UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geology of the uranium prospect at Camp Smith, New York with a new model for the formation of uranium deposits in metamorphosed submarine volcanogenic rocks.

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Layperson's Summary

Uranium occurs in a variety of rock types including a portion of a massive sulfide body at Camp Smith, Westchester and Putnam Counties, New York. This large body of iron sulfide can be interpreted as an indicator of the environment in which it and its enclosing rocks were formed. The interpretation that I favor is that the rocks and massive sulfide body formed in a submarine volcanic environment.

A new model for the origin of the Camp Smith deposit and similar uranium deposits is presented in a speculative fashion. It is suggested that submarine volcanism supplied an abnormal amount of uranium to a hot water system that circulated through volcanic rocks and sediments beneath the ocean floor. The elements in the hot water system were deposited near the interface between seawater and sediments where the hot water mixed with cold seawater. The uranium was probably disseminated in the sediments and was not deposited in economic concentrations. At a much later time the sediments and the uranium in them were metamorphosed at high temperature (greater than 500 degrees C) and pressure (greater than 3 kilobars). During the metamorphic process the uranium was concentrated into possibly economic deposits.

Abstract

Uraninite of Precambrian age occurs locally in and around a massive sulfide deposit at Camp Smith, Westchester and Putnam Counties, New York. The host rocks are believed to be part of a sequence of marine sediments and submarine volcanogenic rocks that were metamorphosed to leucogneisses, amphibolites, and amphobolite gneisses in the granulite facies. Ore grade concentrations of uraninite occur (1) in the outer Cu-Ni-bearing zone of the sulfide body; (2) in magnetite-rich and scapolite-rich layers within amphibolite gneiss; and (3) in amphibole-quartz-feldspar ± pyroxene pegmatites. The uranium-rich horizons are generally near the contact between rocks of keratophyre and spilite affinities.

It is suggested that the iron oxide, uranium-rich, and sulfide-rich horizons and their host rocks were originally deposited in the distal, volcanogenic, massive sulfide environment.

Introduction

Uranium occurs in a variety of settings and a number of places in the Hudson Highlands of southeastern New York and northern New Jersey (Grauch and Zarinski, 1976). There are enough similarities between the occurrences to suggest that they may have a common genesis. The most striking of the common attributes are the apparent stratabound form of most of the occurrences and their close proximity to iron deposits that contain disseminated sulfides. These attributes and the regional geologic setting together indicate a submarine volcanogenic environment. A genetic model based on the concept that the uranium occurrences formed in this environment should benefit uranium exploration and resource evaluation of the region.

This report is a slightly modified version of the text of a paper presented at the 1977 Symposium on Geology of Uranium Deposits sponsored by the Society of Economic Geologists (Grauch, 1977). Its purpose is to present in an abbreviated manner a conceptual model for the occurrence of uranium in a metamorphosed Precambrian volcanogenic environment.

The model is based on the uranium occurrences at and around the Phillips mine massive sulfide deposit, Westchester and Putnam Counties, New York (figure 1). Many of the interpretations and concepts presented have not yet been tested. Therefore, this report should be considered as a progress statement on an ongoing program in the Reading Prong-Hudson Highlands region. Field and laboratory investigations underway are designed to test and refine the model.

Regional Setting

The distribution of Precambrian rocks in the Hudson Highlands region of southeastern New York is shown on figure 1. The Hudson Highlands are considered to be two separate blocks, an eastern and western highlands, each of which as distinct lithologies, structure, magnetic signature, and thermal history. The Ramapo-Canopus fault system has tentatively been picked as the division between the two blocks.

The eastern highlands block (underlain primarily by quartzofeldspathic gneisses) is interpreted by Helenek and Mose (1976) to have been first metamorphosed about 1.3 billion years ago. Other episodes of regional metamorphism affected the area approximately 980 million years ago, about 600 million years ago, and during the Taconic orogeny (450 million years ago).

The western highlands block is underlain predominantly by charnockitic gneisses, paragneisses, and granitoid plutonic rocks. The principal Precambrian events of the region are summarized in table 1. Helenek (1971) suggests that a thick sequence of sediments and volcanics were deposited on a preexisting granitic terrain prior to 1170 million years ago. A major thermal event that affected the western highlands block reached its thermal maximum about 1150 to 1100 million years ago. Accompanying this granulite-facies metamorphism were several deformational events, anatexis, and the emplacement of the Storm King Granite (see Helenek, 1971 and Lowe, 1950). The anatexis resulted in the formation and emplacement of two syntectonic to late tectonic units, the Pochuck digrific gneiss and the Canada Hill Granite of Berkey and Rice (1921). The final crystallization of the Canada Hill Granite took place around 914 million years ago. During the late Precambrian, at least part of the western highlands block was intruded by diabase dikes (Joe Wallach, oral communication, 1975). The post-Precambrian history of the western highlands has not been worked out in detail; apparently no major thermal events affected the area.

Table 1

Precambrian geologic events in the Hudson Highlands Region

(modified from Helenek and Mose, 1976)

pre-1170 m.y.	1.	Deposition: sediments, volcanics
150 m.y.-1100 m.y.	2.	Metamorphism, folding anatexis, plutonism
914 m.y.	3.	Final crystallization of anatectic granite
ate Precambrian	4.	Emplacement of diabase dikes

Figure 1

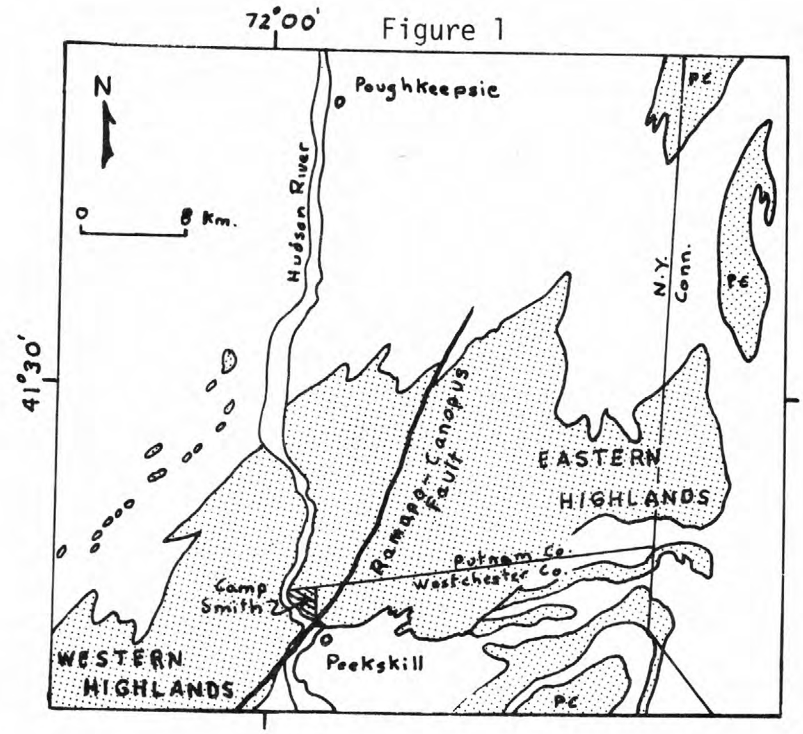


Figure 1. Index map of southeastern New York showing distribution of Precambrian rocks stippled pattern. Modified from Helenek and Mose, 1976.

Table 1

Precambrian geologic events in the Hudson Highlands Region

(modified from Helenek and Mose, 1976)

pre-1170 m.y.	1.	Deposition: sediments, volcanics
1150 m.y.-1100 m.y.	2.	Metamorphism, folding anatexis, plutonism
914 m.y.	3.	Final crystallizaton of anatectic granite
late Precambrian	4.	Emplacement of diabase dikes

The generalized stratigraphy of the western highlands is summarized in figure 2. The basement is a complex unit that is predominantly hornblende granite. Overlying the basement are two distinct metasedimentary units, a biotite-bearing paragneiss unit and a quartz-plagioclase gneiss unit. This lower quartz-plagioclase gneiss unit is highly variable in its mafic content and has large lenses and units of amphibolite. There are also minor units of graphitic pyroxene-scapolite gneiss, marble, and quartzite. Helenek (1971) interpreted this unit as a series of andesitic and basaltic submarine flows, andesitic tuffs and breccias and volcanic graywacke with minor lenses of limestone, siliceous material, calcilutites, and clastic siltstones and mudstones.

The biotite paragneiss unit consists predominantly of non-rusty paragneiss and minor amphibolite. The amphibolites are commonly associated with quartz-plagioclase leucogneiss. There are minor units of sillimanitic paragneiss, quartzite, marble, and garnet-pyroxene rock. This unit is interpreted (Helenek, 1971) to be a heterogeneous series consisting of graywacke with its associated lithologies and the spilite-keratophyre suite.

Local Geology

The geology of a portion of the Camp Smith-Phillips mine are is generalized and simplified on figure 3. The map pattern is the result of at least two periods of folding and at least two periods of brittle deformation.

The first of the two folding events was isoclinal. Two examples of isoclinally folded isoclinal fold noses were observed, suggesing the possibility of multiple pulses within the first event or two separate isoclinal folding events. This event caused severe stretching along fold limbs and thickening and (or) shearing at some fold noses.

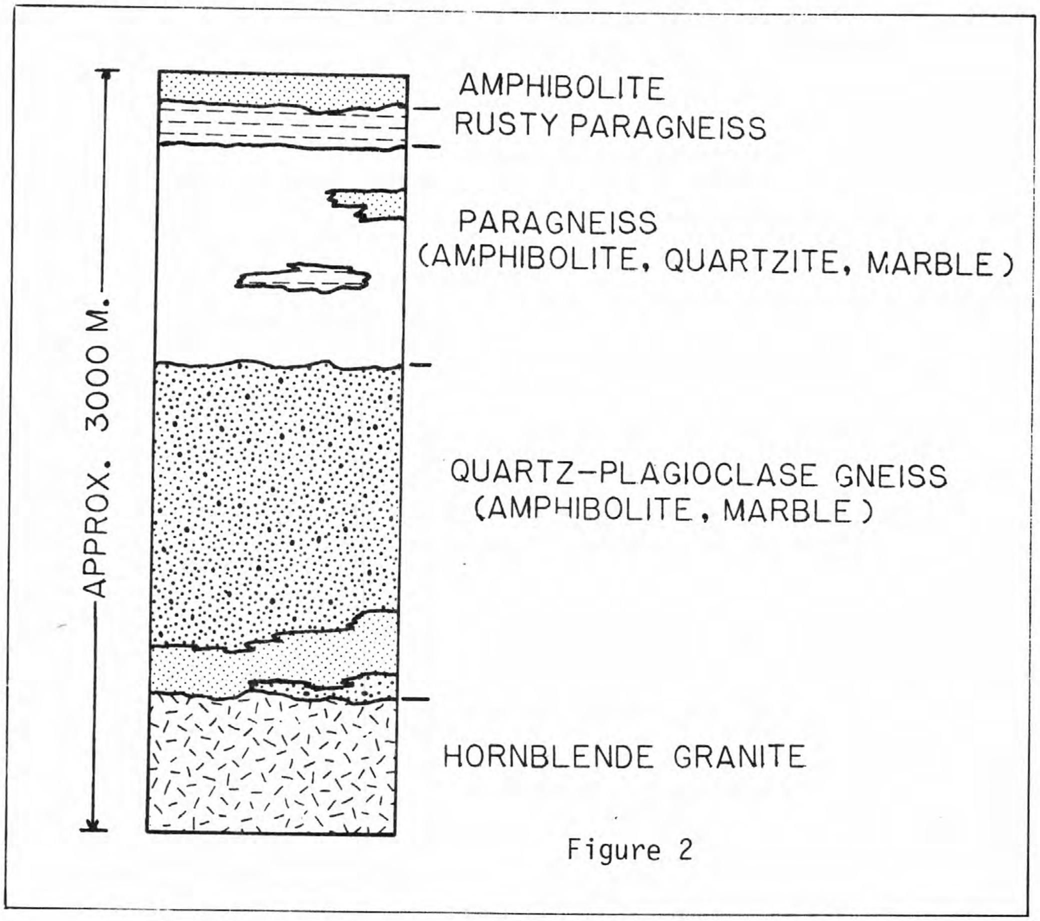


Figure 2. Generalized stratigraphic column of the western Hudson Highlands (from Helenek, 1971). The patterns on the column are consistent with a specific rock type, for instance, the horizontal dash pattern indicates the rusty paragneiss unit as well as rusty paragneiss within the paragneiss unit.

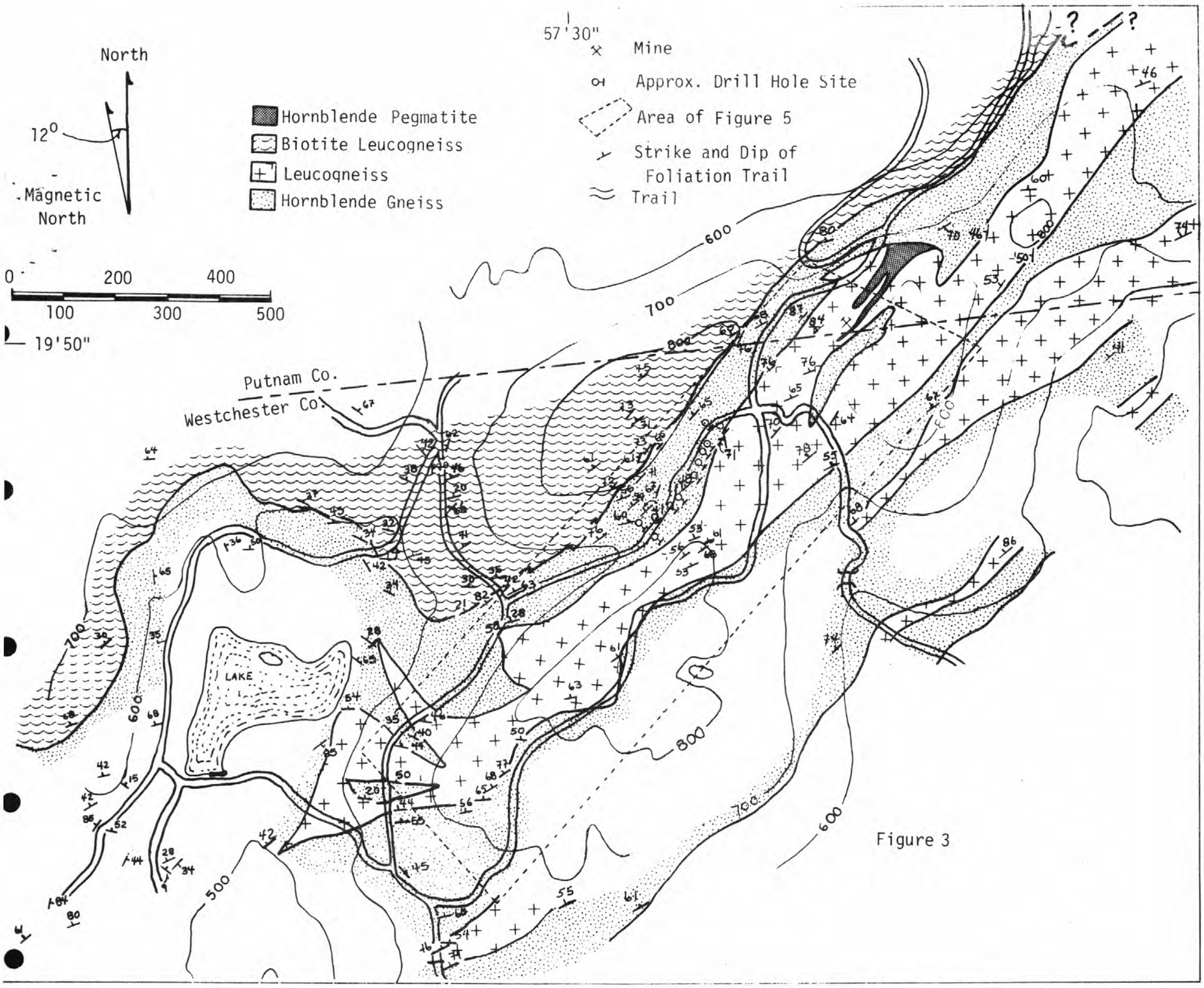


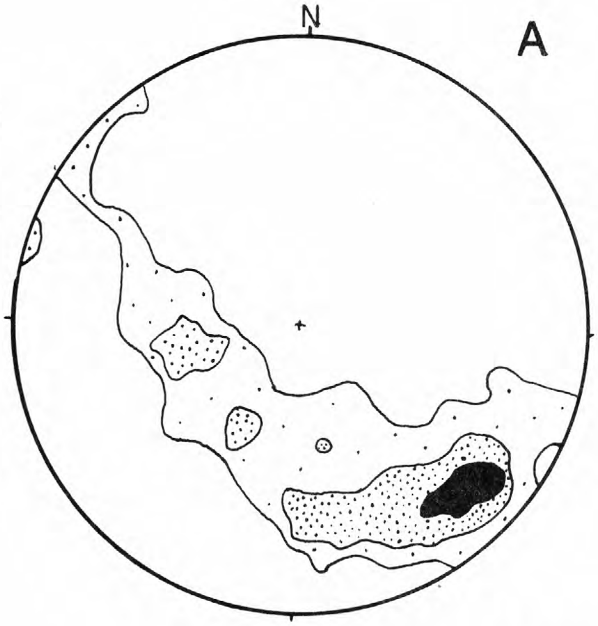
Figure 3. Generalized geologic map of the northeastern portion of Camp Smith, New York (from geologic mapping by Grauch in 1975-1977 and from Klemic and others, 1959).

The second folding event resulted in more open folds. The area of figure 3 is apparently on the north limb of a northeast-plunging antiform that formed during the second event. figure 4A is an equal-area projection of poles to mineral foliation (generally parallel to compositional layering and the axial planes of the isoclinal folds). Most of the measurements were taken within the area of figure 3; however, some were taken on the south limb of the antiform, resulting in the well defined girdle.

The earlier of two fracturing events is recorded as thin, healed breccia zones, some of which contain molybdenite and uraninite. The presence of these two minerals, which were apparently mobile only during the late Precambrian suggests that the fractures probably formed, or at least were closed during late Precambrian time. The later fracturing is readily visible. The most of the faults are curviplanar. There is very little or no apparent offset on any of the faults, but most do have well developed zones of mylonitization.

Two prominent joint sets are developed in the area: a nearly vertical west-northwest-trending set, and a west-dipping, north-northwest-trending set (figure 4B). No uranium mineralization was observed on the joint surfaces.

There are three major rock units exposed in the area (figure 3): a biotite leucogneiss unit, a unit of hornblende gneiss and amphibolite, and a unit of leucogneiss. In most cases the mineral foliation is parallel to compositional layering and may be inferred to be parallel to original bedding.



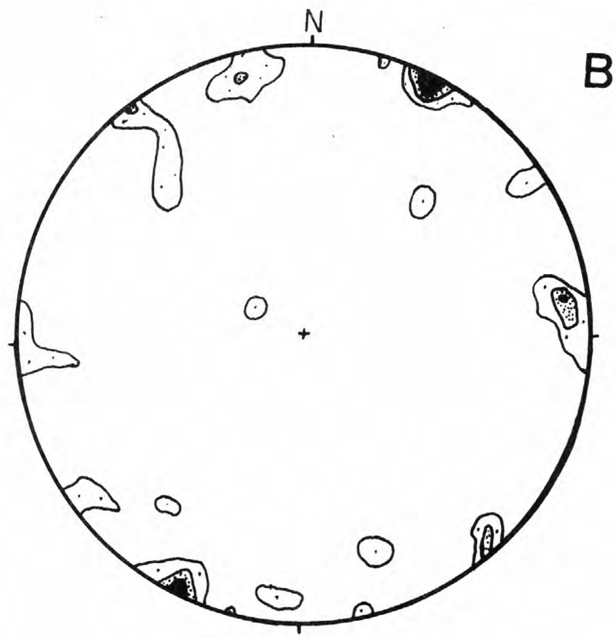


Figure 4

Figure 4A. Southern hemisphere equal-area projection of 241 poles to foliation. Contour intervals are 1.7%, 3.3%, and 6.6%.

Figure 4B. Southern hemisphere equal-area projection of 65 poles to joints. Contour intervals are 1.3%, 2.6%, and 3.3%.

The biotite leucogneiss is composed of quartz, plagioclase, and minor amounts of biotite and microcline. It grades northward into a more biotite-rich gneiss that has thin units of graphitic biotite gneiss and schist. Some of the schists contain accessory garnet. The biotite leucogneiss unit is generally xenoblastic granular in texture, with foliation defined by biotite and occasionally by the elongation of quartz.

The leucogneiss unit is a relatively homogeneous, poorly foliated quartz-plagioclase gneiss. However, some portions of the unit display very thin, well developed compositional layering. It contains a variable amount of hornblende ranging from 0 to 3 modal percent. The rock has a xenoblastic texture with foliation defined by hornblende (when present) and by elongation of quartz.

The third major rock unit in the area is a mixture of amphibolite and hornblende gneiss. The hornblende gneiss is heterogeneous, with the amount of hornblende varying from a few percent to several tens of percent. In a few outcrops it seems to grade into amphibolite where the quartz and feldspar account for only a few modal percent of the rock.

In addition to these major rock types, there are several significant minor rocks types. Unfortunately, the outcrop is so poor and the inferred surface occurrences of these rocks are so small that they cannot be mapped at the scale of figure 3. Most have been observed only as float. The minor rock types associated with biotite leucogneiss are graphitic gneiss, graphitic schist, calcsilicate gneiss, marble, and graphitic metachert. A lens of marble was also observed in the hornblende gneiss-amphibolite unit. Scapolite-pyroxene gneiss, magnetite-rich amphibolite gneiss, and amphibole-pyroxene-garnet-graphite skarn also occur in that unit.

In addition to the above mentioned rock types, there are minor amounts of igneous and metaigneous material. There are at least two different basic-dike associations. The earliest is a premetamorphic set that cuts across the compositional layering of the hornblende gneiss and seems, in places, to feather into it. The foliation of the dikes is generally parallel to the foliation and compositional layering of the hornblende gneiss. The second generation of dikes is a N-S-trending set of diabase dikes. These are poorly foliated and may be equivalent to diabases of very late Precambrian age that occur elsewhere in the western highlands.

There are also two generations of pegmatites in the area. The earlier ones are syntectonic to late-tectonic hornblende pegmatites. Uraninite from one of these pegmatites has been assigned a minimum age of 970 m.y. (K.R. Ludwig, oral communication, 1976), based on slightly discordant Pb-Pb and U-Pb determinations (Klemic and others, 1959). Gradations from hornblende gneiss; to poorly foliated, medium-grained pegmatite; to coarse-grained, poorly foliated to non foliated hornblende pegmatite can be seen in a few localities. These basic pegmatites were probably formed by anatexis of the host hornblende gneiss and amphibolite. The youngest pegmatites of an area are post tectonic quartz-feldspar pegmatites. Crosscutting relationships between these pegmatites, the three major rock units, and the hornblende pegmatite have been observed. These acidic pegmatites may be associated with the late-tectonic Canada Hill Granite.

Mine-site and mineral-deposit geology

The Phillips mine was apparently developed in the 1860's. (Kemp, 1894). It was orignally worked for copper and nickel. When those commodities became subeconomic soon after initiation of mining, pyrrhotite was mined for the production of sulfuric acid. The mine was closed prior to the turn of the century. Based on the earlier reports of the mine (Kemp, 1894; Credner, 1866; and Loveman, 1911) and on material from the dump, the deposit has been interpreted as a zoned massive-sulfide deposit (Heyl and Bozion 1971). The outer zone comprises pyrrhotite, pyrite, chalcopyrite, magnetite, apatite, and uraninite. The core of the body is massive pyrrhotite.

Uranium was first reported in the area in 1939 by Zodac. However, it was not until the early 1950's that the area received serious study for its uranium potential (Klemic and others, 1959). In 1954 a private company concluded that the uranium was primarily restricted to hornblende pegmatite. They drilled eleven holes totaling 502 m based on that assumption. A simple calculation using the eU logs published by Klemic and others (1959) indicates that about 11,000 kg of uranium was intersected. The work of Klemic and others (1959) shows that uranium is concentrated along the contact between the leucogneiss and hornblende-gneiss units. A gamma-ray spectrometer survey of the mine area (Campbell and Grauch, 1977) confirms that observation and shows that the anomalous uranium concentrations are more extensive than previously reported (figure 5).

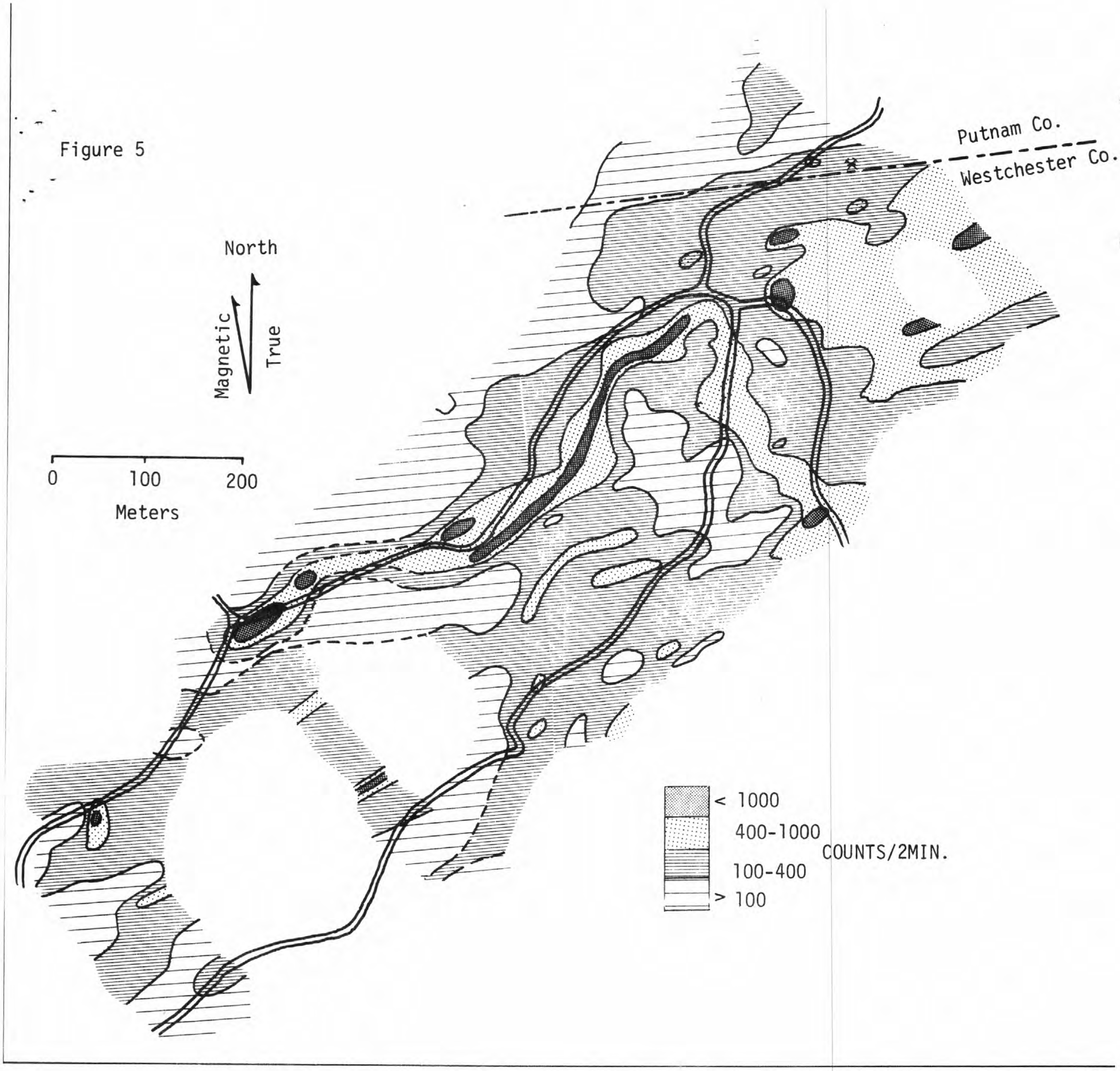


Figure 5. Uranium channel (^{214}Bi) results of a gamma-ray spectrometer survey of the Phillips mine area.

My work and that of Klemic and others (1959) show that the uranium occurs as uraninite in a variety of rock types, including the scapolite-pyroxene-amphibole gneiss, the magnetite-rich hornblende gneiss, the outer zone of the massive-sulfide body, and the hornblende pegmatite. Uraninite occurs as inclusions in scapolite and pyroxene in the scapolite-pyroxene-amphibole gneiss. In the magnetite-rich hornblende gneiss it occurs as inclusions in hornblende and in association with magnetite. There is a variety of textural relationships between uraninite and magnetite. They do not define any clear-cut paragenetic sequence between the two phases, probably because of complex recrystallization during metamorphism. There are also several different textural relationships between uraninite and coexistent phases in the outer zone of the massive-sulfide body. In the Hornblende pegmatite, uraninite occurs in two habits: as inclusions in apatite and as free crystals as much as 2 cm across.

Interpretations and speculations

Helenek's (1971) work indicates that in the western highlands there are two major sequences of metasediments and metavolcanics more than 1170 million years old overlying an older basement. The upper sequence has been interpreted as originally having been graywackes with associated minor sediments and the spilite-keratophyre association. I have tentatively correlated the Camp Smith rocks with this upper unit on the basis of lithologic similarities. Whole-rock compositions from each of the major rock units (table 2) in the Camp Smith area are comparable to those of unmetamorphosed spilite from the Virgin Islands and keratophyre from Japan. The chemical data show that the bulk compositions of the New York rocks are similar to those of unmetamorphosed rocks from environments of deposition like those proposed by Helenek (1971) and myself. I suggest that the Camp Smith rocks were originally a sequence of submarine volcanogenic material with minor amounts of clastic (graphitic pelites) and chemical sediments (iron oxide, chert, and carbonate units).

A simplified geologic map of the Phillips mine area is shown in figure 6. The biotite gneiss and schist unit is interpreted to have been a complex sequence of predominantly graphitic clastic sediments, and the leucogneiss and the amphibolite gneiss units are interpreted to have originally been spilite and keratophyre units, respectively. Additionally, the zones containing concentrations of magnetite, disseminated sulfides, and uranium may have contained some chemical precipitates. The environment of deposition that I envisage for these rocks has been described by Ridler (1973) as the volcanogenic massive sulfide environment. Specifically, the distal environment (fig. 7), is where the Camp Smith sequence may have formed.

Table 2

Average rock compositions

(With the following exceptions, the new analyses are X-ray fluorescence analyses performed by J.S. Wahlberg, W. J. Walz, and J. W. Baker: ferrous iron was determined by a volumetric method by Wayne Mountjoy: ferric iron was found by difference and total iron was determined by XRF; and MgO and Na_2O were determined by semi-quantitative 6-step spectrographic analyses performed by M. W. Solt and J. C. Hamilton).

	Hornblende Gneiss (14) *1 Partial Analysis	Spilite *2 (Virgin Islands) Partial Analysis	Biotite Leucogneiss (7) Partial Analysis	Leucogneiss (10) Partial Analysis	Keratophyre *3 (Hokkaido, Japan)
SiO_2	49	49	62	68	66
TiO_2	.9	1	.4	.3	.3
Al_2O_3	11	15	14	14	17
Fe_2O_3	5	11	1	.5	5
FeO	7		2	1	1
MnO	.1	n.d.	.1	trace	.1
MgO	6.1	7	.8	.6	.6
CaO	10	8	3	3	3
Na_2O	4	3	4	6	6
K_2O	.9	.4	3	2	trace

n.d. = not determined

*1 numbers in brackets (14) indicate the number of specimens analyzed
*2 from Donnelly, 1966
*3 from Bamba and Sawa, 1967

Figure 6

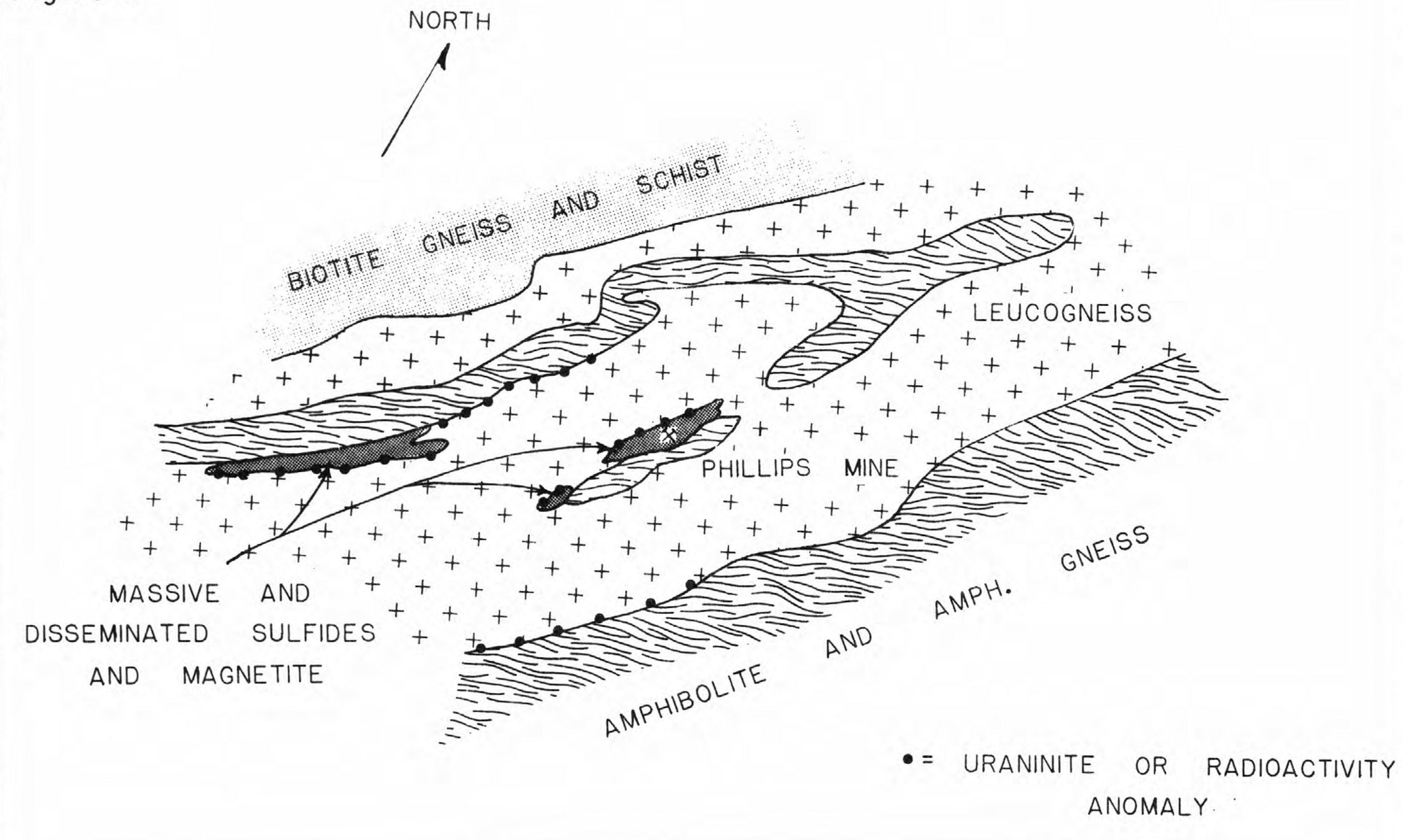


Figure 6. Simplified map of Phillips mine area geology.

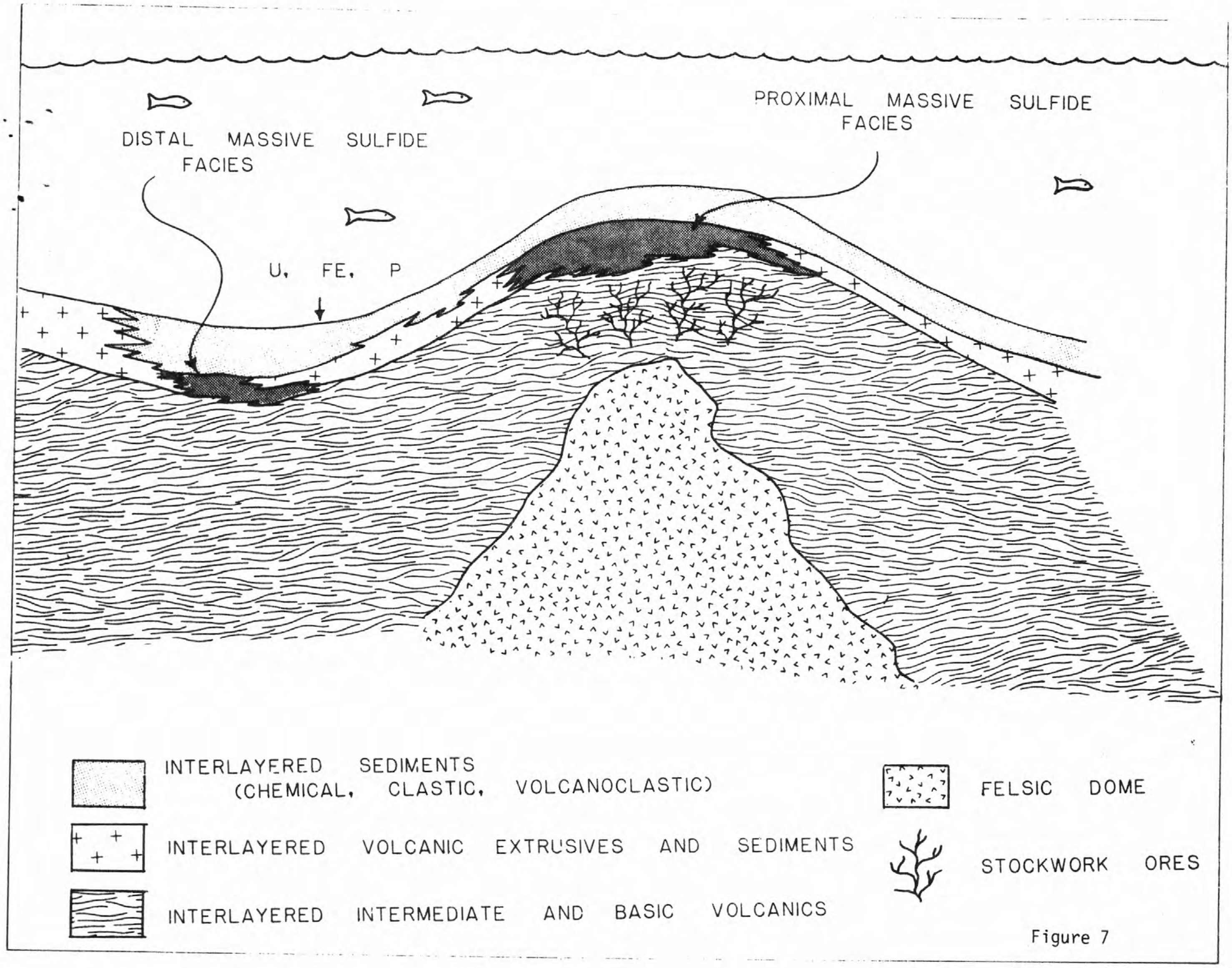


Figure 7. Schematic cross section of massive-sulfide environment of deposition (modified from Ridler, 1973).

In this environment the orebodies are smaller and the rock facies tend to be thinner and more complexly interlayered than in the proximal zone. In order to emphasize the similarities between the lithologies of the volcanogenic massive-sulfide environment and those in the Camp Smith area, the patterns used to indicate the various units on figure 6 are the same as their proposed equivalents on figure 7.

Uranium deposits in rocks that apparently formed in the distal environment have been described by Adamek (1975) and Gandhi (1977). Adamek (1975) describes uraninite, magnetite, and sulfide concentrations that occur at different, but stratigraphically restricted, horizons with in a sequence of metamorphosed (greenschist facies) submarine tuffs and graphitic sediments in northern Sweden. Similar deposits in east-central Labrador (Kitts and Michelin deposits) are described by Gandhi (1977). These deposits are also stratigraphically restricted within a metamorphosed (greenschist to middle-amphibolite facies) sequence of marine sediments including basic and acid tuffs and pillow basalts.

The proposed sequence of events that led to the formation of the mineral deposits in the Camp Smith area is summarized in table 3.

During or shortly after the waning stage of sulfide formation, iron oxides were precipitated. Concurrently, uranium and possibly phosphorus were precipitated. The phosphorus probably precipitated as apatite. There is a variety of mechanisms, such as precipitation of uraniferous apatite, direct precipitation of uraninite, precipitation of a complex tetravalent uranium oxide, or absorption of uranium on the iron oxides, which could create a low-grade concentration of uranium at or near the seawater-rock interface. The subsequent high-grade metamorphism recrystallized, partially mobilized, and further concentrated the uranium.

Table 3

Summary of ore-forming events

1. Submarine deposition of basic extrusive volcanics and volcanoclastic sediments.
2. Submarine deposition of intermediate to acidic volcanoclastic sediments and contemporaneous chemical and clastic sediments;

   Formation of the Phillips mine massive sulfides;

   Deposition of iron-rich horizons.
3. Deposition of carbonaceous pelitic sediments.
4. Burial, consolidation, deformation.
5. High-grade metamorphism accompanied by formation of hornblende pegmatites; Mobilization and concentration of uranium.

Acknowledgments

I am deeply indebted to Harry Klemic, who not only unselfishly shared his original data on the Camp Smith area but also encouraged my studies and asked the questions that have kept my speculations within reasonable bounds. Thanks are also due Tom Nash, who reviewed an earlier version of this manuscript and helped me organize my wandering musings.

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