Phillips sulfide ore body is part of a mineralized zone that is about 2,200 feet long and in places as much as 250 feet wide. The mineralized zone trends northeastward in conformity with the strike of the surrounding rock units. Boundaries of this zone have not been mapped, but the test pits and trenches and the Phillips mine shafts and adits, as shown in plate 11 are within the mineralized zone and indicate roughly its extent.

Most of the Phillips mine is inaccessible and descriptions given by earlier writers are the main source of information about the workings. Material on the mine dump and mineralized rock in the accessible parts of the mine and in many test pits and trenches near the mine were studied for more detailed information about the ore body.

The lenticular ore body at the Phillips mine is at the northeast end of the mineralized zone. It dips about 70° NW. and strikes and plunges northeast. The only first-hand description of the ore in place, known to the authors, is given in German by Credner (1866, p. 17), who states that the ore body

> * * * is an apparently lens-shaped deposit of pyrrhotite and chalcopyrite which at the locality of the mine workings reaches a thickness of 50 feet. Very light colored pyrrhotite, tarnishing brown in the air and carrying about 3 percent nickel, is the predominant ore which encloses chalcopyrite and near this, crystalline masses of black hornblende, and also apatite and quartz crystals. These last have a flowing appearance, but their crystal forms can be definitely recognized. The chalcopyrite lies in great bunches up to several cubic feet in size, in pyrrhotite, yet it seems to be confined to the gangue zones on both sides of the ore deposit, while the middle of the same is almost solely pure pyrrhotite.

Credner (1866, p. 17), as mentioned previously, stated that the ore has a maximum thickness of 50 feet. Loveman (1911, p. 235) states that the thickness of the ore body is fairly constant, ranging from 15 to 25 feet, that it thins out and disappears to the southwest, and that the northeast end has not been uncovered. Kemp (1894, p. 631) reports that the mine was worked to a depth of 300 to 400 feet, and that in depth the workings extend several hundred feet along the strike. The stope, as seen by the authors from the end of the upper adit, seemed to be as much as 40 feet wide; as seen from a ledge in the inclined shaft, the width was estimated to be from 15 to 25 feet. The part of the mine below a depth of about 100 feet is now flooded and inaccessible. Most of the part above this depth is stoped and is also inaccessible. In none of the references cited is there any suggestion that the entire pyrrhotite body was removed.

The Phillips ore consists chiefly of massive pyrrhotite, and minor amounts of pyrite and chalcopyrite. The minerals associated with the ore are magnetite, quartz, feldspar, hornblende, augite, calcite, epidote, apatite, and sphene. Uraninite occurs in the zone of sulfide and magnetite mineralization. Study of dump material shows that pyrrhotite occurs as a massive ore replacing the hornblende facies of hornblende pegmatite and its wall rock.

Kemp (1894, p. 631) reported that the ore yielded 30 percent sulfur, 0.5 percent copper, and 0.3 percent nickel, and was free of arsenic. That the ore contained only small percentages of copper and nickel is confirmed by Raymond (1894, p. 886, 887), who wrote that nearly 30 years earlier he had assisted in experiments in roasting the ore in an attempt to concentrate the copper and nickel. He stated that the product was not valuable enough to be profitably treated because the sulfur was lost in the process. These descriptions suggest that the upper part of the ore body may have been richer in nickel, and possibly copper, than the deeper parts.

ORIGIN

The sulfides, magnetite, and uraninite in the Phillips mine-Camp Smith area are probably genetically related to the same magmatic source. A simplified interpretation of the sequence of events leading to the emplacement of the minerals, as suggested by observations in the field and laboratory, is given in the following summary.

Precambrian sedimentary rocks, in part calcareous, were regionally metamorphosed to hornblende gneiss and were intruded by dioritic magma during the late stages of their metamorphism. The hornblende gneiss and diorite bodies were then intruded by magmatic solutions that formed the hornblende pegmatite. Uraninite crystallized within the pegmatite and in adjacent host rocks into which some of the solutions penetrated. During a late, possibly pneumatolytic stage of the intrusion, hornblende in parts of the hornblende pegmatite and adjacent rocks was altered to augite, and magnetite was deposited, accompanied by embayment of some of the uraninite in the altered rocks. Sulfides were then deposited from hydrothermal solutions that in general followed the channels through which hornblende pegmatite magma and augite-magnetite solutions had moved. At some later period, when this sequence of metamorphism, intrusion, and mineralization had ceased and the channels through which these materials had entered were closed, oligoclase-quartz pegmatite magma was intruded through new channels.

The order of emplacement of the two types of pegmatite, as determined by field observations, confirms the laboratory determination that uraninite in hornblende pegmatite is older than zircon in oligoclase-quartz pegmatite. The origin of the mineral deposits as postulated by the authors agrees in general but differs in a few details with that proposed by Loveman (1911, p. 236–246).

Loveman suggested that the diorite in the vicinity of the Phillips ore body was a pyroxene diorite, and that some of the amphibole in the wall rocks of the ore body was derived from pyroxene. He also stated that magnetite is intermediate in age between pyrite and pyrrhotite. It is possible that the diorite was a pyroxene diorite locally, and that the formation of coarse-grained hornblende pegmatite and emplacement of magnetite and sulfides was favored in this part of the rock. This possibility, however, does not account for the coarse-grained augite in the hornblende pegmatite, and the relations of augite to hornblende as previously described.

The differences between the relative ages of magnetite and pyrite, as interpreted by Loveman on the one hand and as suggested in the present study on the other, may be due to overlapping of these stages of mineralization. In none of the samples examined by the authors, however, was pyrite seen to occur in a manner that would suggest emplacement earlier than magnetite. It seems reasonable to expect that the sulfide minerals would be precipitated during a general stage of sulfide mineralization. Inasmuch as pyrrhotite, which is the most abundant sulfide, is definitely younger than magnetite, the main period of sulfide mineralization may have followed the main period of magnetite deposition.

EXPLORATION FOR URANIUM

MAGNETIC AND RADIOACTIVITY SURVEYS

Magnetic and radioactivity surveys were undertaken to obtain information about the occurrence and distribution of magnetic and radioactive minerals in the Phillips mine-Camp Smith area. A scintillation counter and a dip needle were used to detect radioactivity and magnetic anomalies. Results are shown in plate 12.

Background radioactivity ranged from less than 0.01 to 0.03 milliroentgens per hour (mr per hr). Readings were taken with the scintillation counter held about 6 inches above the surface of rock or ground. Areas of anomalous radioactivity were mapped as zones in which the radioactivity was in the following ranges:

Milliroentgens per hour:

<0.030	0.100–0.499
0.030–0.099	0.500–5.00

The dip needle was set to read zero at a station on an outcrop of diorite near the fork in Riquier Trail. Traverses were made along northwestward-trending lines that were 100 feet apart, except that the last 4 traverses on the southwest were 200 feet apart. Readings on the swinging needle were generally taken at 10-foot intervals. The instrument was held so that the needle swung in a vertical plane parallel to the magnetic meridian. The number of degrees that the north end of the needle dipped below the horizontal was recorded as a positive angle. Deflections above the horizontal were listed as negative angles. In plate 12 the locations and relative intensities of magnetic anomalies are indicated by the traverse lines, and by the amount and direction of deflection of the curves from the traverse lines. Positive angles of dip are indicated by deflection of the curves to the northeast side of the lines that show the location of the traverse. For example, near the center of line 900, the north end of the dip needle had a maximum positive dip of 69° near the hornblende pegmatite-hornblende gneiss contact.

Because of the occurrence of uraninite with magnetite, it was considered possible that magnetic anomalies might be used as guides in locating subsurface concentrations of uranium. Magnetic and radioactivity anomalies were found to be distributed in areas underlain by gneiss, diorite, and hornblende pegmatite, along the zone of mineralization that extends southwestward along Mine Road, and near the junction of Riquier Trail and Mine Road. Some of the magnetic anomalies along adjacent traverse lines show a general alinement with the regional strike. Others, such as those on lines 2100, 2200, and 2300, near Riquier Trail are alined diagonally across the strike. Some areas of magnetic anomalies are also areas of radioactivity anomalies, whereas other areas of magnetic anomalies are not, perhaps because the magnetic minerals are at such depths that the overlying rock would prevent any detectable amount of radiation caused by accompanying radioactive minerals from reaching the surface.

The radioactivity anomalies are surface or near-surface phenomena. If the uraninite-magnetite association persists, radioactivity anomalies should be coincident with magnetic anomalies caused by near-surface sources. In practically every place where a dip-needle traverse was made across a zone of radioactive rock, magnetic anomalies were detected. In some places the magnetic anomalies are weak, and in most places the strongest part of the magnetic anomaly does not coincide with the most strongly radioactive rock.

In general, it appears that, within the zone of mineralization, magnetic anomalies indicate mineralized rock but do not necessarily indicate uraniferous rock.

DRILLING

The zone of magnetic and radioactivity anomalies on Camp Smith, about midway between State Military Road and the Phillips mine, was selected for exploratory drilling (pl. 11). Eleven holes, size AX, totaling 1,647 feet in length were drilled under the Defense Minerals Exploration Administration contract along a line that roughly parallels Mine Road. The holes are inclined 45° to 62° from the horizontal. Holes 1 to 9 are spaced about 100 feet apart. Hole 10 is collared at a point about 110 feet northwest of the collar of hole 9 and extends beneath hole 9. Hole 11 is midway between holes 7 and 8. Holes 1 to 10 were drilled in the first stage of exploration, hole 11 in the second stage.

The drill holes were all collared in areas underlain by hornblende pegmatite or hornblende gneiss. In general the drill cores consist of hornblende gneiss with intervals of hornblende pegmatite (some of which is the oligoclase-quartz facies) in the upper part; below this is a predominantly pegmatitic zone with smaller amounts of gneiss, then diorite with minor amounts of pegmatite, and massive diorite in the lower part of the cores. The hornblende pegmatite zones and some of the gneiss with thin zones of hornblende pegmatite contain variable amounts of sulfides, magnetite, and uranite. Smaller amounts of sulfides and magnetite are in the diorite.

ASSAYS OF CORE AND GAMMA-RAY LOGS OF DRILL HOLES

Results of assays of selected parts of core, as reported by Mines, Inc. are given in table 3. Lithologic logs of cores and gamma-ray logs of drill holes are shown in plate 13. The assays of core show close agreement between chemical and radiometric uranium determinations, which suggests, but does not prove, that the uranium in these rocks is in equilibrium with its daughter products and that thorium is of minor abundance. The crystal of uraninite selected for age determination contained 5.49 percent thorium. A comparison of the location of parts of core that were selected for analysis with zones of radioactivity shown in gamma-ray logs of the drill holes suggests that the core is not of adequate diameter to be representative of the rock. Some parts of core from zones of radioactive rock were not sufficiently radioactive to warrant analysis for uranium; for example, part of a core from a radioactive zone in hole 11 showed enough radioactivity to justify analysis, but the core from two more strongly radioactive zones in the same hole apparently was not sufficiently radioactive to warrant further assays.

Owing to problems of measuring cores, loss of cores, and errors in measuring positions of anomalies in the gamma-ray logs, allowance must be made for possible errors in correlating radioactive parts of drill cores with zones of radioactivity found in the drill holes. If the cores were a representative sample of the rock, however, each radioactivity anomaly in a drill hole should be represented by radioactive parts of the core, and any errors in measurement could be corrected by shifting the lithologic log to fit the gamma-ray log. The gamma-ray logging equipment appeared to be functioning properly, and each hole was logged twice. Therefore, the radioactivity anomalies are real and their locations are reasonably accurate. Because of the inhomogeneous distribution of uraninite some of the cores might be expected to contain more or less than a representative amount of uranium.

TABLE 3.—*Defense Minerals Exploration Administration drill-core assay data*

[Assay report furnished by Mines, Inc.]

Hole	Depth (feet)	Length (feet)	Chemical assay [1] U_3O_8	Radiometric determination	
				eU_3O_8	eU_3O_8
8	37.0- 50.0	13.0	0.144	0.14	0.14
	68.5- 82.0	13.5	.0742	.071	.07
	47.5- 48.0	.5	.198	.185	.18
6	79.0- 83.0	4.0	.0820	.080	.08
9	46.0- 49.0	3.0	.146	.150	.15
11	68.0- 81.0	13.0		[2].028	
4	77.0- 83.5	6.5		.006	
4	96.0-106.0	10.0		.005	
3	57.0- 72.0	15.0		.009	
10	131.5-133.5	2.0		.05	
6	50.5- 52.0	1.5		.005	
11	68.0- 81.0	13.0		[2].050	
7	43.5- 45.0	1.5		.017	
7	69.5- 71.0	1.5		.019	
9	21.0- 23.0	2.0		.042	

Hole	Depth (feet)	Length (feet)	Au (oz. per ton)	Ag (oz. per ton)	Co (percent)	Cu (percent)	Ni (percent)
11	68.0- 81.0	13.0	0.005	0.025	0.045	0.066	0.109
	68.0- 81.0	13.0	.005	.025	.045	.066	.109
4	77.0- 83.5	6.5	.005	.025	.013	.330	.016
	96.0-106.0	10.0	Nil	.025	.072	.198	.154
3	57.0- 72.0	15.0	Nil	.030	.040	.030	.134
10	131.5-133.5	2.0	Nil	.165	.003	1.52	Not detected.
6	50.5- 52.0	1.5	.005	.040	.240	.030	.093
8	47.5- 48.0	.5	Nil	.055	.093	.066	.321

[1] Percent soluble in HNO_3.
[2] Splits from same sample.

For these reasons, it is difficult to evaluate the assays and the gamma-ray logs, and to interpret the gamma-ray logs on the basis of assays. The gamma-ray logs represent much greater volumes of rock than do the drill cores. Practically all the radioactivity that is measured, however, is from sources that are within 1 or 2 feet of the drill holes. The gamma-ray logs and the assays of cores, if evaluated together, are believed to furnish sufficient information about the rock within 1 or 2 feet of the drill hole. In addition to radioactivity measurements, other geologic evidence, such as continuity of zones of radioactivity in outcrop, must be considered in extrapolating the extension of a zone of radioactivity beyond this distance.

INTERPRETATION OF GAMMA-RAY LOGS

An interpretation of the radioactivity anomalies found in the drill holes, and results of assays of matching parts of core, are given in table 4.

K. G. Bell of the U. S. Geological Survey has estimated the thickness and grade of uranium ore, uniformly disseminated in sandstone, that would give similar gamma-ray anomalies on a similar instrument. These estimates are shown in plate 13. It is impossible to interpret accurately the thickness and grade of the zones of radioactive rock that cause the radioactivity anomalies in the drill holes, because of differences in the distribution of radioactive minerals in sandstone-type deposits and in pegmatites. The estimated average grade of the thin zones of radioactive rock plus barren rock between the zones, as given in table 4, is based on comparison of anomalies measured in drill holes with similar anomalies associated with sandstone-type uranium

TABLE 4.—*Comparison of results of assays of Defense Minerals Exploration Administration drill core and estimated grade of rock*

[Based on interpretation of gamma-ray logs of drill holes]

Hole	Sample length (feet)	Estimated grade [1] eU_3O_8 (percent)	Assay grade eU_3O_8 (percent)	Ratio of assay grade to estimated grade
7	1.5	0.132	0.017	0.12
7	2.0	.130	.019	.14
9	2.0	.095	.04	.42
9	3.0	.086	.146	1.69
6	4.0	.120	.082	.68
8	13.5	.121	.074	.61
8	13.0	.116	.144	1.24
11	13.0	.027	.028	1.03

[1] Estimated grade based on interpretation of radioactivity anomalies using information furnished by K. G. Bell (written communication 1955).

deposits. The correlation of the estimated grade with the assay grade is poor in detail but good in general. The discrepancy between estimated grade and assay results is greatest in the thinner zones of radioactivity. The weighted assay grade is a little more than 90 percent of the estimated grade in the thicker zones.

SAMPLES OF OUTCROPS

The radioactive rock is in two major zones that have been sampled in drill holes 6, 7, 8, 9, 10, and 11, and at the outcrop in the area between lines 600 and 1300 (pl. 12). These zones probably extend along planes that are roughly parallel, and about 30 feet apart where cut by the drill holes. Within these zones, the distribution of uranium is extremely inhomogeneous.

Seven channel samples of radioactive rock were cut by Mines, Inc., and three samples were cut by the authors, in the stripped area between lines 1100 and 1300. These 10 channel samples total 31.7 feet in length. The weighted average of the samples is 0.069 percent U_3O_8. The extreme variability in the distribution of the uranium minerals in the rock limits the accuracy of estimates of grade based on assays of channel samples. The zone of strongly radioactive rock (0.1–5.0 mr per hr) is fairly continuous for about 100 feet in this area. The average width of the more strongly radioactive and continuous parts of this zone may be about 3 feet with an average grade of about 0.03 percent U_3O_8.

Radioactivity measurements made in a trench on line 1000 (pl. 12) indicate a zone of rock about 3 feet thick that may contain about 0.05 percent U_3O_8. A channel sample 4 feet long cut by Mines, Inc. in a radioactive zone in a trench on line 900 assayed 0.12 percent U_3O_8. These zones of radioactive rock are near the diorite-hornblende pegmatite contact and probably correlate with the radioactive zones in the deeper parts of holes 8 and 9, near the diorite footwall. The radioactive rock in the stripped area between lines 1100 and 1300 probably correlates with the upper zone of radioactive rock in holes 6, 7, and 11.

EVALUATION

The potential value of the uranium deposit in the Phillips mine-Camp Smith area cannot be calculated precisely on the basis of the sampling that has been done. Evaluation of gamma-ray logs of drill holes and assays of samples from drill core and samples taken from outcrop, however, indicates that the deposit is submarginal under 1955 marketing conditions for uranium. Although the area between the drilling sites and the Phillips mine shaft has not been tested, further exploration does not appear to be warranted at this time. If marketing conditions for uranium become more favorable, the uranium deposit in the Phillips mine-Camp Smith area might be reappraised.

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