

URANIUM AND RARE EARTH MINERALIZATION AT THE BEMCO MINE NEAR CRANBERRY LAKE, NEW JERSEY

Andreas H. Vassiliou

*Department of Geological Sciences,
Rutgers University
Newark, New Jersey*

INTRODUCTION

The Bemco Mine, also known as the Charlotte Mine, is in Sussex County, northwestern New Jersey, about fifteen miles southwest of Franklin (Fig. 1). The mine was created in the late fifties as a result of highly radioactive zones discovered along the perimeter of a Precambrian outcrop of granite pegmatite.

Exploratory mining in 1959, mainly in the form of open cuts, revealed a narrow ore band (average width about 30 cm) along the strike of the contact between the granite pegmatite and the surrounding wall rock, a pyroxenitic gneiss. Additional mining operations conducted in 1959 included a shaft and drift trending northwest along the strike of the pegmatite. The ore mined, a total of 95 tons, was sold for its uranium content, but its high rare-earth values were largely overlooked. The ore consisted of a friable matrix of magnetite (about 90%) and a suite of accessory ore minerals such as zircon, fergusonite and uranothorite which contained rare earths, thorium, uranium, and other associated elements.

Previous published reports on this occurrence include Williams (1967) who briefly described the deposit as part of a Bureau of Mines reconnaissance report on rare-earth resources in northern New Jersey and two short reports by the writer and his associates (Haji-Vassiliou et al, 1974; Vassiliou, 1980). Diamond drill cores studied by Williams (1967) showed that the pegmatite as well as the ore zone narrow considerably with depth; however, the ore was shown to be quite rich in rare-earth oxides (up to 2.4 percent) and to contain 0.45 percent U_3O_8 and 0.24 percent ThO_2 .

This report outlines the general geologic setting of the mine area and describes the mineral assemblage in the ore and in the associated rock units. In addition, a hypothesis on the origin of the ore is suggested on the basis of field as well as analytical data on the deposit.

GEOLOGIC SETTING

Regionally the Bemco mine is in the New Jersey Highlands Province which comprises the centermost portion of northern New Jersey. This province, which is part of the Reading Prong of the New England Highlands, is essentially a belt of Precambrian metamorphic rock 96 km long and ranging in width from 16 to 40 km. The trend of the major structure of the New Jersey Highlands is parallel to the general Appalachian Mountain system, trending N45°E (Sims and Leonard, 1952; Smith, 1969).

Spencer et al (1908) and Bayley et al (1914) mapped the New Jersey Highlands on the basis of four dominant rock units: The Pochuck, Byram, and Losee gneisses, and the Franklin marble. The Pochuck gneiss included all dark colored or black gneisses high in pyroxene, hornblende and biotite, and was considered an early dioritic or gabbroic differentiate. The Byram gneiss included brown and pinkish rocks high in potassic feldspars, and was thought to be indicative of a late stage potassium-rich granite. The Losee gneiss included all light colored or white rocks containing mainly oligoclase and quartz with minor diopside, hypersthene and biotite, and was considered indicative of a sodium-rich granite. The Franklin marble was considered metasedimentary in origin.

Later detailed mapping of smaller areas in the New Jersey Highlands province (Hotz, 1953; Hague et al, 1956; Sims, 1953, 1958; Smith and Baum, 1957; Buddington and Baker, 1961; Smith, 1969) led to the abandonment of Pochuck, Byram, and Losee as map units and the adaptation of mapping units based upon careful mineralogical subdivision of lithologies. The igneous origin for the gneisses was also abandoned in favor of a metasedimentary origin.

In the Bemco mine area, five major rock units (a granite pegmatite, a pink gneissic granite, a leucoalaskite gneiss, a granite gneiss, and a pyroxenitic

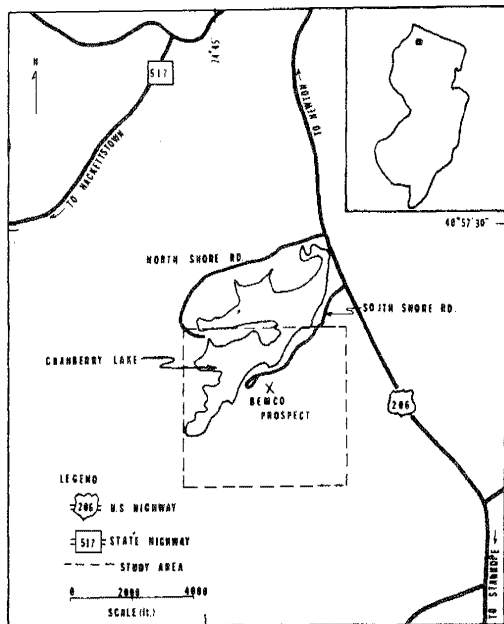


FIG. 1. Location map of the Bemco Mine.

gneiss) were differentiated according to their mineral assemblages and textures. The spatial relationships of these units are shown in a geologic map of the area (Fig. 2). A veneer of glacial drift overlies much of the area of Fig. 2. The metamorphic units are foliated and jointed. In general, the foliation strikes $N45^{\circ}W$ and dips $35^{\circ}NE$. Joint data plotted and analyzed by Fontaine (1976) show that jointing is less uniformly oriented and may be subdivided into two major and one secondary sets.

THE ASSOCIATED ROCK UNITS

Of the five major rock units in the area (Fig. 2), the granite pegmatite and the pyroxenitic gneiss are in direct contact with the ore zone. The mineralogy, texture and spatial relationships of these two units will be discussed in some detail, but a brief outline of the petrology of the other rock units not in contact with the ore follows.

Units Not In Contact With the Ore

Granite Gneiss. This rock was previously mapped as Pochuck gneiss (Bailey et al, 1914) and it is the most aerially extensive unit in the area. On the basis of mineral content and proportions, the rock may be subdivided into two varieties each characterized by the dominant minerals micropertthite-quartz-plagioclase and containing either pyroxene-hornblende-magnetite or garnet magnetite. Smith (1969) and Young (1969) recognized the same basic granite gneiss varieties in the Cranberry Lake area.

Leuco-Alaskite Gneiss. This rock corresponds to two

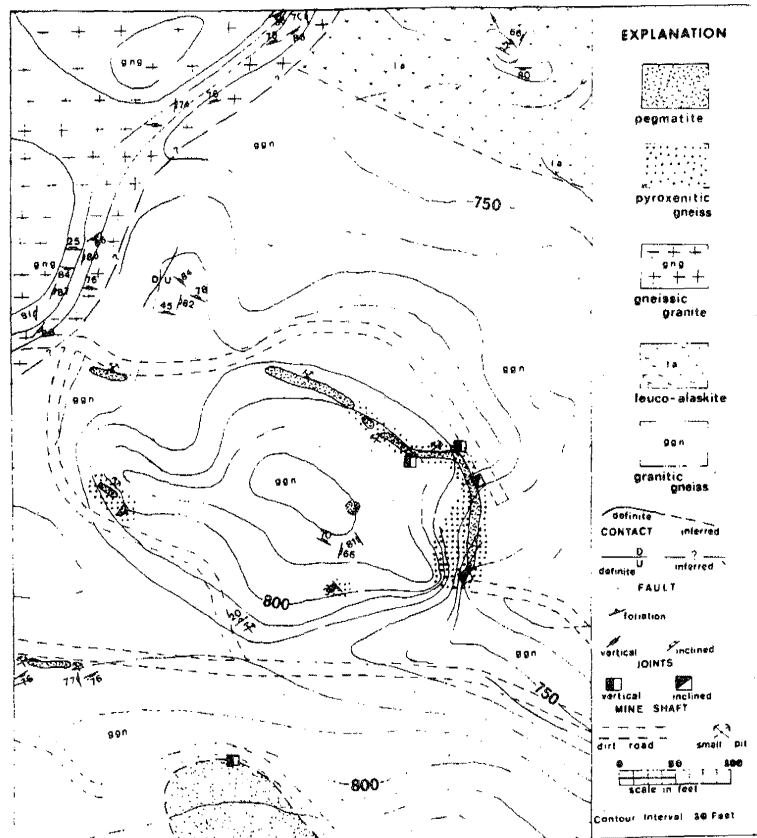


FIG. 2. Geologic map of the Bemco mine, Cranberry Lake, area. Field data provided by Donlon Hurtubise, Wayne C. Orlowski and David A. Fontaine.

types of light-colored gneiss: the quartz-oligoclase gneiss or "leucogneiss" of Buddington and Baker (1961), previously referred to as Losee gneiss; and the sometimes pale pinkish and mainly homogeneous alaskite which is considered to be an igneous body syntectonically intruded into the leucogneiss (Young, 1969). The alaskite was originally mapped as Byram gneiss.

Pink Gneissic Granite. This rock rims the east shore of Cranberry Lake. The predominant minerals are quartz, microcline, micropertthite and plagioclase, with minor hornblende and magnetite. Buddington (1957) discussed the origin of a compositionally similar granite associated with the Edison belt magnetite deposits.

Units in Contact with the Ore

The relationship between the narrow ore zone (or contact zone) and the adjacent rock units (the granite pegmatite and the pyroxenitic gneiss) is shown in Figure 3.

The Granite Pegmatite. This rock, which is easily recognized by its light color and coarse texture, is well exposed in the mine area, especially on the steep face

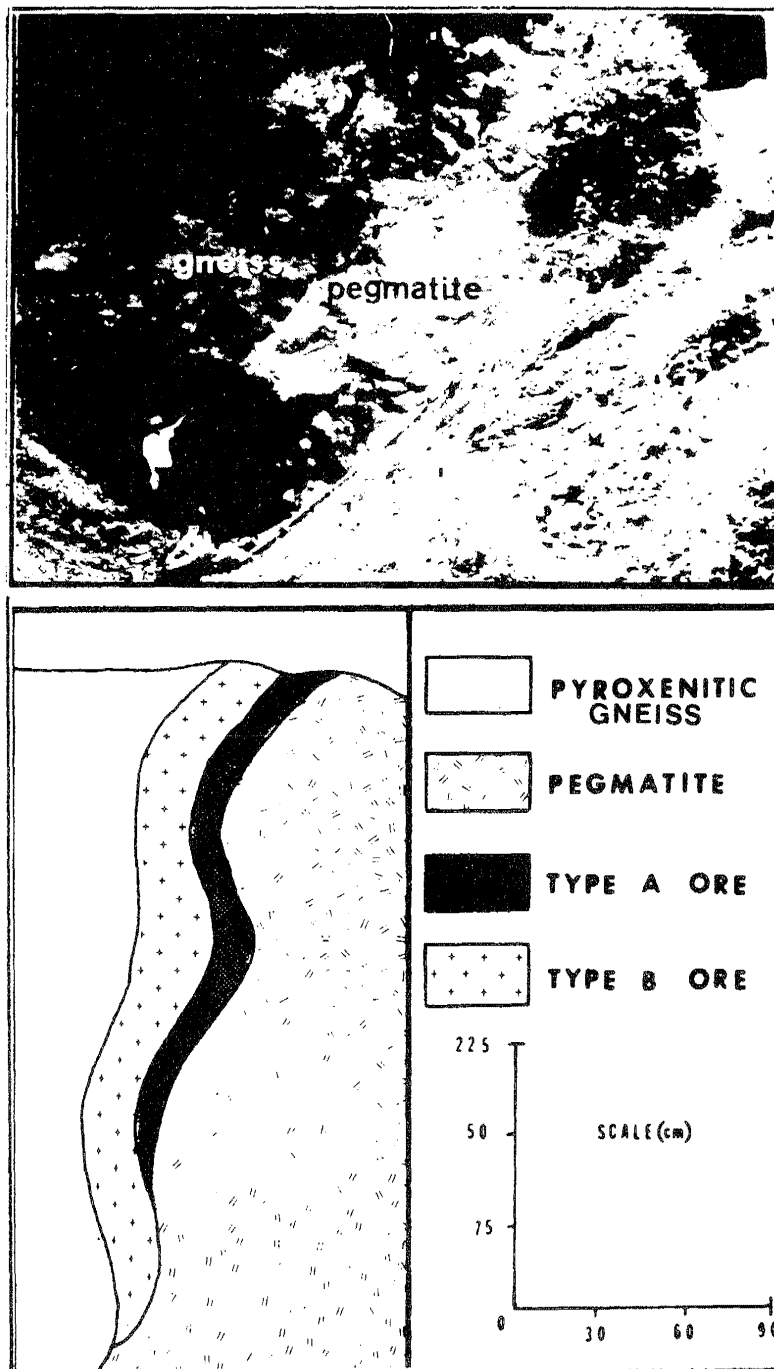


FIG. 3. The pegmatite--pyroxenitic gneiss contact at the Bemco Mine works. Light shaded rock (to the right of traced contact) is the pegmatite (photo). Schematic cross-section illustrating the spatial relationships between the associated rock units (gneiss and pegmatite) and the ore occurring at their contact (diagram).

above the lower mine portal (Fig. 3). Structural evidence indicates that the pegmatite was emplaced discordantly into the metamorphic host rock, the pyroxenitic gneiss, which it intrudes at a high angle to the foliation. The pegmatite strikes about N50°W and dips 60°SW on the average; it has an average thickness of about 2 meters and a length, along strike, of about 84 meters. Diamond cores show that the pegmatite narrows with depth; at a depth of about 30 meters the pegmatite narrows to about 1.3 meters (Williams, 1967).

The attitude of the pegmatite is nearly the same as the general attitude of one of the joint systems in the area (average, N47°W, dip 70°SW). On the basis of this and the absence of features such as wall-rock foliation deflections, drag folds, xenoliths, etc., the pegmatite may have been passively emplaced along a joint fracture possibly developed during regional deformation of the Precambrian gneiss (Fontaine, 1976).

The mineral composition of the pegmatite is shown in Table 1. Its core is essentially made up of K-feldspar (microcline micro-perthite) and quartz. The K-feldspar and quartz decrease and the magnetite increases as we approach the margin of the pegmatite towards the ore zone. Several accessory minerals, including a few grains of zircon and fergusonite, are associated with the major components. Both zircon and fergusonite are metamict and become important constituents of the ore at the contact of the pegmatite with the pyroxenitic gneiss.

Pegmatites are common in the Cranberry Lake area but they are much smaller than the Bemco pegmatite and they are not associated with uranium and rare-earth mineralization. Uranium and rare earth minerals are often found as accessory components in pegmatites (Heinrich, 1956, 1958, p. 189; Page, 1950).

The Pyroxenitic Gneiss. As noted above, in the Cranberry Lake area granite gneisses predominate and include massive, migmatic, and banded varieties. The gneisses in the immediate vicinity of the Bemco pegmatite have been banded with pyroxene (augite) and hornblende. These bands grade into amphibole-bearing pyroxenite lenses such as the pyroxenitic gneiss adjacent to the ore. The latter transition is illustrated by the modal composition of samples PG1 and PG2 in Table 1.

Sulfides are present in relatively high but variable quantities in the pyroxenite (Table 1). These sulfides include pyrite and pyrrhotite with traces of chalcopyrite, sphalerite and galena.

	P1	P2	P3	PG1	PG2	C1	C2	C3	C4
K-feldspar	56	40	10	43					
Plagioclase	11	24	28	18	tr				tr
Quartz	31	25	20	2					tr
Pyroxene (augite)	tr	4	6	30	75			2	1
Hornblende	tr	2	tr	2	20		43	1	1
Biotite			1	2	2	tr			
Magnetite	tr	2	32	2	tr	76	14	92	91
Ilmenite				tr		tr			
Pyrite		tr	tr		2		tr	tr	tr
Pyrrhotite					2			tr	
Zircon		tr				14	19	1	4
Fergusonite		tr	tr			2	4	3	2
Uranothorite (huttonite)						1	9		
Allanite		tr					tr		tr
Apatite (francolite)		tr				7	8		tr
Fluorite		tr							tr

Note: P1-P3 pegmatite. P1: core of pegmatite; P2: intermediate between core and margin; P3: margin near ore contact.

PG1-PG2 pyroxenitic gneiss. PG1: near contact with ore zone; PG2: approximately one meter from ore contact.

C1-C4 ore samples. C1, C2: Type "A" ore (near pegmatite contact); C3, C4: Type "B" ore (near pyroxenitic gneiss contact).

Table 1. Modal composition of associated rock units and ore at the Bemco Mine.

THE MINERALOGY OF THE ORE ZONE

The ore minerals occur exclusively in narrow zones or bands along the hanging and footwall contacts between the pegmatite and the pyroxenitic gneiss. The zones average approximately 30 cm in width on both walls but there is considerable pinching and swelling and in some cases the zones are absent. Diamond drill cores show that the ore zone narrows considerably with depth; at a depth of about 30 meters the zone has a maximum width of about 2.5 cm (Williams, 1967).

Magascopically as well as optically the ore can be divided into two types. The spatial relationship between the two types is shown in Fig. 3. Type "A" ore represents a 7 cm thick zone, in contact with the pegmatite, that may be described as rusty or oxidized. It is composed of a fine-grained matrix of magnetite (up to 76%) that is rich in zircon in the form of euhedral crystals disseminated throughout the matrix (Fig. 4). It is also relatively rich in uranothorite (up to 9%) and fergusonite (up to 4%). Modal analysis of two samples (C1 and C2 in Table 1) shows that apatite (francolite) is a minor constituent of the ore and that hornblende may be a major constituent in certain sections of this ore zone.

Type "B" ore represents a 25 cm thick zone, in contact with the pyroxenitic gneiss, that is essentially a magnetite ore (up to 92% magnetite), but it also contains accessory fergusonite (up to 3%) and zircon (up to 4%). The complete model composition for this ore is in Table 1 (samples C3 and C4). Fergusonite and zircon are not readily recongized megascopically in this ore.

The occurrence of radioactive minerals in magnetite ore is not uncommon. Uranium minerals are associated with several magnetite deposits in the Eastern United States (Walthier, 1955), and rare-earths are associated with magnetite ore at the Scrub Oaks mine, Morris County, New Jersey (Williams, 1967).

With the exception of magnetite, the other ore minerals identified here (zircon, fergusonite, uranothorite) are metamict. A few black anhedral grains separated from the ore have been tentatively identified (through X-ray powder camera) as the yttrium silicate "rowlandite" by Fontaine (1976). The relatively rare metamict mineral "spencite" (calcium-yttrium silicate) has been reported as present in the ore by Williams (1967), but its presence has not been confirmed by the writer. A more detailed description of the ore minerals is as follows:

Magnetite

As much as 90% of the ore zone or contact zone is composed of coarse-grained magnetite. In addition, magnetite occurs in the form of veinlets (up to 16 cm in length) which cut through the pegmatite as well as the pyroxenitic gneiss host rock. It is also commonly disseminated in both the pegmatite and the pyroxenitic gneiss as well as in all the other rocks in the Cranberry Lake area.

The magnetite of the ore zone and the related veinlets is identical in chemical composition to the magnetite found in the pegmatite (with only 0.2% TiO_2 content). On the other hand, the magnetite found disseminated in the host rock (pyroxenitic gneiss) differs strongly from the latter (up to 3.5% TiO_2 content). This suggests a direct genetic link between the ore and the pegmatite.

Zircon

Euhedral crystals, mainly concentrated in the type "A" ore, (Fig. 4), average 4 mm in length, with some as long as 2 cm. These crystals are generally gray, strongly zoned, and some exhibit twinning. The zoning is visible in most crystals observed in thin section, with zircon forming the crystals walls (cyrtolite), and uranothorite and fergusonite occupying the core (malacon) of the crystals (Fig. 5).

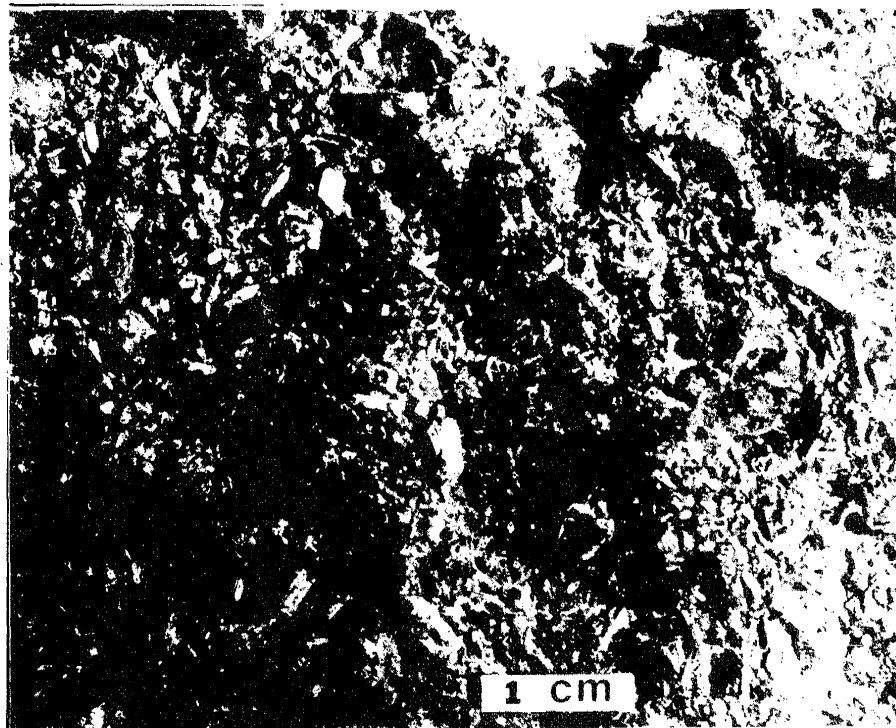


FIG. 4. Euhedral crystals of zircon (light-colored, prismatic) disseminated in fine-grained magnetite matrix of Type "A" ore.

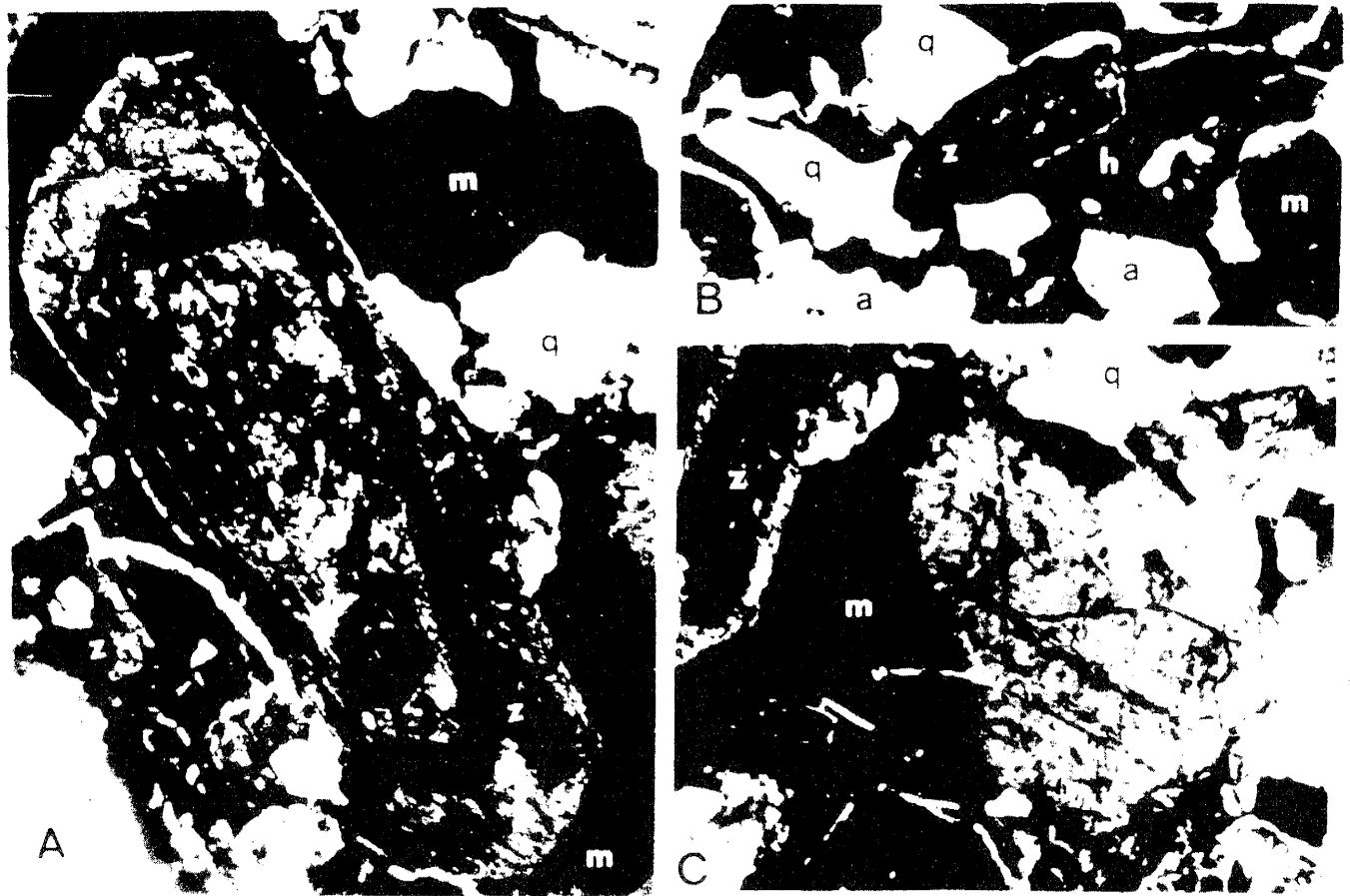


FIG. 5. A. Zoned euhedral zircon (z) with associated magnetite (m) and fergusonite (f) in type "A" ore adjacent to the pegmatite contact. Cyrtolite is represented by the outer zone of the crystal and malacon by the generally darker core which contains uranothorite and some fergusonite. Plane polarized light, 16X.

B. Zoned zircon crystal (z) associated with hornblende (h), apatite (a), magnetite (m) and quartz (q) in type "B" ore adjacent to the pyroxenitic gneiss contact. Plane polarized light, 40X.

C. Large fergusonite grain (f) in association with magnetite (m) and zircon (z) in type "A" ore. Plane polarized light, 16X.

Photomicrographs by L. M. Fukui and R. F. D'Andrea, Jr.

In Table 2 the zircons ($ZrSiO_4$) are shown to be rich in thorium and uranium. The most abundant rare earth present is ytterbium, with other associated elements being hafnium and yttrium.

The crystals are completely metamict. However, with heat treatment (1000°C for one hour in a muffle furnace), the crystal structure of zircon could be ascertained through X-ray diffraction analysis.

Fergusonite

This mineral occurs mainly in the Type "B" ore, and occasionally in Type "A" ore, especially as part of the core in zoned zircons. Optically it appears as red-brown vitreous grains that often contain magnetite inclusions (Fig. 5).

Table 2 shows fergusonite, $Y(Nb, Ta)O_4$, to be rich in thorium, uranium, and several rare earths (ytterbium, erbium, gadolinium) in addition to elements listed in its chemical formula.

The mineral is metamict and, depending on heat treatment, it may exhibit one of several phases. Lima de Faria (1964, Table 18) lists four phases. In this study, the mineral was heated (in a muffle furnace) at 1000°C for one hour, and its diffraction pattern correlated well with the monoclinic phase outlined by Lima de Faria (1964, Table 20).

Uranothorite

This mineral occurs mainly in the cores of zoned zircons and occasionally in the form of veinlets in the ore matrix. Optically it appears as black, isotropic

	Fergusonite	Uranothorite	Zircon
ThO ₂	10.2	50.3	6.7
UO ₃	4.3	26.2	2.8
ZrO ₂	-	-	59.3
Nb ₂ O ₃	36.4	-	-
Y ₂ O ₃	27.9	0.7	0.3
Fe ₂ O ₃	4.7	5.1	1.1
Yb ₂ O ₃	1.7	-	2.2
Ta ₂ O ₃	2.9	-	-
Er ₂ O ₃	2.1	-	-
Gd ₂ O ₃	1.1	-	-
HfO ₂	-	-	0.8
CeO ₂	-	2.1	-
As ₂ O ₃	-	1.0	0.5
Total	91.3	85.4	73.7
100-Total	8.7	14.6	26.3

*Oxidation state unknown

Note: These quantitative estimations were obtained through X-ray fluorescence analysis. Selected peak intensities representing the elements in the oxides listed were compared to those present in artificially prepared standards. The standards were prepared by mixing various proportions of these oxides (weight percent) in a silica diluent.

Table 2. Composition of radioactive ore minerals at the Bemco Mine.

subhedral grains (medium- to coarse-grained), and its identification was confirmed by X-ray diffraction after heating at 1000°C for one hour.

Its X-ray diffraction pattern is very close to the monoclinic huttonite phase of thorite (ThSiO₄) as shown by Lima de Faria (1964, Table 1). However, the presence of large amounts of uranium (see Table 2) in its composition suggests uranothorite, (Th, U) SiO₄, as a more appropriate name.

ORIGIN OF THE ORE

The following is a summary of field and chemical analytical data which suggest that the ore was probably precipitated from hydrothermal solutions. These solutions were associated with the later stages of the intrusion of the pegmatite and were injected along the pegmatite-gneiss contact.

1. The pegmatite was emplaced discordantly into the metamorphic host rock, the pyroxenitic gneiss, which it intrudes at a high angle to the foliation. Permissive rather than forceful injection is suggested for the pegmatite mainly due to the absence of features that usually suggest forceful injection (i.e., drag folds, xenoliths, etc.) and the fact that the attitude of the pegmatite is practically the same as that of one of the joint systems in the area.

2. The ore zone occurs along the hanging wall and footwall contacts between the pegmatite and the pyroxenitic gneiss.

3. The contact appears sharp and discordant with magnetite ore veinlets cutting both the pegmatite and the pyroxenitic gneiss. Veinlets and pockets of sulfides (mainly pyrite, pyrrhotite and chalcopyrite) occur in the pyroxenitic gneiss, especially adjacent to the ore or contact zone.

4. The magnetite of the ore zone and the related veinlets is identical in chemical composition to the magnetite found in the pegmatite (i.e., it contains 0.2% TiO₂). However, the magnetite in the host rock or pyroxenitic gneiss is different (i.e., it contains up to 3.5% TiO₂).

5. A series of samples of pyroxenitic gneiss taken at the contact zone and at intervals of 30, 60, and 90 cm away from the contact were analyzed for Fe₂O₃ content and total Fe content using X-ray fluorescence and atomic absorption. The results show that, in general, the iron content decreases away from the contact, thus suggesting that the ore is not the result of deuteric leaching from the pyroxenitic gneiss.

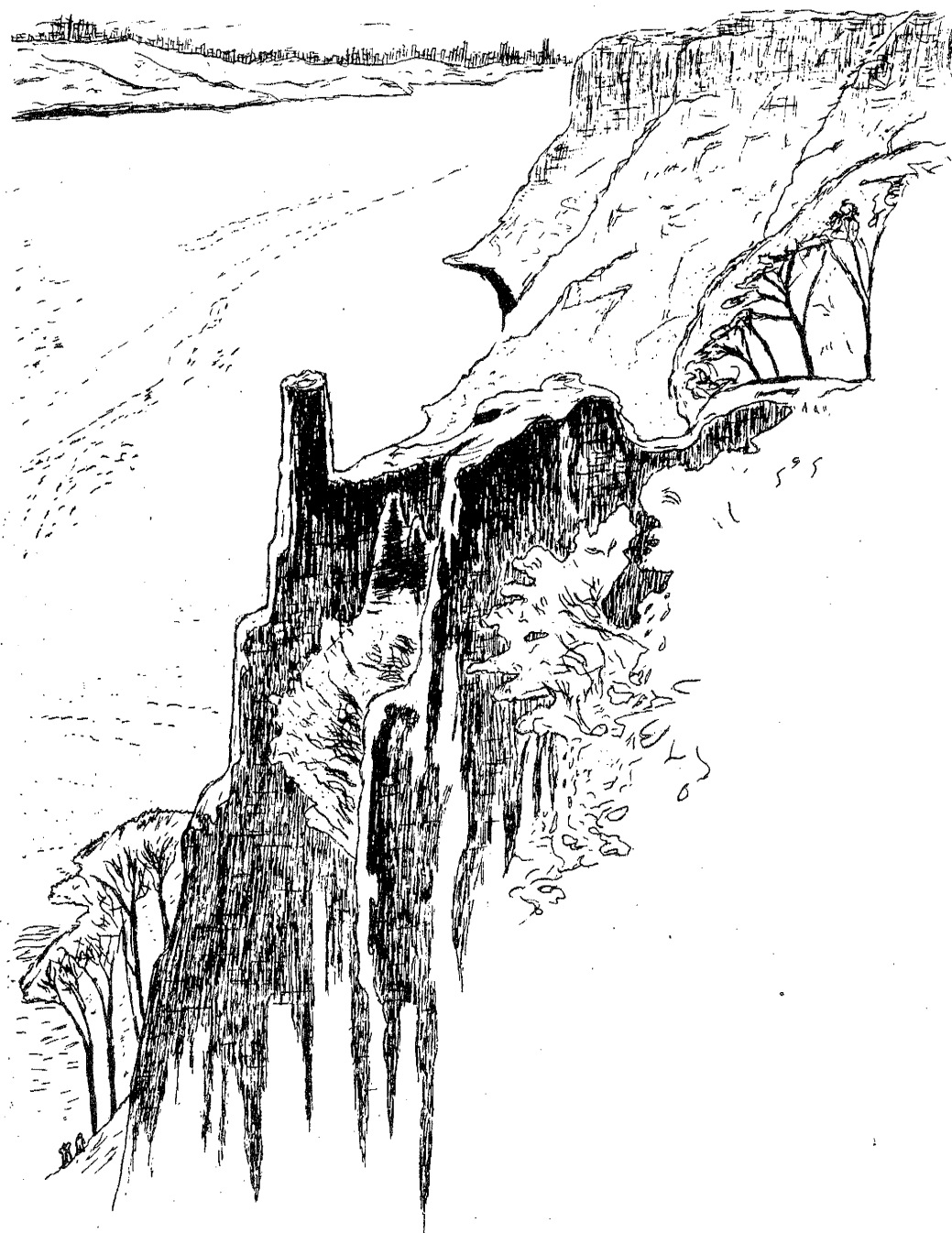
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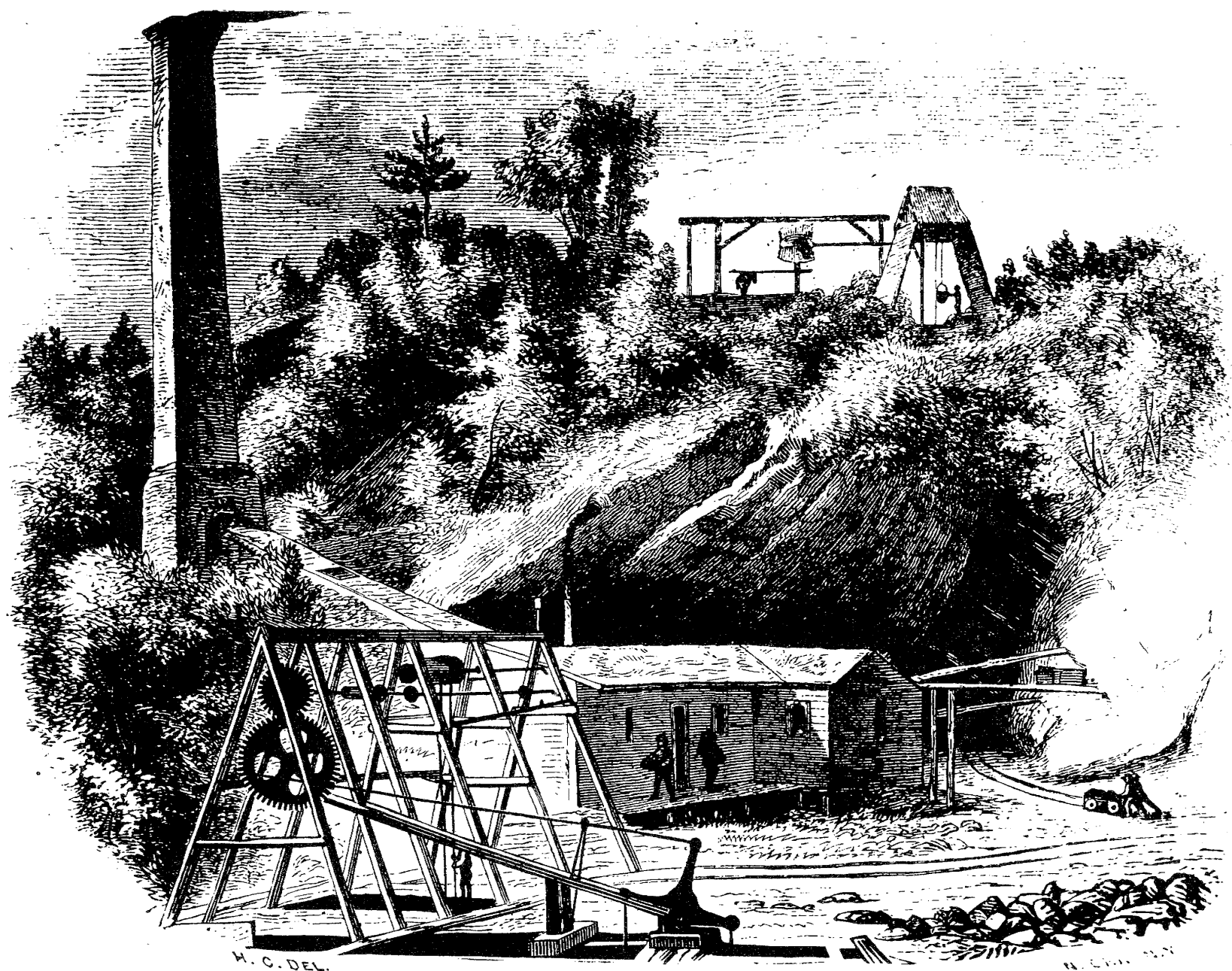
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