MINERALIZATION
at the
EUSTIS MINE, EUSTIS, QUEBEC

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ABSTRACT

The present geological investigation of the Eustis mine has been carried out along mineralogical rather than structural lines.

The sulfide mineralization is chiefly of chalcopyrite and pyrite in four lenses. The lens forming the ore body is called the chalcopyrite lens. It carries on the average 4 per cent copper which corresponds to 12 per cent chalcopyrite. The average size of the copper lens is 40 feet across the dip, 120 feet along the strike and over 6,050 feet in length. All the lenses are conformable to the dip of the enclosing schists. The sulfide mineralization is considered to have been by replacement of schists and green-rock along a zone of tension.

The country rock consists of: (1) porphyritic, slightly schistose quartz-porphyry outside of the ore zone; (2) crenulated muscovite schist with a few quartz phenocrysts in the ore zone; (3) a carbonate rock, locally known as green-rock, which occurs as disconnected massive blocks and as lens-
like bodies in the schist of the ore zone. The green-rock represents mineralization by abundant ankerite of the schist along the above-mentioned shear zone.

Three different chlorites have been developed in the country rocks: (1) diabantite, a high iron, magnesium but low aluminium chlorite, which occurs only in the green-rock; (2) amesite, a high aluminium and magnesium but low iron chlorite, only found in the schist of the ore zone; (3) prochlorite, a chlorite with moderated amounts of iron, magnesium and aluminium, which is the chlorite found in the quartz veinlets in the green-rock.

The sulfide mineralization of the ore body shows no variation along the whole length. The sulfides developed are chiefly pyrite and chalcopyrite with smaller amounts of sphalerite, galena and tetrahedrite.

On the 4825 level the ore body has been definitely cut by a 40 foot camptonite dike. This dike has metamorphosed the ore to within at least 10 feet of the boundary of the dike. Pyrrhotite
and cubanite have developed as a result of this metamorphism in varying amounts by unmixing from an iron rich solid solution of chalcopyrite. The silicate developed as a result of the heat supplied by the dike is the orthorhombic amphibole, anthophyllite.

Many small dikes cut the ore body, but because of their small size, they have effected no metamorphism. These dikes are of an alkaline nature, including olivine diabase, camptonites and monchiquites.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTORY</td>
<td>1</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>2</td>
</tr>
<tr>
<td>RESUME OF EARLY COPPER MINING IN THE EASTERN TOWNSHIPS OF QUEBEC</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICAL FEATURES OF THE EASTERN TOWNSHIPS</td>
<td>11</td>
</tr>
<tr>
<td>GENERAL GEOLOGY</td>
<td></td>
</tr>
<tr>
<td>The Eastern Townships</td>
<td>16</td>
</tr>
<tr>
<td>Metamorphic Belt of Rocks in which the Eustis Mine is Located</td>
<td>24</td>
</tr>
<tr>
<td>Metamorphosed Sediments</td>
<td>26</td>
</tr>
<tr>
<td>Intrusives</td>
<td>26</td>
</tr>
<tr>
<td>Structure</td>
<td>28</td>
</tr>
<tr>
<td>LOCATION OF MINE</td>
<td>30</td>
</tr>
<tr>
<td>PRODUCTION OF MINE</td>
<td>31</td>
</tr>
<tr>
<td>EUSTIS ORE BODIES</td>
<td>32</td>
</tr>
<tr>
<td>Distribution of Lenses</td>
<td>32</td>
</tr>
<tr>
<td>Chalcopyrite Lens</td>
<td>33</td>
</tr>
<tr>
<td>Size</td>
<td>33</td>
</tr>
<tr>
<td>Relation to Enclosing Rocks</td>
<td>34</td>
</tr>
<tr>
<td>Shape of Lens</td>
<td>38</td>
</tr>
<tr>
<td>Pyrite Lenses</td>
<td>39</td>
</tr>
<tr>
<td>Faulting</td>
<td>41</td>
</tr>
<tr>
<td>Other Ore Bodies Analagous to those of the Eustis</td>
<td>42</td>
</tr>
</tbody>
</table>
Generalizations as to the nature of the forces responsible for forming the permeable zone in which the lenses occur ................. 43

GREEN ROCK

Distribution ................................................. 46
Habit .......................................................... 46
Color .......................................................... 47
Texture .......................................................... 47
Relations to Surrounding Rocks .............. 50
Microscopic Characters

Texture .......................................................... 52
Description of Minerals ................................. 53
Origin of the Green-Rock ......................... 60
Summary .......................................................... 61

THE SCHISTS .................................................. 63

Schists Outside of the Ore Zone

General Characteristics ............. 63
Microscopic Examination ............. 64

Schist of the Ore Zone

General Description ......................... 73
Microscopic Characteristics ............ 74
Late Mineralization Features of the Ore Zone Schist .. 86

Summary of Features of the Schists .... 88
ORIGIN OF THE SCHISTS: .......................... 91

DETERMINATIVE FEATURES OF THE SCHIST AND GREEN-ROCK MINERALS

Quartz ........................................ 91
Carbonates .................................. 96
Ankerite .................................... 96
Calcite ....................................... 98
Chlorites ..................................... 98
Diabandite .................................. 99
Amesite ...................................... 100
Prochlorite .................................. 101
Feldspar ..................................... 102
Muscovite ................................... 103
Titanite ..................................... 104
Rutile ........................................ 105
Epidote ....................................... 105
Anthophyllite ................................ 105

ORE MINERALOGY

Minerals ...................................... 107
Distribution .................................. 108
Arsenopyrite ................................ 109
Pyrite ........................................ 109
Chalcopyrite ................................ 111
Detailed Description of the Basic Dikes of the Eustis Mine ............ 160

Distribution and Size of Dikes .... 160

Olivine Diabase ..................... 162

Camptonite .......................... 163

Monchiqueite ........................ 165

Age of the Dikes with Respect to the Ore .......................... 167

CONCLUDING REMARKS .......................... 169
# ILLUSTRATIONS

A. Plates

<table>
<thead>
<tr>
<th>Plate</th>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>Mill of the Eustis Mine, Eustis Quebec</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>Iron pyrite pile of the Eustis Mine.</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>Index map</td>
<td>16</td>
</tr>
<tr>
<td>III</td>
<td></td>
<td>The four orogenic times in Greater Acadia</td>
<td>21</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td>Ore replacing schist. (Hand specimen)</td>
<td>106</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>Porphyritic schist outside of the ore zone. (Thin-sections)</td>
<td>106</td>
</tr>
<tr>
<td>VI</td>
<td></td>
<td>Laminated schist. (Thin-sections)</td>
<td>106</td>
</tr>
<tr>
<td>VII</td>
<td></td>
<td>Contorted schist (Hand specimen)</td>
<td>106</td>
</tr>
<tr>
<td>VIII</td>
<td>1</td>
<td>Muscovite in quartz phenocryst (Thin-Section)</td>
<td>106</td>
</tr>
<tr>
<td>VIII</td>
<td>2</td>
<td>Feather quartz (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>IX</td>
<td>1</td>
<td>Quartz-albite veinlet (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>IX</td>
<td>2</td>
<td>Amesite chlorite (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>X</td>
<td>1</td>
<td>Amesite chlorite (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>X</td>
<td>2</td>
<td>Amesite chlorite (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XI</td>
<td>1</td>
<td>Sill-like green-rock (Hand specimen)</td>
<td>106</td>
</tr>
<tr>
<td>XII</td>
<td>1</td>
<td>Equigranular texture in green-rock (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XII</td>
<td>2</td>
<td>Schistose texture in green-rock (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XIII</td>
<td>1</td>
<td>Quartz inclusions in ankerite (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XIII</td>
<td>2</td>
<td>Zoned carbonate (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>Plate</td>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>XIV</td>
<td>1</td>
<td>Diabandite in green-rock (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XIV</td>
<td>2</td>
<td>Rutile in green-rock (Thin-section)</td>
<td>106</td>
</tr>
<tr>
<td>XV</td>
<td>1</td>
<td>Porphyritic pyrite (Polished section)</td>
<td>119</td>
</tr>
<tr>
<td>XV</td>
<td>2</td>
<td>Sharply outlined pyrite cubes (Polished section)</td>
<td>119</td>
</tr>
<tr>
<td>XVI</td>
<td>1</td>
<td>Chalcopyrite replacing sphalerite and tetrahedrite (Polished section)</td>
<td>119</td>
</tr>
<tr>
<td>XVI</td>
<td>2</td>
<td>Banding amongst sulfides (Polished section)</td>
<td>119</td>
</tr>
<tr>
<td>XVII</td>
<td></td>
<td>Massive quartz replacing tetrahedrite and chalcopyrite (Hand specimen)</td>
<td>119</td>
</tr>
<tr>
<td>XVIII</td>
<td>1</td>
<td>Chalcopyrite replacing pyrrhotite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XVIII</td>
<td>2</td>
<td>Chalcopyrite replacing pyrrhotite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XIX</td>
<td>1</td>
<td>Anthophyllite (Thin-section)</td>
<td>153</td>
</tr>
<tr>
<td>XIX</td>
<td>2</td>
<td>Anthophyllite (Thin-section)</td>
<td>153</td>
</tr>
<tr>
<td>XX</td>
<td>1</td>
<td>Pyrrhotite and chalcopyrite replacing anthophyllite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XX</td>
<td>2</td>
<td>Pseudomorphic pyrrhotite after pyrite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXI</td>
<td>1</td>
<td>Arborescent chalcopyrite in camptonite dike (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXI</td>
<td>2</td>
<td>Arborescent chalcopyrite in camptonite dike (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXII</td>
<td>1</td>
<td>Hypogene marcasite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXII</td>
<td>2</td>
<td>Hypogene marcasite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXIII</td>
<td>1</td>
<td>Cubanite under polarized light (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>Plate</td>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>XXIII</td>
<td>2</td>
<td>Pyrrhotite veinlet in cubanite under polarized light (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXIV</td>
<td></td>
<td>Pyrrhotite in cubanite (Polished section)</td>
<td>153</td>
</tr>
<tr>
<td>XXV</td>
<td></td>
<td>Diagrammatic sketch of metamorphosed ore with respect to the camptonite dike on the 4825 level</td>
<td>153</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

B. Maps

1. Map showing the OLDER COPPER BEARING ROCKS of the Eastern Townships of Quebec and location of the Eustis mine, in addition to numerous smaller ones in relation to these rocks.

II. Plan of the Eustis mine from the 3700 to the 5800 foot level.

III. Composite vertical section of the Eustis mine from the 1800 to the 5800 foot level.

IV. Isometric projection of the copper lens in the Eustis mine from the 3200 to the 5800 foot level.

INTRODUCTORY

The Eustis mine possesses certain mineralization features which make it very interesting from an economic geology standpoint.

The ore lens is unique; there has been continuous sulfide mineralization along it for over 6,000 feet with no perceptible change in type of mineralization from the surface down. The possible causes of localization of the lens have been investigated.

The main country rock consists of schists which have suffered varying degrees of mineralization and hydrothermal alteration dependant on their position with respect to the ore body. The most interesting feature of the country rock is the presence of disconnected fragments of a massive carbonate rock which is locally known as green-rock. The origin of this and its relationships to both schists and ore have been investigated and definite results formulated.

The field investigations were limited to underground work; three visits, aggregating to about three weeks' work, to the mine being made. The examination of thin and polished sections was carried out in the laboratory of Economic Geology at the Massachusetts Institute of Technology.
ACKNOWLEDGMENTS

The author wishes to thank the various men connected with the Consolidated Copper & Sulphur Co., operators of the Eustis mine, for their kind co-operation during the progress of this study. To Mr. Augustus H. Eustis, general manager; to Mr. C.W. Plumb, past mine manager; to Mr. F.W. Snow, present mine manager; and to Mr. L. Chamberlin, mine surveyor, especial thanks are due for the many facilities placed at the author's disposal.

The various members of the Department of Geology at the Massachusetts Institute of Technology gave very freely and kindly of their advice during the progress of the laboratory investigation of the mine specimens. Doctor Waldemar Lindgren suggested the study and very kindly obtained permission from the Consolidated Copper & Sulphur Co. to study the geology of the Eustis mine. He also offered much advice during the laboratory studies. To Doctor W.H. Newhouse special thanks are due, for he supervised both field and laboratory investigations and offered much timely advice.
Plate I.

Figure 1.

Mill of the Eustis Mine, Eustis, Quebec.

Figure 2.

Iron (pyrite) pile of the Eustis Mine, Eustis, Quebec.
3.

RESUME OF EARLY COPPER MINING
IN THE EASTERN TOWNSHIPS OF QUEBEC

The discovery of copper ore on the ground now occupied by the Eustis mine was made in 1865. The original discovery on lot 4, Range IX of Aston Twp. was called the Lower Canada or Hartford mine. In 1865 it produced 400 to 500 tons of 12 per cent copper ore. It is by no means the oldest mine in the Eastern Townships.

In the Geological Survey of Canada's report for 1847-1848, Sir. Wm. E. Logan, then Director of the Survey, refers to copper in the Eastern Townships. He mentions a location on the 4th lot, Range II. Inverness County, where a quartz vein, "with a mixture of chlorite, presents the thickness of about two feet, and the ore is disseminated in it in irregular patches and lumps, some of which weigh upwards of a pound; but the patches at the outcrop, in the spot experimented

upon, are so thinly scattered that, notwithstanding
the produce of the pure ore, which is variegated copp-
per, is upwards of 60 per cent, the whole two feet of
the lode do not yield more than 0.74 per cent, which
would not give more than 90 pounds of copper in a
fathom vertical." On the strength of this showing
the Megantic Mining Company was formed; however, work
was carried on only until about 1856. Discoveries in
the neighboring township of Leeds were more interesting,
and upon the instigation of Doctor Douglas, the elder,
were reported upon by an English engineer. His report
covered the ground of the Harvey Hill mine. This mine
attracted much attention for many years, but was on
the whole unsuccessful. In the words of Doctor James
Douglas, referring to the suspension of operations by
the last company to operate, a Glasgow one, "The company
was formally wound up in 1879. The same series of events
have, I believed, been repeated since then -- resuscita-
tion, a lingering life, death and burial. And yet I
think the property may deserve a better fate."

An interesting digression here, is that in
reference to the early life of one of the most pro-

1. Douglas, James, Early Copper Mining in the Province of
minent figures in the history of North American Copper Mining, viz., Doctor James Douglas, who, in an article on Early Copper Mining in the Province of Quebec says:

"My personal recollections are of spending my summer holidays of 1850 at these mines in Inverness. I recollect my father finding one of the shareholders reading by the light of a candle stuck into the blasting powder of an open keg, and another calculating seriously on the best way of disposing of his enormous prospective fortune and deciding on patriotically paying off the British national debt."

It might be noted that the same measure of optimism was displayed by Doctor Douglas in 1910 when he said, "And yet I think the property, (The Harvey Hill Mine in the adjacent township of Leeds) may deserve a better fate."

The production of the Harvey Hill was always slight. In the years 1858 to 1864 about 671 tons of 2,352 pounds, and averaging between 30 and 20 per cent

1. Douglas, James, op. cit. p.255.
copper were shipped. Between 1867 and 1879 the output rose at times to as much as 500 tons of concentrates a year.

Another mine to be considered in this very brief resume of mining, prior to and around the time that Eustis came into production, was the Acton. Quoting from a discussion by Mr. Dresser in Doctor Douglas' paper: "The principal mine of the last-mentioned class was the celebrated Acton Mine that in its time was the largest copper mine producing in the world. This was operated for some ten or twelve years successfully, but it eventually found its termination." This was around 1860.

From Logan's Geology of Canada: "The whole amount of ore raised from this mine from its opening in 1859 to its close in 1861, including a portion of the above period, is stated to have been nearly 6,000 tons averaging 17.0 per cent copper."

1. Douglas, James, op. cit. p.270.
Quoting from Bancroft: "The Acton Mine proved to be such a phenomenal source of wealth and industry, and the rich ores of the Harvey Hill Mine attracted so much attention that prospecting for copper became the order of the day in the Eastern Townships. Shortly after the outbreak of the Civil War in the United States (April, 1861 to April, 1865) the price of copper rapidly increased on this continent. This stimulated prospecting operations to such a degree that great excitement was aroused. Since the majority of the copper mines and prospects of the Eastern Townships, that figure prominently in the subsequent literature, were discovered and worked under the abnormal conditions that prevailed in this period. It is very important to delineate these conditions in some detail."

"From 1860 to 1864 the Acton Mine was the chief producer, while small shipments of rich ore were made from Harvey Hill. From 1866 to 1869

the Hartford or Lower Canada (now the Eustis) Mine and the Huntingdon Mine contributed by far the major portion of this production."

It is to be noted that there are over 500 occurrences of copper showings mentioned in the appendix to the Geological Survey of Canada's report for 1866, but it is to be remembered that the purpose of such was for merely emphasizing the widespread distribution of traces of these minerals, and their constant relation to what was then considered as the middle or Lauzon division of the rocks of the Quebec group.

Intensive prospecting, the result of the copper excitement of 1861 to 1866 when the price of that metal went up to a high of 55 cents per pound on the New York market in July 1864, produced the Capleton Mine in 1863 and in 1865 the Eustis Mine adjacent to this, along with many other smaller propositions in the Eastern Townships.

9.

These two mines remained in production after the Harvey Hill, Ives and Huntingdon died out in the decade of 1869 to 1879.

In succeeding years little of interest was either found or brought into reproduction with the exception of the discovery, in 1909, of the McDonald or Weedon Pyrite Mine in Weedon Twp. This mine has been worked intermittently for several years. In the five years, 1910 to 1915, 174,000 tons of ore, averaging about 3.62 per cent copper and 40.74 per cent sulphur, payments being made for these two elements, were produced.

The Capleton Mine continued production until about 1907; during the latter years of its life the property was split up into two parts, the Capel and Albert Mines, the latter being the larger. Complete production records were not obtainable, but in 1888 the outputs of the two were 34,600 tons and in 1889, 36,000 tons. The deepest shaft, the Albert, reached 2,300 feet, and then the mine was closed, presumably due to decrease in the amount of ore.
10.

The Eustis Mine has had, since its discovery in 1865, several names and has been under several ownerships. In 1865, the year of its discovery, it was known as the Lower Canada Mine, the following year as the Hartford. In successive years it has been known as the Crown and also as the Orford. A few years subsequent to 1880, the mine passed into the hands of the Eustis interests and has since been known as the Eustis Mine.

1. Bancroft, J. A. op. cit. p.244.
2. Douglas, James, op. cit. p.270.
PHYSICAL FEATURES OF THE EASTERN TOWNSHIPS

The Eastern Townships of Quebec may be divided into two main parts: a western, comprising the St. Lawrence Lowlands of unfolded Paleozoics, and an eastern, comprising the continuation of the Appalachian region of eastern United States into Canada. (Plate I)

The St. Lawrence Lowlands comprise that tract of low-lying and level region extending from the St. Lawrence River eastward to a line running northeastward from Lake Champlain to Quebec City. Within this region the land nowhere rises above 500 feet, save in the cases of a few isolated hills; below Montreal the regions bordering the St. Lawrence have a general elevation of 100 feet, and rise to less than 300 feet at the edges of the region.

The Appalachian equivalents of the same portion in United States, are the Green Mountains of Vermont, and in the extreme east, the White Mountains of New Hampshire. In the Eastern Townships, these mountains find expression in a set of three parallel groups of hills, from west to east, extending from the eastern
shores of Lake Champlain, from Lake Memphramagog, and in the far east from Lake Megantic.

The most westerly range of hills, extending from Lake Champlain, is the most pronounced and persistent of the three. Immediately north of the Vermont border they form the so-called Sutton mountains, Sutton mountain itself being the highest point in the Eastern Townships, 3,000 feet in elevation. This range decreases in general elevation northeastward but increases in general width, being about 24 miles wide in Megantic township and maintaining this width to Quebec City. From here northward the hills increase in height until in Gaspe peninsula they achieve elevations of 3,400 to 4,200 feet.

This westernmost range of hills has been designated the Sutton belt by Dresser, which he considers to run through the townships of Sutton, St. Armand, Brome, Shefford, Ely, Melbourne,


Cleveland, Shipton, Tingwick, Arthabasca, Chester, Ham, Wolfestown, Inverness and Leeds, as well as the seigniory of St. Giles, known as the Handkerchief, and Ste. Marguerite, in the County of Lotbiniere.

The range of hills running northeastward from Lake Memphremagog are much more subdued than those to the west. This group of hills is not significant enough to receive any local designation, but they have been grouped into what Dresser describes as the Ascot belt.

Bancroft describes its location as follows: "In reality this belt embraces two ridges, one which extends through Hatley, Ascot (where it is crossed by the St. Francis River), and Stoke townships and into Dudswell Township for a short distance; after a break of three or four miles, the other ridge appears to the east of the St. Francis River and extends from Dudswell through Weedon and Stratford townships to Lake St. Francis."

This range is very short and soon loses its identity to the north, in the vicinity of Lake St. Francis.

The easternmost range of hills lies on the border between Quebec and Maine, in the vicinity of Lake Megantic. These represent the northeastward continuation of the White Mountains, passing past Lake Megantic and up into Maine. It has been designated as the Megantic belt but is little known.

A conspicuous feature of the landscape of the Eastern Townships in the vicinity of Montreal and eastward are the Monteregian hills. These are circular or oval hills a few square miles in diameter and rise abruptly 600 to 1200 feet above the surrounding flat country. The flanks of the hills are sediments, but the central portions are igneous rocks of a decided alkaline character, alkali syenites, nepheline syenites, essexites, etc.

The drainage of the Eastern Townships is into the St. Lawrence by tributaries which parallel and transect the structures. Concerning the drainage
Young says, "In the Appalachian region, (in speaking of Canada only) largely occupied by indurated strata, some of the drainage channels of Cretaceous time persisted as the region rose and underwent warping, and thus resulted some of the deeply incised valleys that cross the structural trend of the region. Later in Tertiary time, a further regional uplift occurred and the earlier formed lowlands were trenched by the streams."

1. **Index Map**

showing general geology of the Eastern Townships of Quebec in relation to the northern Appalachians of North America.

Clark, T.H., *Structure and Stratigraphy of Southern Quebec*, Geol. Soc. America, Bull., 45, 1934, Figure 1.
Figure 1.—Map of Southern Quebec and New England
Showing location of Lacolle, Sutton, and Memphremagog quadrangles, Quebec.
The Eastern Townships:

The structures responsible for the Paleozoic and later developments of the Eastern Townships are the St. Lawrence geosyncline and east of this the New Brunswick anticline. East of this again, but outside of the Eastern Townships are the Acadian geosyncline and the borderland of Nova Scotis. These are all proterozoic structures of Schuchert. (Plate II). Since their formation in the proterozoic time, they have been refolded. In the late Ordovician (Taconian) and in the Devonian (Acadian), the Acadian has suffered more recent foldings, being finally deformed in the Appalachian revolution of the Permian.

The result of such orogenies has been the metamorphism of the rocks now contained in the three parallel ranges of northeastward trending hills described in the section on the physical features of the region. These hills are anticlinal ridges of metamorphic rocks, and it is in these that the copper

replacement deposits of the Eastern Townships are found.

The orogenies to be described resulted also in extreme faulting in the region, with the creation of both transverse and strike faults; overthrusts and underthrusts have also been described, these in southern Quebec between Lakes Champlain and Memphramagog.

A brief review of the stratigraphy of the St. Lawrence trough, as compiled from publications of Young and Schuchert, is given so that the background for the geology of the metamorphic belt of rocks in which the Eustis Mine is located may be better understood.

Fossiliferous strata of Lower Cambrian age have been found in situ in Vermont, New York and Newfoundland. Fossiliferous pebbles of this

age have been found in the Ordovician conglomerates of Bic and Levis, Quebec. In this connection, it is important to note that Young says, "In southeastern Quebec, in the western range of the Appalachian Highlands, beds of this age (Lower Cambrian) occur in the limbs of a broad anticlinal form whose axial portion is developed in the metamorphosed pre-Cambrian sediments. The Cambrian beds, in the western limb of the anticline, form a thick series consisting of, in ascending order, altered volcanics, quartzitic strata with several limestone members, and dark slates. The beds appear to be unfossiliferous, but members of the series have been traced south into Vermont and found to be part of the Georgia formation of Lower Cambrian age." 

It is also to be noted that Clark finds between 2800 and 3200 feet of Lower Cambrian sediments in the vicinity of Lake Champlain in Canada.

Between the Lower and Upper Cambrian there was a land interval with no deposition.

Marine sediments of Upper Cambrian age are described from Newfoundland, in the pebbles of the Ordovician at Levis, in the vicinity of Lake Champlain, both in Canada and in Vermont.

An orogeny occurred between the Cambrian and the Ordovician. This is known in Vermont, and Clark has found evidence of it in the Philipsburg region immediately north in Canada, between the Potsdam and the following Beekmantown.

Schuchert says that by Ordovician time the St. Lawrence geosyncline was divided into two depositional troughs, separated by the Quebec barrier; these are the western Chazy and the eastern Levis. In these troughs Ordovician sediments were deposited. Clark mentions Beekmantown, Chazy, Trenton and Utica? from the Champlain region. Here it is to be noted that Young at an earlier date says, "Ordovician formations younger than Trenton have not been found in the Appalachian or Acadian regions,

except along the St. Lawrence coast of Gaspe."
The later work of Clark shows that there are probably later sediments, namely, the Utica, although he places a question mark after the designation.

The great Taconic orogeny closed the Ordovician, the Levis channel being thrust westward over the Chazy.

Great thicknesses of sediments were deposited in a trough to the east of the old Levis during the Silurian and Devonian. Young mentions 2,500 feet of Silurian in southeastern Quebec.

In late Devonian occurred the Acadian disturbance when "the whole Saint Lawrence geosyncline, and the Acadian trough as well, were blotted out by the Acadian disturbance, and all greater Acadia was transformed into mountains."

During late Mississippian the marine Windsor formation of the Maritime provinces of

Canada was deposited.

In the Pennsylvanian fresh water material was deposited in intermontane valleys; again in the Maritimes.

The last paroxysm to affect the Appalachian region was the Appalachian revolution of the Permian.

That the amount of and the dating of the orogenic forces affecting the Appalachian belts of the Eastern Townships, and hence the Ascot belt of metamorphic rocks in which the Eustis lies, may be properly gauged with respect to associated regional disturbances, a summary of these as given by Schuchert is quoted. "The four-fold deformation of Greater Acadia progressed from the interior oceanward, as illustrated in fig. 4. These times of orogeny are as follows: (1) Apparently an arch-making movement at the close of the Cambrian, which separated the Saint Lawrence geosyncline into two seaways. (2) The Taconic intense isoclinal folding overthrusting, with

The Four Orogenic Times in Greater Acadia, plotted diagrammatically.

1. Schuchert, Charles, Orogenic Times of the Northern Appalachians, Geol. Soc. America, Bull., 41, Figure 4.
Figure 4.—The four Orogenic Times in Greater Acadia plotted Diagrammatically

(1) Latest Cambrian folding, known only in northwestern Vermont, shown in the black line to the east of AD = Adirondacks. 
(2a) The unfolded area of the Saint Lawrence geosyncline, dotted. 
(2b) Next below, the narrow area of the Taconian orogeny, not subsequently deformed, single lines from left to right; the total area of Taconian orogeny is of course common to both geosynclines and the geanticline. 
(3) The extent of the Acadian disturbance, in both geosynclines, diagonal cross lines. 
(4) The crossing of the Appalachian folding (vertical lines) over the older orogenies (diagonal lines). The New Brunswick geanticline and the borderland Nova Scotia are left unshaded, to differentiate these positive masses from the sinking (shaded) areas. The solid black areas are certain of the Devonian granitic intrusions, shown diagrammatically; those of Newfoundland are not drawn in.
nappes, making a deformed area that is now very widespread in the western part of the Saint Lawrence geosyncline through eastern New York the Taconic, Green; and the inner or northern side of the Notre Dame Mountains, thence across the Gulf of Saint Lawrence and central Newfoundland, where in rias coasts the Taconian folds (and the Acadian as well) are broken down into the Atlantic Ocean; this disturbance continues south in the Appalachian geosyncline as far as central eastern Pennsylvania and dies out at the Maryland boundary. (3) The Acadian disturbance, when the remainder of the Saint Lawrence geosyncline, the New Brunswick geanticline, the Acadian trough, and the border land of Nova Scotis were folded almost wholly into permanent dry land; later, however, in late Lower Carboniferous time, the ocean again invaded the area through the Northumberland strait. (4) The Appalachian revolution, which elevated epeirogenically and faulted the Maritime Provinces (best seen in the Long Range Mountains of Newfoundland) and refolded (crossed) the southwestern part of the Acadian geosyncline from central Nova
23.

Scotia and the Bay of Fundy across southernmost Maine and eastern Massachusetts and Rhode Island, where these mountain folds also have gone into the depths of the Atlantic.

It is evident from the above that Schuchert assigns the major orogeny of the Northern Appalachian region to the Taconic. In this connection, it is significant to note that Clark also places the general overthrusting in the region north and east of Lake Champlain in the same orogeny.
General Geology of the Metamorphic Belt of Rocks in Which the Eustis Mine is Located.

A discussion such as this resolves itself into one of the so-called Ascot-Stokes Mountain belt, which is the middle of the three ranges of metamorphic rocks described in the general geology.

The rock types found in this belt may be classified as follows:

1. Metamorphosed volcanics or igneous rocks
2. Metamorphosed sediments
3. Intrusives definitely proved as such

Metamorphosed Igneous rocks:

There are two variations found, namely, chlorite and sericite schists.

The chlorite schists are derived from diabases, porphyrites, fine-grained diorites or andesites, the sericite schists from quartz porphyries.

The sericite or more correctly muscovite schists, if the name is applied to those at the Eustis mine, constitute the greater bulk of the rocks
of the Ascot belt. They are considered to have been derived by the metamorphism of quartz porphyries. This is Bancroft's, as well as the author's contention, support of which will be found in the section on the Origin of the Schists.

In most cases the schistosity of the sericite schists is well developed. On exposed surfaces they tend to have a banded rusty appearance due to the dissemination of pyrite crystals and in some instances to a little chalcopyrite with ankeritic carbonate, where best developed these rusty bands trend with the schistosity for lengths of a hundred feet and vary in width from a few inches to several yards. In addition to these, there are often transecting veinlets of quartz which carry sulfides and carbonate in very small amounts.

Most of the mineralization of the Ascot belt is associated with the above-described schists, in some cases being developed at the contact of these with chlorite schists. The ore bodies of the Eustis mine are entirely enclosed in the muscovite schists.
Metamorphosed Sediments:

Inasmuch as the schistose equivalents of sedimentary rocks play a very subordinate role, they will not here be described.

Intrusives Definitely Proved:

The only definite intrusives in the Ascot belt are some scattered occurrences of quartz porphyry and late basic dikes. Concerning the former, Bancroft says, "In a few localities, however (.... ..........), the quartz porphyry, in the form of dikes, is plainly intrusive into rocks of more intermediate composition."

The basic dikes comprise camptonites, monchiquites and olivine diabases; there are also some occurrences of Bostonite. They are all later than the ore bodies, which they transect very definitely, and against which they show chilled margins.

There are granite intrusions in the region, but the nearest of these, the granite mass of Barnston,

Quebec, lies about 12 miles to the south. This is the northerly extension of an area, 25 miles in diameter which is in the vicinity of Stanstead, Quebec. It is possible that similar granite masses lie at no great depth below the surface in the vicinity of the Eustis mine.

In relation to the intrusives of the region and their general period of intrusion, Clark says, "Succeeding the formation of the Silurian and (?) Devonian series, and presumably at the time of the Acadian orogeny, there occurred the intrusion of the Stanstead granite, which is so abundantly displayed in the southeastern part of the Memphramagog sheet. Elsewhere there are dikes of Monteregian affinities, and a few others of uncertain age."

This statement, then, implies that the granitic intrusions south of the Eustis are late Devonian in age, that is, belonging to the Acadian Orogeny.

Structure:

No detailed information concerning the structure of the Ascot belt has been published. Clark, however, has published some information on a narrow east-west belt of metamorphics from Lake Memphramagog west to Lake Champlain, that is across the southern extensions of the Ascot and the Sutton belts respectively.

Clark maintains that the Appalachian Mountains in this region consist of a series of thrust slices; overthrust (He also mentions two underthrusts on the east.) from the east onto the St. Lawrence foreland, the latter consisting of more or less Cambrian and Ordovician strata resting upon an unknown basement. The boundary between the foreland and the thrust zone is a large thrust fault, which from the early days has been referred to as Logan's Fault, extending from Lake Champlain up to Quebec City.

From west to east, Clark considers the region divisible into five thrust blocks, or as he calls them "slices" and two metamorphic complexes. The divisions from west to east are: the Granby, Philipsburg, Rosenberg and Oak Hill slices, the Sutton mountains and the Memphramagog complexes and the Tomifobia slice.

The region comprising the Memphramagog complex and the Tomifobia slice is that which is the structural continuation to the southwest of the Ascot belt, and there is then the possibility that such structures continue northeast.

It is to be noted that the westernmost slice, the Tomifobia, which is an underthrust, is bounded by a line which passes up through Lake Massawippi. If this be extrapolated to continue northward through the lake and thence down the Massawippi River past the Eustis, then the plane of the underthrust, which dips flatly to the northwest, should have been encountered in the mine; such very flat faulting is not found, however. The projection of structures over such a distance, 10 to 15 miles from the south is, it must be remembered, a very dangerous procedure.
LOCATION

The Eustis Mine is in the Eastern Townships of Quebec, which lie in that portion of Quebec southeast of the St. Lawrence River. The mine is about 10 miles southeast of Sherbrooke, the largest town in the Eastern Townships, with a population of around 28,933 in 1931. The mine is in lots 2 and 3 of Range IX in Ascot Township.

It can be reached by a highway from Newport and Derby Line in northern Vermont, or by one from Sherbrooke and Lennoxville, Quebec. The Quebec Central Railway from Newport, Vermont, also passes by the mine and maintains a flag station there.

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1. Canada Year Book, 1932, p.103.
2. Bancroft, J. Austen, op. cit. p.239.
Published production figures of the Eustis are scanty. From those published in Bancroft's Bulletin on Geology of the Eastern Townships, it is estimated that up to 1914, over 800,000 tons of ore had been mined, averaging around 4 per cent copper, and 30 per cent iron. Since the mine has been operating almost continuously since then, the above production figure needs to be greatly increased for total production to date (May, 1934).
The mineralization at the Eustis mine has found expression as concentrations of chalcopyrite and pyrite in lens-like masses which follow the dip of the enclosing schists. There are four such lenses, one being called the chalcopyrite lens and the other three the pyrite lenses. This does not imply that the first is mainly chalcopyrite, but refers to the fact that the lens carries from 10 to 20 per cent of that mineral, the rest being mainly pyrite. The pyrite lenses, on the other hand, carry only 1 per cent or less of chalcopyrite. The markedly higher copper content of the chalcopyrite lens makes this lens the ore-body of the Eustis; and the pyrite lenses, may or may not be mined, dependant upon the company's desire for more pyrite, which they ship to sulphur dioxide plants.

**Distribution of lenses:**

The four lenses are arranged en echelon. The chalcopyrite lens lies farthest to the southwest;
the pyrite lenses to the northeast, each succeeding lens to the northeast being across the dip and below that lens on the southwest. It is noted that there is but one chalcopyrite lens; that is, in referring to the chalcopyrite lens as the ore body, one does not speak of this ore body as consisting of a series of lenses arranged en echelon, but as one very long persistent lens.

**Chalcopyrite Lens:**

The "chalcopyrite lens" is defined as that lens which carries from 10 to 20 per cent chalcopyrite, the average being 12 per cent corresponding to 4 per cent copper, the run of mine average, and is, therefore, mineable for its copper content. This lens is to be differentiated from the three "pyrite lenses" which carry but 1 per cent or less of copper and are hence not mineable for such; they are, however, used occasionally for their pyrite content.

**Size:**

The greatest thickness of the chalcopyrite lens is 40 feet normal to the dip, this on the 4000
foot level. The strike lengths are as follows: greatest, 180 feet on the 3,700 level; smallest, 80 feet on the 5,450 level with an average of around 120 feet.

Relation to Enclosing Rocks:

This lens follows the schistosity and dip of the enclosing schists quite closely, cross-cutting not having been noticed by the writer, although Dresser in describing the deposits of the Capleton says, "Though rarely, the ore bodies, occasionally, cross the planes of foliation of the county rock." It is evident then that the general tendency of the ore is conformability to the dip of the schists. The general strike of the enclosing schist is northeast-southwest with a southeasterly dip. The dip varies considerably, from nearly horizontal to 80 degrees, the average and resultant dip being between 45 and 47 degrees. Below the 5,450 level and to the depths attained at this writing, the dip has been noticed to fluctuate from nearly horizontal to

80 degrees much more often than heretofore. Furthermore, it is to be noticed that the lens is perceptibly thicker in the flatter portions than in the steeper. This is suggestive of the damming tendency by flat portions of a depositional ore conduit.

The walls between ore and country rock are not sharply defined; they are transitional. Where there is an appearance of sharp transitions, it is often found that there are numerous narrow bands of schist, up to 4 inches wide and at varying distances, up to one foot, apart. These bands contain disseminated chalcopyrite and pyrite alternating with ones without any such sulfide. In the case of sulfide disseminated at greater distances from the main ore body, it is mostly pyrite, chalcopyrite apparently not being prone to migrate great distances into the walls. In the ore bodies there are often horses of unreplaced schist. These horses are, of course, in all stages of replacement, from those quite distinct to those whose schist ancestry is only recognizable in an indefinite banding preserved by the sulfides.
36.

Associated with the ore, in hanging or foot wall, or even enclosed entirely by sulfide, is the so-called green-rock, which occurs as fragments or bodies of varying size distributed throughout both schist and ore bodies. It also occurs as horses in the ore. These horses are, it is true, in varying stages of replacement, from fragments only partially to those almost entirely replaced by the ore. From the banding often assumed within these fragments, especially their replacing sulfides, and from their conformity to the schistosity of the schist, the green-rock is considered to be an alteration product of the schist. This conception will be more fully treated in the discussion of the green-rock.

The ore follows a lineal structure down the dip of the schists. When this is viewed on a wide expanse of dip surface, especially in the white lustrous schists, the structure appears as low ribbings, one-half to one-quarter inches wide and one-eighth to one-sixteenth inches high, and on the average four to eight inches apart. In studying these ribbings, they must not be confused with the
broken edges of schistosity planes. This lineal structure, running down the dip of the schists which are within 400 feet of the sulfide lenses, is noticeably absent in the schists outside of this range. The lineal structures are, therefore, in some way related to the structures responsible for localizing the ore.

A number of joint planes which cut both the dip and the schistosity of the schists are developed in varying amounts from the surface down. They have been called back-structures by the miners, inasmuch as they cut back across the dip of the schist and therefore of the ore body. Where most abundant they are steeply dipping joint planes from two to eighteen inches apart, along which the schistosity has been slightly bent; this bending is in the direction of slippage. The downthrown side of each joint plane is in the hanging wall of the joint, and they are, therefore, normal faults. These back-structure joints are earlier in formation than either the green-rock or the ore. Large masses of green-rock lie across these joints, that is the former is later in
formation than the joints. Pyrite occurs both in the joints and across them, indicating that the sulfide is also later than the back-structure. As far as could be ascertained, this back-structure bears no direct relation to the formation of the ore.

**Shape of Lens:**

When the copper lens is viewed in the horizontal plane of the shaft, it is seen to assume the form of an open spiral, and therefore, the lens plunges to southwest or northeast, dependant upon the level from which the observation is made. This effect is probably due to slight changes in the strike of the schists, and of their dip, with the result, that, when the ore lens is studied with respect to an undulatory plane, the changes in strike and dip result in a spiral-like form.

A very striking and suggestive form is assumed by cross-sections of the lens, namely that of a sigmoid curve. The cross-section of the lens at almost every level conforms to this form and all maintain the same direction of curving, that is, each section is conformable to the ones above and
below. It is as evident in those with a short strike length as in those with a long. This form is that assumed by a body subjected to stress by two opposite and tangential forces. In this case it would result if two forces acted on the schists from a northeast and southwest direction, that is, acted but slightly inclined to the plane of the schistosity. Such play of forces would tend to develop a zone of tension in the subjected schists. This is the zone of tension, through which the ore solutions are conceived to have passed and to have deposited their mineral content.

Pyrite Lenses:

The pyrite occurs in three separate lenses. They are usually less in size across the dip than is the chalcopyrite lens, but are greater along the strike of the schistosity than is the latter. Only on one level, the 3,850, has the eastern end of a pyrite lens been reached, and here the width along the strike of the schists is 230 feet at 270 feet east of the shaft. The pyrite lenses have not been explored to their ends, the western portions being the only parts
developed; despite this, if one judges from the size and shape of those portions thus exposed, the pyrite lenses appear to have the same general dimensions as those on the 3,850 level.

It is to be noted that with reference to the schistosity, the lenses occur below the copper lens, and are always to the east; there are, in places, slight overlappings along the schistosity, but never a complete crossing of the copper by a pyrite lens. This may be ascribed to the fact that the combination of both the physical and the chemical natures of the wall rock and those of the postulated zone of disturbance varied with different horizons in the schists. The result was a set of conditions suitable for the deposition of pyrite which were different from those for the deposition of chalcopyrite.

Nowhere does a pyrite lens appear to be a continuation along the strike of the schists of the copper lens; this, of course, is to be expected from the difference in the location of the lenses with respect to a schistosity.
Faulting:

Faulting in the Eustis mine is not marked, the few faults encountered being of small displacement, not exceeding a few feet. They strike slightly north of west and dip to the north, and are all normal faults. There have been only three major faults encountered so far. As from Bancroft "A few hundred feet below the tunnel, a fault was encountered which cast the ore body about twenty-five feet into the hanging wall; here a long drift, known as the 'slide-drift' was then extended for over 900 feet toward the southwest. At the nineteenth level below the tunnel (about 2,450 feet below the collar of the Hartford shaft) there is a fault which has a throw of about 60 feet." Faults with displacements of about 20 and 30 feet have been since encountered, one cutting the pyrite lens respectively on 3,850 level and the other the chalcopyrite lens on 5,550 level. No faults have been seen to transect the dikes, so whether they are earlier or later than these cannot be decided. Inasmuch as the dikes dip and strike in the same manner as these faults,

the suggestion is, at least, that they may follow fissures which were opened at the same time as the faulting which affected the ore body.

Other Ore Bodies Analogous to those of the Eustis:

There are several occurrences other than the Eustis of lens-like ore bodies enclosed in schist along the Ascot belt. They are the Park, Short, Howard, King, Silver, Star, Suffield, Belvidere, Clark, Hepburn, Capleton, Moulton Hill, Stratford, Albert and many other still smaller mines. These are all much smaller, developed to a lesser extent than the Eustis and have been non-productive for some years.

Interesting analogies to the Eustis mine are found at the Ely and Pike Hill mines of Orange County, Vermont. Here the ores have formed by replacement of schists along openings caused by folding which was after the regional deformation of the region. The mineralogy of the ores differ somewhat from that of the Eustis, chiefly, in that there

is much more pyrrhotite in the Vermont ores. The closest analogy is in the matter of structure. The ore body of the Ely is a chimney of ore of small cross-section and short strike length, but it is persistent in depth. It occurs in one of a series of cross-buckles, in which the beds have parted, leaving a series of connected open spaces which were followed by the mineralizing solutions, so that the ore is in part open filling but in major part replacement.

Generalizations as to the nature of the forces responsible for forming the permeable zone in which the lenses occur.

The sigmoid shapes which are assumed by most cross-sections of the Eustis lenses are of considerable genetic significance. Sigmoid shapes are those assumed by quartz lenses found in folded rocks, and are considered to have been formed by mineralization in zones of tension which were caused by drag folds formed in strata of different competency.

It has been shown that such zones of tension form in material between parallel and oppositely
directed forces which act on the limbs of an anticline or syncline. Along the limbs of a fold the direction of these forces can be determined, and it has been found that the characteristic sigmoid shape displayed by a section of the zone of tension, is oriented always in the same direction for a similarly disposed set of the forces responsible for the tension. The direction of the length of the lens, that is, that direction normal to sigmoid section, is the axis of rotation of the couple formed by the force system.

The sigmoidal shapes displayed by the cross-section of the Eustis lenses are compared to those of quartz lenses in the drag folds of sedimentary rocks because, in this latter instance, the stratification aids in the correct interpretation of the direction of the forces responsible for the drag folding. So, when lenses, also of a sigmoidal cross-section are found at the Eustis, not in sedimentary strata but in the schistose equivalent of a quartz-porphyry, the direction of forces responsible in the latter case can be determined by a study of the shape and orientation of the sigmoidal cross-section and from the direction of elongation of the lens. It
will be seen then, that, the forces responsible for the creation of the zone tension at the Eustis would be opposite and parallel forces, acting from the northeast and southwest horizontally in the plane of the dip of the schists. The movement was such that the sides of the lens near the northeast end moved southeast, and those sides towards the southwest end moved northwest.

Within a major zone of tension it is conceivable that there would be several zones formed within the major one which would be outstanding in their superior development of permeability to ore bearing solutions, and hence would result in the formation of several sulfide lenses.
GREEN ROCK

Distribution:

The type of rock which is termed green-rock occurs from the surface down to 6,000 feet, the depth attained at the time of this writing. It is in greatest abundance in the ore zone but some green-rock of the block type was found as much as 800 feet east of the shaft on the 2300 level.

Habit:

The green-rock has two modes of occurrence, one as swelling and pinching sill-like lenses in the schist, (Plate XI, Figure 1.) and which vary in width from one-half inch up to two and three feet. The other habit is as irregular blocks occurring both in the ore and in the schist. They vary in size from indistinguishable remnants, one-half inch or so in diameter, up to ones seventy-five feet in largest diameter. It has been noticed that the sill-like habit is lacking in green-rock outside of the immediate vicinity of the ore zone.
Color:

Green-rock is a very appropriate name, inasmuch as the commonest color is a dull olive green. This, however, becomes of a fainter hue, a light buff, in sill-like masses. The color is a manifestation of the amount of chlorite in the rocks, varying from deep green in those which have abundant chlorite to a buff in those with a lesser amount.

In some of the older workings where the surfaces of the green-rock have remained exposed for some considerable time and have not spalled off to give fresh surfaces, the rock has a decidedly rusty appearance. This is only on the exposed surfaces, for when the rock is freshly broken it assumes the usual color. This rather rapid development of iron rust is an indication of the large amount of iron in the green-rock as contrasted to the lesser amount in the schists which seldom show such rusty surfaces.

Texture:

The grain size varies from dense and very
fine up to grains 2 to 3 mm in diameter. A variation of this degree of magnitude is often seen within a single block, from fine on the periphery to coarse in the central portions. Some of the blocks have a very dense selvage varying from one-sixteenth to one-eighth inches in width. This is by no means common to the green-rock blocks.

The most outstanding feature of the green-rock is its massive character. The enclosing schist is always very schistose and often laminated to a marked degree, but the green-rock is blocky, possessing an almost conchoidal fracture. Jointing is absent. This large scale massiveness is a feature strikingly similar to that of the ore body. The resemblance undoubtedly genetically relates the two -- green-rock and ore body. The massiveness of the blocks is the characteristic which is first impressed upon one and is only modified slightly upon closer examination.

Some of the larger blocks possess a border cleavage. This takes the form of very closely spaced cleavage planes, about one thirty-second inches apart,
lying at an angle of approximately thirty degrees to the contact. In the blocks in which it is developed, the cleavage extends all around the fragment. This cleavage is by no means a common characteristic. It is considered to be a local manifestation of weak stresses which still lingered after the main deformation of the rock in pre-green rock times. It is significant that there are no transverse joints as are common in intrusive bodies, such as dikes.

Despite the large scale massiveness and even granular texture of the green-rock, there is developed a very fine-grained schistosity. (Plate XII, Figure 2.) This is best seen in the finer-grained facies of the rock, and, when blocks of such are viewed on sections normal to the schistosity of the enclosing schist. When thus examined the schistosity of the green-rock is evident and it is seen to parallel that of the enclosing schist. This possession of schistosity and its parallelism to that of the schist is strongly suggestive of the former having formed by replacement of the schist, the green-rock
schistosity being an inheritance from the schist.

Examination of schistose green-rock under the microscope, in thin-section, shows that the schistosity is due to an alternation of chlorite rich bands with chlorite poor ones. It is not due to an alignment of muscovite laths as is the case with the schist. The muscovite is not developed in any great abundance, and where it is in abundance the laths are short and their arrangement is similar to that assumed by plagioclase laths in diabases; a genetic analogy is not to be inferred, however. The schistosity which is best displayed in thin-section is to be found in the very fine-grained varieties. (Plate XIII, Figure 2.)

**Relations to Surrounding Rocks:**

All the green-rock, both blocks and sill-like masses, conform to the schistosity of the schist. There are never any cross-cutting relationships as are common to bodies intrusive into their surroundings. The contacts are always strikingly sharp; in very few cases are there evidence of gradations from one rock to the other. In a few instances definite
residuals of schist in the green-rock were seen. These are always small and close to the border. They are lenticular areas from two to four inches long and one-sixteenth to one inch wide and grade off imperceptibly into the surrounding green-rock.

The contacts of this rock with the ore conform as they do in the schist, to the banding of the ore. This banding is an inheritance from the schistosity. The actual contacts are somewhat less sharp to the ore than to the schist and show evidences of corrosion. These latter are much more clearly exemplified in smaller fragments four to six inches in largest diameter than they are in the large ones. There are also definite cross-cutting relationships of the green-rock by ore.

Quartz-chlorite-calcite veinlets and lenses are prominently associated with the green-rock. Where they are found in connection with the sill-like masses, they interrupt the continuity of the sill-like habit. In the massive and blocky green-rock such veinlets transect the fragment in a widely spaced reticulate pattern, the spacings being from six to eighteen inches,
the lenses and veinlets varying from one-eighth to three inches in width. It is significant that this mineralization is so closely associated with the green-rock and not with the schist, the relationships suggest a similarity of origin. That is, the green-rock is a result of mineralization phenomena as well as the undoubted mineralization feature—the quartz-chlorite-carbonate bodies—although the two mineralizations may be separated by a time interval.

The green-rock has formed definitely later than the back-structure. This is clearly shown, for example, on the landing at the 5,900 level where a lens of green-rock six feet long lies athwart the back-structure joints, these latter being quite persistent and closely spaced, from three to six inches apart.

**Microscopic Characters:**

**Texture:**

When examined in thin-section the green-rock is seen to be holocrystalline, the finest material being quite recognizable as crystals. Its grain
is phanerocrystalline varying from medium (1 mm) to fine-grained (.01 mm). The fabric is hypidiomorphic, there being euhedral muscovite and rutile surrounded by anhedral quartz and chlorite and carbonate. The texture is in the main even-granular, there being, however, in some of the green-rock, as above-described, a faint schistosity. (Plate XII, Figures 1 and 2.) This is caused by alternation of chlorite rich with chlorite poor layers and an alignment of the chlorite laths in these.

Description of Minerals:

Listed in their order of abundance, the minerals found in the green-rock are as follows:

<table>
<thead>
<tr>
<th>Blocky Masses per cent</th>
<th>Sills per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>58</td>
</tr>
<tr>
<td>Carbonate</td>
<td>25</td>
</tr>
<tr>
<td>Muscovite</td>
<td>10</td>
</tr>
<tr>
<td>Chlorite</td>
<td>6</td>
</tr>
<tr>
<td>Rutile and Leucoxene</td>
<td>1</td>
</tr>
</tbody>
</table>

The quartz of the green-rock is more or less of a ground mass of elliptical anhedral grains for the other minerals. It is much finer in grain
size than are any of the others, the average size being .03 mm on the longest diameter. The deviation from this size is very slight, that is, the grains are of quite uniform proportions. The greatest concentration of quartz is between the carbonate grains, but it is also found, in lesser amounts, as inclusions in the latter. They are still of the same general elliptical shape and size.

The carbonate, which has been determined as ankerite, occurs as discrete grains which average 0.2 mm in largest diameters. The amount varies from 25 per cent in some of the massive fine-grained green-rock of the larger blocks to 50 per cent in the lighter colored sill rocks.

The most noticeable feature of the carbonate, viz.: ankerite, is its lack of good crystal outlines; this is in marked contrast to the almost perfect development of such in the vein carbonate, which is found to be calcite. The shape is sub-rounded and is decidedly anhedral, almost to the same degree that quartz is anhedral. The grains are quite equidimensional, and even in those which
have a tendency to assume elliptical outlines, there is no inclination to alignment in schistosity planes where such is made evident by the presence of chlorite bands.

Another noticeable feature of the ankerite is the great number and variety of minerals found as inclusions. These, in order of abundance, are as follows: quartz, muscovite, rutile, but no chlorite.

The quartz inclusions are similar, in every manner, to the quartz grains of the ground mass; they are of the same general size, are rounded to elliptical and show no inclusions. Their distribution within the ankerite grains is very haphazard, and their concentration bears no relation to the grain boundaries, being as numerous in the central portions as they are on the peripheral regions of the grains. Manifestation of this characteristic is seen in the manner in which the edges of the ankerite are markedly serrated by the quartz inclusions. This interruption of the borders does not in any way interrupt the directional continuity of
any one side of a grain. (Plate XIII, Figure 1.)

Muscovite occurs as a haphazard distribution of blades in the green-rock. Some of these are found as inclusions in and across ankerite grains. However, it appears to be merely coincidental that they occur as inclusions in the carbonate grains. This rather sporadic occurrence as inclusions is to be correlated with development of the muscovite at the same general time as the carbonate.

The inclusions of rutile and of its alteration product, leucoxene, bear the same relation to ankerite and surrounding minerals as does the muscovite. It possesses the same ubiquitous distribution with respect to ankerite and the rest of the green-rock.

In the study of ankerite inclusions, one feature is very noticeable, viz.: the complete absence of chlorite within the carbonate grains. This would indicate that the chlorite is of later formation than the carbonate.

A characteristic of rather rare occurrence is ankerite rimmed by a narrow band of carbonate, in
optical continuity with the core, but with a different index of refraction. (Plate XIII, Figure 2.) It is thought that such represents a development of carbonate with different iron content than that of the ankerite, and, is possibly due to slightly changing solutions during the carbonatization which formed the green-rock.

Some of the ankerite grains are partially rimmed by a narrow band of alteration product. The material is light brown to colorless and shows a spotty double refraction of the carbonate order. It very commonly rims one side of a grain, and then continues along as a band of the same width along the slight schistosity of the rock. In this latter environment the material is intimately associated with chlorite and other irregular areas of the same material. It is thought that it represents a breakdown of the iron and calcium carbonate of the ankerite into a mixture of iron hydroxide and a less iron rich carbonate than ankerite.

Muscovite occurs quite widespread throughout the green-rock, although, in general, it is quite
randomly distributed. There are places where it forms segregations, from small up to 0.5 mm across, of laths. It is typically developed as laths, the largest being about 0.2 mm in length, but there are also, in considerable amount, broad, low doubly refracting, plates; these are very irregular in outline and are, on the average, 0.1 mm on longest diameter.

The chlorite of the green-rock has been called diabantite, as deduced from its optical properties, described elsewhere. It is quite widespread throughout the green-rock, but the amount of it varies, and with this variation, there is a concomitant change in the color of the rock. The large irregular blocks contain the most chlorite, up to 10 per cent, and the sills much less. Some of the latter have only traces of chlorite. The chlorite occurs as small irregular blebs more or less segregated into separate areas of disconnected habit in the quartz matrix, and as chlorite bands. (Plate XIX, Figure 1.) The latter have very poorly matched walls, and may or may not
parallel the schistosity. They are typical replacement veinlets.

Chlorite, of the amesite variety, occasionally occurs as isolated bundles of laths, and because of this isolated habit, its age relations to the other minerals of the green-rock were indeterminant. In some specimens from a highly sheared fragment of green-rock found in the hanging wall side of a fault on the 5,550 level, amesite comprised 75 per cent of the rock, the remainder being sub-parallel bands of ankerite. These conditions are considered to represent a heavy amesite mineralization impressed on the carbonatization and diabandite development in the green-rock.

Rutile (Plate XIII, Figure 2.) and its alteration product, leucoxene, occur very abundantly in the green-rock. They are confined exclusively to this rock. The rutile occurs either as single grains, usually less than 0.02 mm in length, or as clusters as radiating crystals. In some of the masses, the needle-like habit of the rutile is almost lost, due to the abundance of cloudy leucoxene between the needles. In others the clusters consist of narrow
rutile needles radiating from a common centre. The amount of these minerals developed varies with the amount of carbonate, there being most in the sill-like masses of green-rock, these latter possessing a great abundance of carbonate. The radiating habit of the needles and the direct relationships born to the amount of carbonate suggest that it, as well as the latter, is an introduced hydrothermal mineral.

**Origin of the Green-rock:**

It is considered that the green-rock has formed by a replacement of schist along a zone of tension. It has, as inheritances, from the schist, a marked schistosity in places, and a ground mass of quartz grains which are in every way similar to those which form that of the schists. As evidences of replacement by the green-rock, there are the schist residuals found in the former, unquestionable evidence of replacement of the schist by mineralization. The green-rock is not to be considered as a rock which has been intruded, and, therefore, to replace it bodily, but as a portion of the schist which has suffered re-
placement by introduced mineralization. This mineralization has induced the formation of carbonate, this an iron rich variety, which is the type formed during the earlier stages of any mineralization period. At about the same time muscovite developed, and slightly later, but definitely later, diabandite, an iron-magnesium rich chlorite formed. The above mineralization, viz., iron rich carbonate and chlorite as well as muscovite, is that which is found in the early stages of mineralizations. Furthermore, it is an assemblage which forms in low-intermediate temperature mineralizations. Note the absence of biotite in this connection, a mineral belonging to a higher temperature type of mineralization.

**Summary:**

The green-rock is one which varies in color from dull green in the massive and blocky types to light buff in the sill-like varieties. As intimated, there are two habits, small to large inequiangular blocks and sill-like masses up to two feet in thickness. It is the most massive
appearing rock in the mine. In this, it is similar to the ore bodies, but on close examination shows a faint though distinct schistosity which always parallels that of the enclosing schist. It replaces the schists but, is itself, in places, replaced by the sulfide masses.

It is mainly a carbonate rock, consisting of ankeritic carbonate, with later chlorite muscovite mineralization features and the quartz, an inheritance from the schist.

The green-rock originated by an intense ankeritic carbonatization of schist along a zone of tension, this zone making the schist very susceptible to replacement.
Schists and their variations make up the bulk of country rock in the Eustis mine. They may be classified, for the sake of description, into two gradational types, one, which is outside of the ore zone and is but very slightly schistose, and the other more schistose in the ore zone.

**Schist Outside of the Ore Zone:**

**General Characteristics:**

The rock which is away from the ore zone varies in the amount of schistosity developed in it. Some of it is quite massive, but still possessing enough schistosity to give lustrous surfaces in one direction. Both the massive and the more schistose varieties show abundant phenocrysts in the hand specimen. There is another type lacking phenocrysts which is decidedly laminated. It is a very dense dark green rock which breaks easily parallel to the laminae, exposing lustrous dark green surfaces possessing a waviness reminiscent of that found in phyllites. In speaking of the cause of banding in the alaskite porphyry of the Shasta County, California, copper
deposits, Graton says, "Over large areas the rock is much sheared and differences of alteration and weathering, emphasized by and partly dependant on this shearing, give it in places a banded aspect."

Shearing is very much less marked in this rock than in that of the ore zone. Its general appearance in contrast to the latter is that of a more massive rock. However, it is not, as indicated above, so massive that its schistosity is not evident upon close examination of the hand specimen.

**Microscopic Examination:**

These rocks are composed entirely of crystals, there being no glass in the thin-sections examined, as might be expected in extrusive flow rocks. The texture is decidedly porphyritic, there being abundant phenocrysts of quartz and feldspar. (Plate V, Figures 1 and 2.) These vary in size from elliptical blebs 2 by 1 mm in size, to those about one-tenth the size. The ground mass is very fine, averaging .01 mm in

size of grain.

The minerals found forming decided phenocrysts are quartz, albite, and an occasional carbonate grain. The ground mass consists of very fine-grained quartz and feldspar, the grains being about 0.01 mm in size. In addition to these, there are others of intermediate size and of random distribution, viz.: muscovite, chlorite, medium-grained quartz, epidote and titanite.

Quartz occurs in these rocks as phenocrysts, ground mass and vein quartz. The phenocrysts vary in size, as above-mentioned, from 2 to 0.2 mm along largest diameters. All the quartz phenocrysts show undulatory extinction and contain strings of fine-grained dusty-like inclusions. These are usually segregated in sub-parallel rows, but they bear no relation to the direction of the schistosity. There is occasionally a suggestion that the grains have been rotated. It is quite conceivable that this may have been so, inasmuch as elsewhere in the rocks there is evidence of shearing action, a process which would certainly have tended to rotate any resistant grains. In this connection, it is remarkable that the phenocrysts
are free from any development of mortar structure. They have, however, in places, been somewhat fractured, and the fractures filled by an aggregate of quartz grains which are coarser than the ground mass quartz, except that the grains, though very small, are elliptical with an eccentricity of 1.2 and are definitely aligned in the direction of the schistosity.

The medium-grained quartz, possessing an average grain size of 0.03 mm is distributed in vein-like masses which vary in width from 0.05 to 0.5 mm. These veins are always parallel to the schistosity. It is significant that some of these veinlets commence as wide fan-like aggregates behind some of the quartz phenocrysts, and narrow away from them in the direction of the schistosity into very thin veinlets of this same medium-grained quartz; the material nearest the phenocrysts forms, therefore, the so-called quartz tails. (Plate V, Figure 1.) These are regarded as the result of low pressure areas which have been developed during shearing around the resistant phenocrysts, the lessened
pressure area thus available being filled by later quartz.

The other main constituent which occurs in the massive schists as phenocryst matter is albite. Other plagioclase and orthoclase are absent. The grain size of these is comparable to that of the quartz phenocrysts. They are remarkably free from any great development of sericitic alteration, the amount developed amounting only to a few scattered shreds of sericite. The albite has, however, been more susceptible to internal fracturing and comminution than has the quartz. The result has been an incipient mortar structure inside some of the albite grains, with a recrystallization of feldspar along the lines of fracture. Where the shearing has been more effective, the grain has been broken apart and the fracture filled with quartz. In one case, where this phenomenon is considered to have taken place, the smaller piece which had been broken off had been slightly rotated from its original orientation, this was shown by a difference in orientation of certain twin laminae.
which were comparable to some identical laminae in the parent from which it had been torn. It is significant that there are more smaller phenocrysts of albite than there are of quartz and also that the former shows more evidence of comminution than the latter. This all suggests that the albite is more susceptible to shearing forces than is the quartz and will, therefore, upon the application of greater stresses disappear first. This thought must be borne in mind when trying to account for the absence of albite in the highly mineralized schist of the ore zone, and also for its absence in the green-rock.

The amount of muscovite developed can be estimated from the amount of sheen and schistosity possessed by any rock. In the least schistose phases, and, therefore, in those which show the greatest number of plagioclase phenocryst there is very little, less than 1 per cent. The material is sufficiently well crystallized, however, to distinguish it from the very fine-grained sericite which is developed in the plagioclase phenocrysts. The muscovite is segregated into very thin, non-persistent bands which
curve around all the phenocrysts. These bands seem to be most numerous and thickest where there is evidence that there has been a greater amount of shearing than is ordinary in this rock. It is an open question how much of this muscovite is due to a recrystallization of original muscovite material, that is from a break down of possibly previously existing potash feldspar, or to an introduction of muscovite as part of the widespread mineralization of the region. The fact that there are also carbonate and pyrite of the mineralization epoch present, even in these rocks, makes it possible for some of the muscovite to be also a mineralization phenomenon, and in all probability related to the same mineralization.

Epidote, although rare in most of the rock, constitutes up to as much as 1 per cent of some of the less schistose phases. It has not been observed in the laminated types. This mineral occurs most abundantly as prisms, with a maximum length of 0.15 mm and width of .05 mm. Many of these prisms are, however, broken and the fragments of such strewn
between the more perfect material. The mineral is segregated into bands which parallel the schistosity and are often seen to curve around the phenocrysts just as the other linear components of the rock do.

Carbonate is quite commonly present, although in amounts never exceeding 1 per cent. It may occur as discrete well-formed rhombohedrons which contain numerous residuals of quartz or as narrow veinlets, up to 0.05 mm in width, which very definitely cross-cut the schistosity. Such a habit is very clearly shown in some of the well-laminated rock. These characteristics form good evidence of the replacement nature of the carbonate. To be correlated with this habit is that wherein the carbonate occurs as an almost continuous segregation of grains along some of the chlorite bands of the latter rock. Because of the better crystallized form of this than the green-rock carbonate and the fact that it occurs as veinlets, the carbonate found in the outlying schist is considered to be unrelated to that of the green-rock and to have formed at the same time as that of the quartz-chlorite-carbonate veinlets found in the
green-rock and to be, therefore, a less iron rich carbonate, probably almost pure calcite.

Titanite occurs as an occasional constituent, up to 1 per cent of the well-laminated rocks. It is usually as broken fragments, although in a few cases the diamond-shaped habit was recognized. The fragments occur segregated in bands, usually in those which have an abundance of chlorite. It evidently represents material which has been crushed and strung out in bands by shearing forces.

Chlorite, which has been identified as diabandite and is identical with that found in the green-rock, is found in both the laminated and the more massive porphyritic rock. It possesses a very shreddy habit; nowhere is it arranged in aggregates which can be construed as having been once the site of a previous ferro-magnesian mineral. The shreds are commonly concentrated in bands which parallel the schistosity or lamination of the rock. In such cases it is seen to be almost exclusively associated with the medium-grained quartz of these bands, or, with that found as quartz tails at the ends of phenocrysts.
This association with quartz which has been concluded to be introduced material, suggests that most of the chlorite is also introduced and not original. It is entirely possible that the few very small, 0.01 mm in width and up to 0.1 mm in length laths of chlorite which are distributed in the ground mass, represent original material which has to some extent been recrystallized. The possibility of its being a mineralization phenomena is further enhanced by the fact that it is similar in general optical characteristics, and, therefore, presumably, in chemical composition, to that found in the green-rock. Here the chlorite is considered to be mostly a mineralization feature.

In other words, mineralization, represented by the introduction of chlorite and other minerals is in evidence as far as 1,100 feet east of the main copper lens.
Schist of the Ore Zone:

The rock of the ore zone is very much more schistose, sheared, and contorted than that found elsewhere. (Plate VII). On the dip surfaces it is very lustrous and crenulated, the many muscovite foils adjusting themselves to the crenulations and being themselves responsible for the sheen.

The structural relations of this schist to the green-rock are discussed in the description of the latter. The schist has evidently been replaced by mineralization solutions to give the green-rock.

The contact relations show that the schist has been replaced by the ore. Gradational contacts between the two are the rule, and a widespread permeation, both along and across the schistosity, is a very common habit of the sulfides. Remnants of schist in ore are quite common. These are recognizable as pieces from a few feet across to ones so small that the schist parentage of such small masses has been all but obliterated by the replacing sulfides.
The schistosity of the ore zone is caused by numerous and closely packed foils of muscovite, comprising in some cases, up to 75 percent of the rock. These foils of mica are very undulatory in their direction. This characteristic is caused in part by their wrapping around, either still existing quartz phenocrysts, or around areas now consisting of medium-grained quartz which were previously the site of the above-mentioned phenocrysts.

**Microscopic Characteristics:**

The non-metallic minerals found in this rock comprise the following, listed in their general order of abundance: muscovite, quartz, chlorite, carbonate, and quartz-albite veinlets. The mineral, anthophyllite, has been developed as a post-ore, metamorphic mineral in one locality, where the ore body has been cut by a fifty foot dike on the 4825 level. The description of this mineral will be given in the section devoted to a discussion of the mineralogical transformations effected by this dike.
Muscovite occurs in varying amounts in all the rock of the ore zone, varying from about 5 per cent in the less schistose types to 75 per cent in those which are very schistose. It has two main types of occurrence, viz.: one as isolated laths disseminated in the medium-grained quartz matrix and the other, as curving foils of shreddy muscovite. As the former habit, the laths vary in size from those only 0.05 mm to those about 0.5 mm in length. It is to be noted, however, that even the smallest laths are sufficiently large for a determination of the optical characters of the mineral. That is, such material is called mica rather than sericite, a name which is better reserved for the very fine-grained material which forms as an alteration product in feldspars. The muscovite of the foils is somewhat different from that just described, inasmuch as the material comprising the foils is more shred- than lath-like, and clear cut crystal outlines are lacking. It is to be noted that these foils seldom maintain a uniform width for more than
a centimeter. They very often dwindle in width to bands only a few laths in width, and just as frequently disappear entirely. This rather discontinuous habit suggests that the material surrounding the foils, which is mostly medium-grained quartz, replaces these foils, that is, the muscovite, though itself a mineralization feature in great part, has been replaced by medium-grained quartz. The evidence that the bulk of the muscovite, both that occurring as individual laths and that in foils, belongs to the mineralization epoch and is not residual, is of a field nature, viz.: the amount of muscovite increases from very occasional amounts in the rock, 1000 feet or more removed from the ore to amounts in the ore zone, where in many cases, they constitute the bulk of the mineral composition of the rock; muscovite increases as the ore is reached. There is one bit of evidence of a later origin of the muscovite available in thin-section; where a still remaining phenocryst of quartz has been fractured, this fracture is often healed by muscovite which is either as short transverse laths, or as very long ones lying
along the length of the fracture. (Plate VIII, Figure 1.)

Quartz is one of the most persistent minerals of the schist, occurring in all specimens. It forms from about 10 per cent of the rock in those specimens which contain abundant muscovite to about 75 per cent in the very quartzose varieties. There are three main grain sizes, fine, medium, and coarse. The fine-grained material averages 0.03 mm, that is, though here it is termed fine, it is three times as coarse as that which forms the matrix in the but slightly mineralized schist which is found further removed from the ore zone. It does, however, compare favorably in size with that quartz of the latter rock which occurs as veinlets in the fine-grained ground mass. The analogy in size holds, but there is not necessarily one in genesis. The veinlet quartz of the slightly mineralized rock is considered to be mainly introduced, whereas the quartz of the same grain size in the ore zone is thought to be recrystallized material. As objective evidence for the latter might be mentioned the very widespread and uniform distribution of this as a ground mass in the rock; it does not occur in lenticular bodies or in more continu-
ous bands suggestive of veinlets. As subjective evidence may be cited the necessity of accounting for the very fine-grained ground mass of the unmineralized schist. This very fine-grained ground mass has entirely disappeared in the ore zone, and the material which here most closely resembles it in relation to the other minerals is the much coarser quartz. Therefore, the latter represents the very fine-grained ground mass of the unmineralized schist recrystallized to a coarser grained aggregate.

Classed as a medium-grained quartz is all material not forming the fine-grained ground mass and not including quartz phenocrysts still remaining. The average grain size of this material is 0.1 mm. This quartz occurs as lenticular aggregates, which are but slightly larger than the quartz phenocrysts, as crystallizations around sulfides, and as a constituent of the quartz-albite veinlets. The lenticular areas consist of a mosaic of clear quartz grains, which are noticeably free from inclusions such as are so common in the quartz phenocrysts. These areas average 0.3 mm in their greatest widths and 1.0 mm
in their length. They usually lie with the schistosity; although some areas curve across this; but such cases are to be interpreted as sharp and more or less imperceptible turns in the schistosity rather than decided cross-cuttings of it. Quartz of this general medium-grained size is also well-developed around the sulfides, especially pyrite cubes. Some of these grains are elongated and arranged normal to the faces of the pyrite grains, and this material can best be called feather or shadow quartz. (Plate IX, Figure 2.) The development is by no means as perfect as that which is found around pyrite grains in slates. There is neither the perfection of outline nor of internal structure such as is the case in typical feather quartz. The


width of the areas containing the normal quartz is very variable, from very narrow up to widths equaling the diameter of the pyrite cube. Furthermore, the outer edges of such areas are always very irregular, the irregularity being due to the contact with the medium-grained quartz, or, where sulfides are abundant, with the quartz of other shadows. This material, though not forming perfect shadows, was formed under the same conditions as the more typical variety, namely: as a result of the formation of a zone of lessened pressure caused by a linear extension in the schist which tended to lessen the pressure on the ends of the pyrite porphyroblasts, and the development of quartz mostly by replacement rather than by filling, in the low pressure areas according to Riecke's principle. Most important is the fact that this quartz is evidently later in formation than the pyrite to which it has developed as normal crystals.

Quartz phenocrysts occur frequently in the ore zone schist, but in very reduced numbers as compared to the schist away from the ore zone. They are of the same general size but differ in that they are more frequently fractured, sometimes so much so
that the recasting of the separated fragments into an original phenocryst is difficult. A variety of material fills these fractures, muscovite, both short and long laths; carbonate, occasional chlorite and fine-grained quartz. Where the latter occurs in fractured quartz, there is seldom any other mineral present, suggesting that here there has been a development of mortar structure, thereby producing small grains in the fractures of a larger individual, the phenocryst. That there still remain quartz phenocrysts to the exclusion of albite, even in those schists which are most highly mineralized, certainly demonstrates the great stability of such quartz. It is, furthermore, fortunate that such do remain, for they serve as an important link in correlating the schist of the ore zone with the rock outside of such where mineralization has not so radically altered the original nature of the rock.

Schist which is very heavily pyritized is often cut by quartz-albite veinlets. These are on the average 1.00 mm in width. The minerals found in such veinlets are, quartz, albite and occasional carbonate. The grain size is 1.00 mm on the longest
diameters, and 0.5 mm on the shortest. The albite grains are well twinned, show no evidences of bending, and, are quite free from sericitic alteration. The quartz grains, however, contain numerous cloudy inclusions in their central portions. The carbonate is on the whole as well-shaped rhombohedral crystals, but some of it is quite fragmental as though it had either suffered from fracturing or from replacement by the surrounding quartz and albite. A very thin sinuous line of fine-grained quartz was seen in one specimen to maintain its path through several quartz grains. This probably represents granulation of quartz along a very weak fracture, caused by stresses which were still existing after the latest phases of mineralization. The manner in which these quartz-albite veinlets transect whole sections of ore specimens, maintaining a persistent course through all sulfides and gangue, certainly indicates that they are much later than any of the sulfides, and, of course, than the gangue. Isolated areas of pyrite and of chalcopyrite are found in such veins, but the bodily interruption by such large transecting masses of sulfide
has not been observed. These isolated areas of sulfides are considered to be unreplaced remnants.

The chlorite, amesite, is developed in varying amounts throughout the ore zone schists. (Plate X, Figure 2.) In some of the rock there is only about 1 per cent present, the average is less than 5 per cent, but, in some highly sheared rocks, this mineral and sulfide constitute the bulk of the material. The amesite occurs as small single laths and as large bundles of such laths. (Plate IX, Figures 1 and 2.) The small sizes are on the average 0.1 mm in length and .02 mm in width. They lie commonly in the fine-grained quartz oriented only roughly in the schistosity oftentimes lying directly across this. This contrast in habit as between chlorite and muscovite may be attributed to the fact, that, for amesite, the ratio of length to width of any one lath is less than that of muscovite laths of similar dimensions, and hence would not have such a tendency to conform to the schistosity. The bundles of amesite are usually 0.7 mm in largest diameter, which is here a length, because the bundles have a tendency to
elongation in the direction of the constituent laths, or fibres. These bundles are fan-shaped and the extinctions displayed by the group of fibres recall the extinctions shown by a segment of a spherulite in its general radial habit. These amesite bundles occur in all environments in the ore-zone schist, amidst quartz grains, concentrated muscovite aggregates, and, in heavy sulfide rock. The boundaries of the bundles are always very clean and sharp to the surrounding minerals. They show no signs of alteration, either centrally or peripherally. The very weak and sinuous outlines possessed by a chlorite which has formed as the result of alteration from some pre-existing ferro-magnesian mineral or mineral aggregate, are entirely absent in connection with the amesite. The amesite is considered to belong to the muscovite stage of the formation. Its relations to the mica are very indeterminant, but the general indications are of contemporaneity. In some instances it has been seen to comprise almost all of a green-rock specimen, just a few scattered carbonate residuals remaining; whereas lesser amounts in green-
rock, it occurred in much the same independent manner as in the schists. The former occurrence suggests that the amesite is later in formation than the carbonate of the green-rock. On the other hand, the medium-grained quartz of the ore-zone schist has been seen to replace, as cross-cutting veinlets, large amesite bundles. The amesite is considered a late mineral, part hydrothermal and part recrystallized, formed in the ore zone schist and the green-rock after the carbonatization of the latter, and in the schist previous to the sulfide and last introduction of quartz.

Carbonate is rather sparingly developed in the schist of the ore zone. It is found in greatest abundance in association with quartz-chlorite veinlets, to be discussed later. Where there is any amount of carbonate developed in heavy sulfide rock, it is seen to very intimately fill the interstices between the sulfide fragments, suggesting that, although not in vein-like masses, it is later than the sulfides. The carbonate occurs also as isolated grains in quartzose schist. The material
is always very clear and free from the cloudiness and numerous rutile needles such as are found in that of the green-rock. It does, however, contain the usual number of rounded quartz inclusions, relics of the ground mass. The first two features indicate that the isolated grains of carbonate in schists are very late material and not the same as that found in the green-rock. The last, the ground mass inclusions, indicates that this carbonate is of late development. This latter lends support to the thought that such ground mass of the ore zone schist represents recrystallized fine-grained ground mass of that schist which is outside of the ore zone.

Late Mineralization Features of the Ore Zone Schist:

The late mineralizations comprise the formation of veins and veinlets of quartz-albite carbonate, quartz-albite-carbonate-chlorite and quartz-sulfide.

Quartz-albite-carbonate veinlets are common as very narrow veinlets traversing massive sulfides.

Quartz-albite-carbonate-chlorite veins and irregular masses are very common in the green-rock, as will be later described. They consist of the above-named minerals in intimate intergrowth, the age relations
to one another being indeterminate. The quartz of these masses shows granulation within large grains, indicating that there has been post-mineral shearing, possibly related to the post-ore faults which are found throughout the mine. The plagioclase grains, which, by the use of immersion oils, were found to be albite, are on the average somewhat smaller than the quartz, that is less than 1 mm. The carbonate presents well-developed rhombohedral outlines, is very clear and free from inclusions of any kind. It was determined as calcite, and as being quite different from that, ankerite, which forms the mass of the green-rock. Material similar in outline and in freedom from inclusions, is often found as isolated material in the schist. Both in the ore zone and away from it, this is considered to be calcite and to belong to the same general late period of calcite mineralization. The chlorite found associated with the above mineral aggregates is prochlorite, one which differs in optical properties from that of both the green-rock and the ore-zone schists. This difference is to be expected if the material belongs to the period
of late hydrothermal activity.

Frequently, at distances of 100 feet or less away from the main ore bearing lenses, there are found wide three- to six-inch veins of white quartz which both transect and follow the schistosity of the country rock. These are always very sinuous and thicken and thin quite perceptibly. They are on the whole massive quartz but contain very minute aggregates of sulfides, namely, pyrite, sphalerite, tetrahedrite, chalcopyrite and galena. The manner in which such a vein, which at the particular locality examined carried an abundance of tetrahedrite, cut the ore body as a definitely transection mass, suggests that this mineralization was later than the carbonatization of the green-rock, than the mineralizations in the schist, and than that of the ore bodies.

**Summary of Features of the Schists:**

For the sake of description the schists have been classified as slightly mineralized and as abundantly mineralized.

The slightly mineralized types in general
occur at distances greater than 400 feet from the ore bodies. They comprise a porphyritic schistose type and a non-porphyritic laminated one. The first consists of phenocrysts of quartz and albite set in a very fine-grained ground mass of quartz, with occasional carbonate and muscovite. The laminated phase is chiefly very fine-grained quartz, the laminae being separated by thin chlorite bands, these latter of later formation. An occasional pyrite grain is seen in both the above rocks.

The heavily mineralized variety of the schist is that which occurs in the ore zone. It is extremely schistose and much more sheared than further out. There are still a few phenocrysts of quartz but no albite left. The rest of the rock consists of abundant foils of muscovite, amesite chlorite, much quartz, recrystallized and introduced, some carbonate, and in one locality, anthophyllite. This latter is genetically related to the intrusion of a large dike. The schist which occurs in the ore zone is considered to represent an extreme mineralization phase of the porphyritic rock found
outside of the zone of heavy sulfide mineralization.

The changes experienced in the ore zone might be as follows: carbonatization along an easily permeable zone, in a portion of the porphyritic non-mineralized schist; this carbonatization, where most intense, yielded the green-rock; later mineralization of both schist and green-rock, involving the recrystallization of quartz, development of abundant muscovite and chlorite, and the introduction of sulfides.
ORIGIN OF THE SCHISTS

The schists are thought to have been originally intrusive quartz-porphyry.

In the general vicinity of the Eustis, Bancroft has found quartz porphyry dikes intruding rocks of more intermediate composition. In connection with this he says, "One may observe every phase from a thoroughly typical quartz-porphyry to silvery-gray sericitic-schists in which phenocrysts have been eliminated by processes of crushing and recrystallization. In some instances, sericitic schists still retaining phenocrysts of quartz and feldspar, appear to pass gradually through chlorite schists, containing similar phenocrysts, into chlorite schists in which no such crystals are discernible. In a few localities, however, (as on lots 27 and 28 of Ranges III and II, respectively, of Hatley Township) the quartz-porphyry, in the form of dikes, is plainly intrusive into the rocks of more intermediate composition."

The evidence inside the mine is poor. In the non-schistose varieties of rock, no bedding planes suggestive of a sedimentary origin were seen. On the other hand, the rock possesses a very blocky, often jointed habit which is characteristic of intrusive bodies.

The thin-section evidence supports but does not prove the rock to be a quartz-porphyry. The schists, with their high quartz feldspar content, and absence of ferro-magnesians excepting a little chlorite, are definitely acid types. They correspond to the general types described by Harker in his discussion of the metamorphism of igneous acid rocks.

A striking mineralogical and texturally analogy to the schists of the Eustis is the intrusive alaskite porphyry from Shasta County, California, which has been described by Graton, "The phenocrysts of the rock, consisting of quartz, albite and rarely oligoclase-albite, are generally of small size, though

2. Graton, L. C., op. cit. p.84.
in a few places they may attain a diameter of one-quarter inch or even more; in such places the ground mass also commonly increases in coarseness. Much of the albite is untwinned."

The schists of the Eustis include both a slightly schistose and a highly schistose type. The former occurs outside of the ore zone, and the other in the zone which is almost 800 feet in width. The first type of rock (Plate V, Figure 1.) contains abundant phenocrysts of quartz and poorly twinned plagioclase, in a very fine-grained quartz ground mass. It is quite comparable to the Shasta County, California alaskite porphyry. The second ore zone type, shows evidence of much shearing. It possesses quartz phenocrysts but none of albite. A further change is the abundant development of carbonate to form green-rock of muscovite and chlorite. Despite the rather great difference of the ore zone schist from the less schistose variety outside of the ore zone, the derivation of the former schist from the latter type is certain; these being similar to described metamorphosed quartz-porphyries.
94.

The tentative conclusion, then, is that the schists of the Eustis represent intrusive quartz-porphyries which have suffered a low-grade of regional metamorphism.
DETERMINATIVE FEATURES OF THE SCHIST
AND GREEN-ROCK MINERALS

Quartz:

Grain size has served to distinguish the genetically different quartzes present in the country rock.

The very finest grain size is about 0.01 mm and forms the ground mass for the unmineralized schist. It represents the ground mass of the quartz porphyry and is but slightly metamorphosed.

A fine-grained quartz, but 0.03 mm in size, which is coarser than that found in the mineralized schist, forms the ground mass for the mineralized schist of the ore zone as well as for the green-rock. It represents recrystallized ground mass.

A medium-grained quartz, with an average grain size of 0.1 mm occurs, in a few instances, as narrow veinlets along the laminae and schistosity of the schist away from the ore zone, as elongated lenticular aggregates and as feather quartz in the ore zone schist. It represents in part recrystallized and in part introduced material.
The largest grained quartz is that which occurs as phenocrysts in the schists. They vary in size from 2.0 to 0.2 mm on their longest diameters. This material is quite persistent, being present in the schists which are relatively unmineralized, as well as in those which are very heavily mineralized. This demonstrates the great resistance of quartz grains to destruction.

The quartz of the quartz-albite veinlets is a medium-grained variety, and constitutes the latest deposition of quartz.

**Carbonates:**

All the carbonate is hydrothermal, but there are two periods of formation, an earlier, in which the ankerite of the green-rock was formed and, a later, in which the calcite of small veins was deposited.

**Ankerite:**

The determined indices of this material are:

\[ N = 1.718 \]

\[ N = 1.518 \]

Such indices correspond to ankerite.

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The ordinary $\text{HNO}_3$ and $\text{NH}_4 \text{OH}$ test for iron was made and a very abundant flocculent $\text{Fe(OH)}_3$ precipitate was obtained. An organic reagent test was run for magnesium and positive results obtained. The organic test made was a very sensitive one, but the presence of magnesium in addition to iron further distinguishes the carbonate as ankerite.

The ankerite is further distinguishable from the calcite by a very poor crystal form and by a great number of inclusions, chief of which are rutile needles. These latter are entirely absent from the vein calcite.

1. Organic Wet Test for Magnesium:

Reagent: para-nitrobenzene azoresorcinol

Procedure:

To a few drops of solution free from the sulfide groups, add HCl to make slightly acid, add one drop of the reagent, and then make alkaline with NaOH, shake to coagulate. A sky blue precipitate denotes the presence of magnesium.
Calcite:

Because of perfect development of cleavage, it was possible only to determine the one index $Ne_1$ on the cleavage rhomb. The value obtained for $Ne_1$ was 1.568.

This value of $Ne_1$ corresponds to that for relatively pure calcite.

The vein calcite is always present as well-shaped rhombs and is very clear in its general freedom from inclusions.

It not only occurs as later veinlets, but is distributed as isolated grains in mineralized schists, and is undoubtably associated with the calcite of the veinlets.

Chlorites:

Three varieties of chlorite are present in the rocks of the Eustis Mine. They have been enumerated as follows:

(1) Diabantite - from the green-rock and unmineralized schist.

(2) Amesite - in the mineralized schist of the ore zone.

(3) Prochlorite - associated with quartz-carbonate veinlets.

Diabandite:

The optical characteristics of this chlorite as determined in several specimens are summarized as follows:

Sign indeterminant

\[ N_m = 1.623 \]

\[ N_g - N_p = 0.004 \pm \], that is abnormal blue

Color = in small grains it is green; in thin-section pleochroic, from green to colorless.

According to Winchell, a chlorite with these optical characters corresponds to diabandite; one which is a ferriferous clinochlore with a higher iron and magnesium but lower aluminium content than amesite.

Diabandite is found as the chlorite in greatest abundance in the green-rock and as a minor constituent in the unmineralized schist.

Amesite:

The optical properties of this chlorite are as follows:

\[ (+) 2 V = \text{small} \]

\[ N_m = 1.60 \pm \]

\[ N_g - N_p = 0.010 \pm \], shows low yellows, much higher than diabandite or prochlorite.

Color = small grains pale green in thin-section it is colorless.

1 Winchell designates a chlorite with the above optical characters as amesite, one with relatively high aluminium and magnesium content, but very little iron.

Amesite is confined to the schists of the ore zone, and here often occurs in considerable amounts as closely packed bundles of chlorite fibres. It always has strong crystal outlines, this is in

contrast to the weak outlines of diabandite.

Prochlorite:

The optics of this chlorite are as follows:

\(\pm 2V = \text{small}\)

\(N_m = 1.617 \text{ to } 1.620\)

\(N_g-N_p = 0.004-0.01, \text{ less than for amesite}\)

Color = small grains very deep green: in thin-section, apple green to colorless.

A chlorite such as this, Winchell has called prochlorite, one which contains moderate amounts of iron, magnesium and aluminium.

Prochlorite occurs as a constituent of quartz-carbonate veinlets which are very commonly found cutting the green-rock and in lesser degree some of the schists. It is quite characteristic in its marked blocky habit of segregating into square bundles of laths. In paragenesis it is much later than either the diabandite or the amesite.

Paragenesis of the Chlorites:

The chlorites are mainly hydrothermal phenomena, although there is probably some recrystal-

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lized material present in both schists and green- 
rock. Diabantite and amesite probably represent a 
gradational change in mineralization, since it is 
to be noted that the tendency from a high iron con-
tent to a lower one is the same as a similar ten-
dency in the associated carbonates where there is 
a change from ankerite mineralization to calcite. 
That is, a decrease in iron content with time. 
The same decrease in tenor of iron is seen from 
diabantite to prochlorite, that is from the chlo-
rite of the green-rock to that of the quartz-car-
bonate-chlorite veinlets. This same decrease in 
iron with time in mineralization is seen in the 
order of sulfide deposition, the higher iron con-
tenent minerals being the earliest. 

**Feldspar:**

The only recognizable feldspar found in 
the Eustis rocks was albite, with indices of refrac-
tion as follows:

\[
\begin{align*}
N_g &= 1.535 \\
N_m &= 1.530 \\
N_p &= 1.525
\end{align*}
\]
Albite occurs as:

(1) Phenocrysts in the schists.
(2) A constituent of some of the fine-grained ground mass of both schists and green-rock.
(3) A major constituent of quartz-albite veinlets cutting the country rock and the ore.

The albite is in all cases remarkably free from sericitic alteration, there being but a slight development of such in some of the phenocrysts of the schist. The twinning lamellae are not well-developed even in large grained material. These have not suffered any deformation in the nature of bending or breaking.

The relation of albite to associated minerals has been discussed in the sections devoted to rock descriptions.

Muscovite:

This is a colorless mica, with an index of \( N = 1.590 \) and a negative optic angle of \( \pm 50 \) degrees. It is always well crystallized and in too large laths to be called sericite.
It is in greatest abundance in the schists of the ore zone, where it occurs as curving foils of closely packed muscovite laths. It occurs in lesser amounts in the green-rock and in the schist away from the ore zone, it is often absent from some of the latter rock.

The muscovite of the green-rock and the unmineralized schists probably represents in great part recrystallized material, forming from the felspathic constituents; but the majority of that found in the ore zone is a mineralization feature, the very great abundance of it here being suggestive of that.

The remaining minerals are found in minor amounts, and fuller descriptions of them are contained in the rock descriptions.

**Titanite:**

Titanite occurs in the chlorite layers of the laminated schist away from the ore zone. There are a few imperfectly developed grains, but the majority of the material is as small grains which are evidently the result of comminution of the larger
more diamond-shaped ones.

**Rutile:**

Rutile seems to be confined to the green-rock. It is as radiating needles in clusters or as single prisms surrounded by the constituents of the green-rock. In some of the aggregates the needle-like habit is almost lost in a surrounding cloudy mass of brown leucoxene, which has formed as an alteration product from the rutile needles. Inasmuch as the rutile is confined to the green-rock, a rock whose existence is due to a set of mineralization phenomena, the rutile is considered to be introduced material.

**Epidote:**

Epidote occurs as grains strung out in linear aggregates in the same manner as the titanite. The epidote occurs, however, only in the non-laminated schist away from the ore zone.

**Anthophyllite:**

The orthorhombic amphibole, anthophyllite, is found in the schist and gangue of the ore in the immediated vicinity of a forty-foot camptonite dike on the 4.825 level. This mineral has a mean index
of refraction of 1.600, and a low yellow, that is intermediate, birefringence. Its habit is that of very long and thin needles, so small that interference figures were not obtainable. It possesses parallel extinction, and the needles have inclined terminations. The above characteristics determine the mineral as the high magnesium bearing anthophyllite, as described by Winchell. The anthophyllite was formed under the influence of the elevated temperature in the rocks at the time of intrusion of the dike. It is to be noted that anthophyllite is a mineral characteristically developed under conditions of high temperature.

Figure 1.

Specimen showing banded nature of ore replacing schist.
Crossed nicols. X 55.
Photograph showing phenocrysts of quartz and very slightly altered albite in schist outside of the ore zone. Note quartz tails at ends of phenocrysts, and the very fine grained quartz-felspar ground mass.

Crossed nicols. X 55.
Photograph similar to figure 1, but displaying a coarser ground mass, this rock is nearer the ore zone.
Figure 1. Crossed nicols. X 35.
Fine grained laminated schist, dark bands in centre and bottom of photograph contain more chlorite than the lighter bands.

Figure 2. Plane polarized light. X 55.
Broken titanite grains in a band in laminated schist. These grains are always concentrated into such layers.
Figure 1.

Typical contorted schist from the ore zone.
**Figure 1.**
Crossed nicols.
Muscovite filling fractures in a quartz phenocryst from the ore zone schist.

**Figure 2.**
Crossed nicols.
Feather quartz normal to faces of pyrite grains.
Crossed nicols. X 55.
Quartz-albite veinlet in massive sulfide of the ore zone.

Crossed nicols. X 55.
Abundant development of amesite chlorite in ore zone schist. Note bundle like habit of the amesite laths around the end of the pyrite grain.
Crossed nicols. X 55.

Amesite chlorite developing as minute laths sparsely disseminated amongst quartz grains of the ground mass in the ore zone schists.

Crossed nicols. X 55.

Massive, bundle-like development of amesite chlorite, almost to the exclusion of all other minerals.
Figure 1.

Specimen showing sill-like or banded habit of one variety of the green rock. The rock on either side of the band is a highly micaceous schist.
Crossed nicols. green-rock.

Figure 1. X 35. Equigranular texture in

Crossed nicols. green-rock.

Figure 2. X 35. Schistose texture in
Figure 1.
Plane polarized light. X 55.
Large carbonate (ankerite) grains containing numerous rounded quartz inclusions, these inclusions represent unrepalced ground mass quartz.

Figure 2.
Plane polarized light. X 55.
Large ankerite grain surrounded by a rim of carbonate of slightly different refractive index; this zoning probably represent slightly changing carbonate solutions.
Crossed nicols. X. 35.
Photograph showing development of two parallel bands of diabandite chlorite in green-rock.

Crossed nicols. X 250.
Rutile needles in carbonate of the green-rock. The irregular black areas represent rutile which has largely altered to leucoxene.
ORE MINERALOGY

Minerals:

The metallic minerals found in the Eustis ores are listed in their order of paragenesis as determined from a study of the relationships as seen in polished sections of the ores, as follows:

Normal Ore,

arsenopyrite
pyrite
sphalerite
tetrahedrite and tennantite
tennantite
cubanite
galena

Metamorphosed Ore (Later described in section on Metamorphosed Ore Body)

pyrite
pyrrhotite
marcasite
chalcopyrite
cubanite
Distribution:

Pyrite, chalcopyrite, sphalerite and galena occur at all depths in the ore body, arsenopyrite on the 5,000 foot level, tetrahedrite and tennantite a few hundred feet below the Slide Drift and in a quartz vein at 6,000 feet in the shaft; pyrrhotite, marcasite and cubanite occur only where the ore is cut by a camptonite dike on the 4850 level. Pyrite and chalcopyrite are the most abundant, pyrite ranging up to 95 per cent in the pyrite lens and to 75 per cent in the copper lens; chalcopyrite rarely exceeds 20 per cent, averaging around 12, that is, 4 per cent copper which is the run of mine average assay value. Sphalerite and galena occur only incidentally, never in amounts greater than 1 per cent. Tetrahedrite occurs as the major constituent of a quartz vein below the Slide Drift, and as only a very minor mineral in such a vein at 6,000 feet; it is only of mineralogical interest. Tennantite, though not seen in the present investigation, has been described by Hanson.

Arsenopyrite:

This mineral was found in only one locality, and that in the copper lens on the 5,000 foot level, where it occurred to the extent of 1 per cent. Arsenopyrite occurred as diamond-shaped grains on an average of 0.5 mm on longest diameter. These were surrounded by both pyrite and quartz.

Because of its strong crystallizing tendencies, its age relationships were not determinable. On a priori grounds it has been deemed safe to say that it was the earliest sulfide formed.

Pyrite:

Pyrite occurs as an important constituent of both chalcopyrite and pyrite lenses.

It varies in size from very dense and massive material up to grains 4 mm in diameter. The coarser grained material carries more chalcopyrite than does the dense. Where the grain is coarse, the ore attains a porphyritic appearance which is caused by the large pyrite grains glistening in a ground mass of chalcopyrite and small pyrite grains.

When the ore is studied in polished section
under reflected light the above-mentioned porphyritic habit is still more apparent. The pyrite grains are often very angular and possess cubic outlines, indicating that the amount of post mineral deformation has been slight. (Plate XV, Figure 2.) Where these cubic outlines are lacking, the grains are rounded and smoothed by the other minerals, chiefly chalcopyrite, in the usual replacement manner. In some of the larger grains a marked reticulate pattern is formed by replacing minerals; in some cases its perfection of development is comparable to that developed by supergene chalcocite in its replacement of pyrite. It must be cautioned here that a similar origin for the Eustis minerals is by no means implied or meant. In the pyrite grains there are often well rounded elliptical areas of the other ore minerals; these must not necessarily be interpreted as residual material still unreplaced by the pyrite, but rather as matter, which, in dimensions other than in the plane of the section, represent protruding tongues from larger masses of minerals.

Of the ore minerals, pyrite is the earliest.
With respect to the gangue it is later than all the silicates but earlier than the feather quartz, and than the quartz-albite-carbonate veinlets.

Chalcopyrite:

Chalcopyrite occurs chiefly in the "Copper lens" where it is found in amounts varying from 10 to 20 per cent; it is to be noted that the run of mine average is 4 per cent copper which corresponds to 12 per cent chalcopyrite; in the pyrite lenses chalcopyrite rarely exceeds 1 per cent. It also occurs in the quartz veins away from the ore lenses. In these veins the sulfides are only in very minute amounts compared to the quartz.

Etching tests were applied to the more massive chalcopyrite to determine the grain size and texture. It was found to be quite equigranular with no tendency to elongation of the grains in any one direction, this indicating that there had been no dynamic metamorphism of the sulfide after its formation. The average size of the grains was 0.5mm.

Chalcopyrite is intergranular with respect to the pyrite, its contacts to the latter being always
smooth and flowing. The narrow veinlike masses, which commonly occur in large pyrite grains, possess the smooth boundaries and unmatched walls which are typical of replacement veinlets. It is to be noted that veinlets of gangue occur in the chalcopyrite and that these are similar in every respect to those of chalcopyrite in the pyrite. These gangue veinlets definitely transect the grain boundaries of the chalcopyrite and continue through pyrite grains. They represent post-sulfide deposited material; when examined in thin-section they are seen to consist of quartz-albite and disseminated carbonate and also pure carbonate. In the copper lens the relation of chalcopyrite to galena and sphalerite do not indicate the paragenesis of the minerals. Mutual boundaries exist between the three. The galena and sphalerite occur as small rounded blebs in a field of chalcopyrite. However, in material from the tetrahedrite locality, chalcopyrite was seen to replace both tetrahedrite and sphalerite. The evidence consisted of chalcopyrite entirely rimming an elliptical area of sphalerite, the latter having been veined by tetrahedrite, the continuity of the tetrahedrite veinlets being
interrupted by the rim of chalcopyrite. (Plate XVI, Figure 1.) In a quartz vein from the bottom of the shaft, when this was at 6,000 feet, a sulfide mass consisting of chalcopyrite, sphalerite, tetrahedrite and galena were found. The sphalerite of this locality was definitely transected by narrow veinlets of chalcopyrite. The latter occurred in the sphalerite also as minute blebs which, where the concentration of them was sufficient, it could be construed as being along octahedral planes and not the dodecahedral cleavages of the surrounding sphalerite; the former relationship is considered by Scheiderhöhn to be indicative of the chalcopyrite as having separated from a solid solution.

Sphalerite:

There are two main occurrences of sphalerite in the Eustis ores. One is as minor and small blebs amongst the pyrite and chalcopyrite of the main ore body, and the other is as somewhat larger segregations in quartz veins.

The first occurrence is widespread. The sphalerite is, however, in such small amounts, that

any generalizations as to increase or decrease with depth, or as to any other variations, are rendered invalid. It is to be noted, however, that in one specimen from the 2,800 level, (Plate XVI, Figure 2.) there is sphalerite interbanded with chalcopyrite and pyrite, the sphalerite amounting to 10 per cent of the sulfides, this amount has not been found in any of the material from depth; this might suggest a decrease in sphalerite with depth, but because of the rarity of the above occurrence, no great amount of importance can be attached to it.

Sphalerite occurs always as small irregular blebs with smooth outlines, and is moulded between the pyrite grains in the same manner that the chalcopyrite is. Galena is often associated with the sphalerite in these blebs. Small veinlets of sphalerite in the pyrite are common. Veinlets of gangue have been seen transecting sphalerite areas.

Sphalerite is, as shown by the above-described relations, later than the pyrite, but before the gangue veinlets, chalcopyrite and galena.

The sphalerite associated with the quartz
veins was found in these on the 2,800 level and at the foot of the shaft at 6,000 feet; the latter occurrence of quartz was in country rock at least 20 feet from the foot wall of a chalcopyrite lens.

This sphalerite is light brown resinjack variety and is much better crystallized than that of the ore; this is shown by the presence of many lustrous cleavage surfaces and of some imperfect crystal faces.

It is definitely earlier than both the associated quartz and chalcopyrite, as is well shown by the specimens from the 2,800 level. Galena associated with sphalerite was found only at the foot of the shaft and here the relations were those of the mutual boundaries and hence relative ages of the two indeterminant, but, on a priori grounds, the galena might be considered to be the later.

**Galena:**

Galena has, similarly to the sphalerite, two modes of occurrence. One as rounded blebs in the heavy sulfide where it exhibits mutual boundaries to the other minerals; the other as larger areas in
the quartz veins which are present both in the ore bodies and in the country rock. Considerable amounts were found in a quartz vein at the foot of the shaft, when at 6,000 feet. Here it was associated with sphalerite, chalcopyrite and tetrahedrite. The age relations of the galena to the other minerals were here indeterminant. The galena of the quartz veins was etched with dilute HNO$_3$ to determine the presence or absence of argentite; none of the latter was found.

The relationships of galena to the other sulfides being such as to give no clue as to its position in the sulfide paragenesis, one can merely place it where it is most commonly found in other mineral occurrences; and that is later than the sphalerite and chalcopyrite.

**Tetrahedrite:**

Tetrahedrite was found in only one place and that on the west side below the Slide Drift. It occurs in the foot wall side of a quartz vein one to two feet wide and about thirty feet long, this vein in the hanging wall side of a copper lens. (Plate XVII, Figure 1.) The country rock is very lustrous sericite schist.
117.

The mineral occurs in lens-like masses surrounded by quartz, pyrite and chalcopyrite. It is not distributed over wide areas as minor disseminations amongst the other sulfides, but it is strikingly localized as above described.

On the polished surface the color is a drab olive green in reflected light, this against galena. The contrast to the bright and lighter green of tennantite against galena is to be noted. It is considered that this color corresponds to that cited by Schneiderhohn for silver bearing tetrahedrite, but not freibergite. This idea was developed by observing the color of typical tetrahedrite and noting the color assigned to it by Schneiderhohn and then inferring from the color of silver bearing tetrahedrite as given by him what that would be under conditions of light as prevailing in the above examination.

This material gave a very good plaster plate bismuth flux sublimate of antimony. The CsCl microchemical test was also run, well developed hexagonal crystals of antimony cesium chloride
(SbCl₃-CsCl) were obtained. Microchemical tests were made for silver, the ammonium bichromate test, and no results were obtained. This latter, however, does not prevent the tetrahedrite from being silver bearing, but not to the extent that freibergite is. Similar runs for silver were made on a type specimen of the latter mineral and very beautiful crystals of silver bichromate were obtained. It is to be considered in this regard that Short states, "The writer was unable to get a bichromate of silver in tennantite which assayed 1 per cent of Ag." Positive arsenic tests were also obtained. A wet test for iron was run, but none found.

The conclusions, then, are that this is an arsenic bearing tetrahedrite possibly containing a trace of silver presumably less than 1 per cent. Blow pipe tests were run for antimony on typical tennantite from Tsumeb, Africa, but no antimony was obtained.

Paragenesis:

The tetrahedrite is definitely earlier than

the clear watery quartz which is in such abundance in the tetrahedrite locality. In the hand specimen may be seen small elliptical areas, 4 by 6 mm, which are very definitely veined by clear quartz (T-1).

It is also definitely later than sphalerite; several veinlets were seen to transect a small elliptical area of sphalerite, and these former were from a large parent mass of tetrahedrite.

The evidence of the polished sections is that the chalcopyrite is later than the tetrahedrite, note how it surrounds as a narrow band of large bleb of sphalerite, isolating the tetrahedrite veinlets which cut the sphalerite. (Plate XVI, Figure 1.) Schneiderhöhn says that tetrahedrite very commonly replaces sphalerite and high pyritic minerals, but less often does it replace chalcopyrite and galena."

Polished section. Figure 1. X 19. Large grain of porphyritic pyrite (bright and high relief) surrounded by smaller very angular grains of pyrite. Interstitial, darker colored and low relief mineral is chalcopyrite.

Polished section. Figure 2. X 19. Pyrite grains (high relief) with interstitial chalcopyrite (low relief). Note perfect cubical outlines of some pyrite grains, such show absence of marked post-mineral shearing.
Figure 1. Polished section. X 45. Chalcopyrite (white) surrounding a grain of sphalerite (dark grey) and severing two veinlets of tetrahedrite (light grey) which replace the sphalerite. Hence the paragenesis is here: sphalerite-tetrahedrite-chalcopyrite.

Figure 2. Polished section X 15. Sulphides showing banding inherited from the schist. The sulphides are: pyrite, white; sphalerite, dark grey; chalcopyrite, light grey.
Figure 1.

Specimen showing quartz replacing sulfides, which are here pyrite, sphalerite, chalcopyrite and tetrahedrite. The tetrahedrite is quite massive and abundant in this specimen.
GENERAL TEMPERATURE-PRESSURE CONDITIONS
DURING FORMATION OF THE EUSTIS ROCKS

The remarkable freshness of the feldspar phenocrysts, which is indicated by their lack of alteration, sericitic or otherwise demonstrates the stability of the feldspar in the environment of slightly mineralized schist. This environment has been changed, from conditions of unaltered quartz-porphyry, to those where the porphyry was regionally metamorphosed and, further to those where it was subjected to chlorite-muscovite-carbonate mineralization. This mineralization was effected not entirely by introduction of material but also by conditions of temperature and pressure suitable for the development of such minerals from material available in the porphyry. That is to say, the albite was stable during the development of muscovite-chlorite and carbonate. That albite forms under conditions suitable for the formation of last-named minerals has been discussed by Harker.

In the ore zone there has been, along with other changes a much greater development of muscovite, chlorite and carbonate as compared with the amounts outside of the ore zone, and, a disappearance of albite. The disappearance of albite can be attributed partly to sericitization and partly to the effects of extreme shearing forces, such as have been shown to have prevailed in the ore zone. An abundant development of potash mica and chlorite with a concomitant disappearance of albite has been described by Bateman in his discussion of the wall rock alteration of the quartz porphyry at Rio Tinto, he says, "All the rock-forming minerals have been replaced by sericite, the feldspar most and quartz least. Residuals of quartz, partly penetrated by rods of sericite or embayed by a felted mass of sericite fibres, lie wholly included in the sericite." It is to be noted that Bancroft refers to the potash mica as sericite, that is, the Rio Tinto mica is probably quite fine-grained as compared to the coarsely

1. Bateman, p. 582.
crystallized mica of the Eustis, which it has been thought better to call muscovite because of the large size of the laths.

The great development of ankerite carbonate in the ore zone and its lesser development outside of this, is compatible with the formation of chlorite and muscovite. Ankerite or calcite occurs with albite and vermicular chlorite at Bendigo, Australia, and at Rio Tinto; carbonates are associated with chlorite, sericite and quartz. Other examples of the development of carbonates with chlorite, muscovite and other minerals could be given to show that such an environment is common for carbonates. This is an environment of low to intermediate temperature and pressure.

The predominant sulfide mineralization, namely pyrite and chalcopyrite with sphalerite and galena is also one of intermediated temperatures and pressures.

There exists, then, an approximate similarity between these three sets of geological phenomena; first, the low-grade metamorphism of the quartz-porphyry to a schist; second, the low to intermediate grade of mineralization imposed on these schists and, third, the strong sulfide mineralization of a type commonly associated with low to intermediate conditions of temperature and pressure.
METAMORPHOSED ORE BODY

Distribution:

Pyrrhotite and cubanite are found developed in only one locality at the Eustis mine, namely on the 4825 level where a forty foot dike of camptonite cuts diagonally across the copper lens.

This camptonite dike is definitely later than chalcopyrite lens. The dike cuts the ore on the 4825 level; the larger portion of the chalcopyrite lens being on the southwest side of the dike, the faulted off and smaller northeastward end of the lens occurring on the northeast side of the dike. As further proof of the dikes emplacement later than the ore, are the very fine-grained to dense border phases of the dike when in contact with ore; such dense borders are also present towards the schists.

Had the ore developed later than and around the dike, it is inconceivable that such continuous dense dike margins would remain. They would be destroyed by the replacing actions of the ore solutions. The dike then has intruded the ore body and in so doing
has metamorphosed that portion of the ore in the immediate vicinity of the dike.

When the occurrence was examined by the author, the ore had all been stopped out, so that, only a small portion of it, that up to ten feet from the vicinity of the dike, could be examined. However, of the material available, hand specimens were taken at measured distances from the ore dike contact. These were then studied in polished sections and some in thin-sections. The accompanying sketch shows, first, the location with respect to the dike, and, second, the mineralogy of the specimens collected. (Plate XXV)

It is to be noted that the material within ten feet of the dike consists of the mineral aggregate, pyrite, chalcopyrite and pyrrhotite. This same association plus cubanite is found in only one region, this at about eighteen inches from the dike. Beyond the ten foot limit the mineral association is pyrite and chalcopyrite, that of the typical Eustis ore.

**Description of Sulfide Aggregates:**

The material characterized by pyrite and
chalcopyrite is similar in every respect to the same mineral aggregate which forms the average ore of the Eustis, and for that reason, need not here be described.

The material which contains pyrrhotite in addition to the usual pyrite and chalcopyrite, has an average mineral composition as follows:

<table>
<thead>
<tr>
<th></th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>2</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>57</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>36</td>
</tr>
<tr>
<td>Gangue</td>
<td>5</td>
</tr>
</tbody>
</table>

The pyrite of this material usually occurs as well rounded porphyritic grains, which vary in size from 1 to 4 mm. They are always quite rounded, the sharp cubic forms which characterize the ordinary pyrite, being conspicuously absent. The great numbers of reticulating veinlets of all the other minerals and the many smooth and rounded contacts of the pyrite to these, indicate that it has been replaced by all these, pyrrhotite, chalcopyrite, and the gangue associated with the dike.
127.

The pyrrhotite, in those specimens which do not contain cubanite, occurs as very irregular areas which range in size up to 4 mm in diameter of continuous pyrrhotite. The granularity of the material is proportionately large, the individual crystal being from 1 to 4 mm in size. The boundaries of the pyrrhotite, where in contact with other minerals, are very irregular, and usually are as sharp promontories around which cluster groups of small islands of pyrrhotite. (Plate XVIII, Figures 1 and 2.) In areas of appropriate size, it is often found that the islands plus promontories plus mainland constitute but one pyrrhotite crystal, that is, different stages of replacement of the pyrrhotite by the surrounding minerals are shown in these three forms of pyrrhotite. Many of the more massive areas of pyrrhotite are transected by narrow veinlets of chalcopyrite, which possess all the features of true replacement veinlets. These chalcopyrite veinlets are most numerous in the pyrrhotite in the immediate vicinity of the dike, and are to be correlated with a concentration of chalcopyrite because of the proximity of the dike.
It is to be remarked, that, whereas there is chalcopyrite in the dike mass, there is no pyrrhotite; this is of genetic significance, to be discussed later.

Chalcopyrite forms a matrix for the areas of pyrrhotite. In polarized light the chalcopyrite is only slightly anisotropic, and twinning indistinctly shown. When the material is etched with a hot acid solution of potassium dichromate, the grain structure is well displayed. It is quite granular and well twinned, there being no evidence of shearing action. The average size of the grains is about 0.5 mm. It is to be observed that the very narrow veinlets of gangue, carbonate, which are so common in the chalcopyrite areas, definitely cut across the crystal boundaries of the latter. As explained in the description of pyrrhotite, the chalcopyrite definitely replaces this mineral, the best evidence being the numerous thin veinlets of chalcopyrite transecting pyrrhotite crystals, cutting across the inter crystal boundaries of the latter.
Ore Gangue:

The aspect of the gangue found in the sulfide body in which pyrrhotite has developed is entirely different from that of the main ore body. There has been an abundant development of the orthorhombic amphibole, anthophyllite, (Plate XIX, Figure 1.) This mineral is present to the almost complete exclusion of any other silicate. The only mineral remaining of the ordinary gangue is quartz, of which there are a few poorly preserved phenocrysts, as well as some of the feather quartz. The manner in which the anthophyllite transects areas of normal quartz, and is along fractures of the few remaining phenocrysts, indicates that it is later than both the phenocrysts and feather quartz; this latter material is later than the sulfides of the main ore body, so that the conclusion regarding the age of the anthophyllite, is, that it is later than the chalcopryite-pyrite ore but not the pyrrhotite. It is to be noted, however, that, in the pyrrhotite masses, there is late carbonate; this material is seen as later rims around the sulfides and as veinlets
cutting across anthophyllite blades. This then, is the latest mineralization feature. In the heavy sulfide masses of the pyrrhotite ore no muscovite or chlorite was observed.

In the country rock adjacent to the dike there has not been such an abundant development of anthophyllite, but it is nevertheless present as a mineral which definitely replaces the schist minerals. The material examined, contained an abundance of medium quartz, less anthophyllite and carbonate. The anthophyllite areas consisted of very cloudy anthophyllite, and were of such an outline and size as to simulate the areas occupied by the muscovite and chlorite of the ordinary mineralized schist, (Plate XIX, Figure 2.) the suggestion being that these latter minerals contributed in part at least to the formation of the amphibole. The carbonate occurs in irregular transecting veinlets, an obviously later mineralization feature.

Sulfides in Relation to the Gangue:

Pyrrhotite and chalcopyrite definitely replace the anthophyllite, therefore, replace the
other gangue minerals; carbonate is, however, later than the sulfides. Pyrite does not replace the anthophyllite; it is undoubtedly the one sulfide which has more or less maintained its status quo during the intrusion of the dike. The pyrrhotite and the chalcopyrite replace the anthophyllite blades in a most intimate manner. (Plate XX, Figure 1.) It can be best described as similar in appearance to a lit-par-lit injection, this is purely descriptive and by no means infers a genetic analogy. Away from the main areas of sulfides, the pyrrhotite and chalcopyrite are distributed in very thin and veinlike aggregates which curve and interleave with the anthophyllite fibres. Such replacement textures by the sulfides do not prevail where massive quartz grains exist; there the replacement has been practically nil, or where existent, it is as embaying and poorly transecting masses of sulfide, this because of the very resistant nature inherent in quartz. Pyrrhotite is much more abundant in these replacing masses than is chalcopyrite, but the latter does occur in the same habit as the former, that is, it also definitely
replaces the anthophyllite.

One of the most interesting features of the mineralized schist adjacent to the dike is the very perfect pseudomorphic pyrrhotite after pyrite. (Plate XX, Figure 2.) Where pyrite cubes have been developed in a rock which has a high proportion of gangue the external outline has been preserved by the replacing pyrrhotite, in some cases the replacement is so perfect that no pyrite remains, in others there are left a few residuals of pyrite. Often the replacing mass includes a small amount of chalcopyrite, but nowhere, does the latter constitute even a major part of the aggregate; pyrrhotite is always in greater amount. It is to be noted that, here as in the massive sulfide bodies, chalcopyrite replaces pyrrhotite. In spite of this lesser development, the intimacy with which some of the chalcopyrite areas maintain the original pyrite grain outlines indicates that the chalcopyrite is also pseudomorphic after pyrite. The granularity of the pyrrhotite is apparently the same as that of the replaced pyrite, for in many areas a pseudomorph of pyrrhotite consists of but a
single grain, in other and larger ones two to three grains are present as though this latter were originally an aggregate of pyrite grains. This conformity in grain by the host is a characteristic replacement phenomenon.

The above discussion has concerned itself chiefly with the conditions found in the ore and in the schist country rock, both that part remaining in the ore and that adjacent to the dike. Now shall be discussed the conditions prevailing where the dike itself is concerned.

The dike is bordered by narrow carbonate-quartz stringers and usually by a band of chalcopyrite, 0.5 mm wide, in which there is very little of either pyrite or pyrrhotite. The carbonate-quartz stringers definitely cut and are, therefore, later than all the sulfides. For about one-quarter inch the dike is permeated by disseminated chalcopyrite and by larger masses of this, arranged in arborescent forms which protrude in from the main chalcopyrite ore and are normal to the contact. (Plate XXI, Figures 1 and 2.) The fringes or outer portions of these masses are
clouded by numerous gangue residuals but the medial portion is often solid chalcopyrite. The latter probably represents the filling of a clean cooling fracture in the dike. The material of these masses is much finer in grain than that of the ordinary chalcopyrite, and the twinning is less evident. It is noteworthy that in the dike no pyrrhotite is associated with the chalcopyrite. This is probably due to the fact that only the last sulfide to crystallize, viz., chalcopyrite from solid solution, was the one which permeated the dike.

**Marcasite:**

A very interesting development in the immediate vicinity of the dike, within one-half inch, is that of marcasite. It occurs in the typical feather-like aggregates about 0.4 mm by 0.2 mm in dimensions. It is more commonly found in pyrrhotite than in pyrite and seems to have been localized by fractures in these minerals. Many of the marcasite masses are cut medi ally by thin veinlets of both carbonate-quartz and chalcopyrite, (Plate XXII, Figures 1 and 2.) areas of pure quartz are also commonly associated, but
age-relationships to the quartz are not determinant. It is to be noted that there are no globular areas of marcasite connected with the reniform masses. The similarity of this material and its associated minerals, to some of that found at Kokomo, Colorado, and described by Newhouse, is to be considered in the formation of this marcasite. There is no doubt that the formation of the marcasite is intimately related to that of the carbonate-quartz veinlets and more significantly to that of the chalcopyrite. It is because of this latter association that a supergene origin for marcasite is inconceivable, inasmuch as chalcopyrite is a hypogene mineral. Because of the carbonate-quartz association, the solutions were probably but very slightly alkaline, possibly neutral at the time of the marcasite formation. It is possible then that "The last ebbing phases of hypogene solutions carrying carbonate are then conceived to be the medium which formed the marcasite in the cases

noted under hypogene marcasite. A very significant fact is that the depth at which this marcasite is found is 4,325 feet on the incline, that is, 3,300 feet beneath the outcrop, a rather great depth for marcasite to form by descending solutions.

Development of Cubanite:

As has been previously described, cubanite associated with pyrrhotite, chalcopyrite and pyrite occurs in rather large amounts, (Plate XXII, Figure 1.) in a small mass situated about eighteen inches from the dike. The proportion of minerals present in those specimens containing the greatest amounts of cubanite are as follows:

<table>
<thead>
<tr>
<th>Per cent</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>2</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>20</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>10</td>
</tr>
<tr>
<td>Cubanite</td>
<td>63</td>
</tr>
</tbody>
</table>

Pyrite:

The pyrite of this aggregate is similar in every respect, that is, in grain size, shape and roundness of grains, to that found in the pyrrhotite ores, and need not be further described.

Chalcopyrite:

The chalcopyrite is also similar, possessing both the same grain size, and amount of twinning as in the pyrrhotite ore.

Pyrrhotite:

The habit of the pyrrhotite, is however, different. The bleb-like areas are fewer, and those present are much smaller, half the size of those found in the masses lacking cubanite. In addition there are very irregular veinlike masses in great abundance. These occur, invariably, as far as the author could detect, between the chalcopyrite grains and around the ends of cubanite blades. They never transect either chalcopyrite or cubanite in the manner of true replacement veinlets. It is of considerable genetic significance to note that the veinlets of pyrrhotite narrow where they join other similar pyrrhotite vein-
It is important to note, however, that the material of these veinlike masses consists of very fine-grained pyrrhotite, the crystals being more or less acicular and arranged normally to the walls, that is, transverse to the length of the veinlet. The pyrrhotite of the rounded blebs consists, on the other hand, of coarse grained pyrrhotite, similar to that found in the specimens lacking cubanite. The material of the veinlets does not possess the marked anisotropism as is displayed by valleriite which is a copper-iron-sulfide (Cu$_2$Fe$_4$S$_{7}$).

For these pyrrhotite veinlets, there are three possible origins, namely:

1. Later hydrothermal material cutting and replacing both chalcopyrite and cubanite.
2. Residual veinlets of pyrrhotite after chalcopyrite and cubanite.
3. Exsolution material from the chalcopyrite.

Militating against the first hypothesis is the fact that none of the material transects the crystals of chalcopyrite: it is always intergranular,
that is, intercrystalline with respect to the latter. Furthermore, there are no residuals of chalcopyrite isolated in the central portions of the veinlets, as is so commonly the case with replacement veinlets or other forms of replacement.

Evidence which is not in support of the second hypothesis is the fact that the grain size of the pyrrhotite of these veinlike masses is very much finer than that of the large bleb-like areas. In addition, the tendency of replacement in these latter masses is for the chalcopyrite to reduce the pyrrhotite first to promontories, then to island-like areas, and finally to very small isolated masses. (Plate XVIII, Figures 1 and 2.) That is, in that material which lacks cubanite, and where the chalcopyrite definitely replaces the pyrrhotite; nowhere is there a stage in the replacement process in which there is the development of veinlike aggregates. It is tenable then that the pyrrhotite veinlets of the cubanite specimens are not later hydrothermal material.

All the evidence suggests an origin by exsolution from chalcopyrite. The strongest evidence
for this is the fact that the pyrrhotite veinlets are always between the chalcopyrite grains. In this connection, Van der Ween says, "In normal cases in metallography with metallic solutions, with very slow cooling we may assume that segregation of the new phase which is thrown out first, starts at the boundaries of every grain and that gradually every grain will become surrounded by a layer or film of this substance. Then the texture of the section looks like a 'network' (network texture, cell-texture) of these films around the grains," and further, "Sometimes this texture is called secondary or tertiary in metallography. Similar network textures we have sometimes in magmatic deposits, e.g., in some specimens of nickeliferous deposits. The grains of pyrrhotite are surrounded by pentlandite. (Figure 15)."

The very great similarity of the texture developed when pentlandite separates out of pyrrhotite on cooling, as is shown by Van der Ween's figure 15,

to the texture as between the pyrrhotite and chalcopyrite as above-described from the Eustis, indicates that the two have a similar origin, that is, if, as postulated by Van der Ween, the texture displayed by pentlandite and pyrrhotite, is due to exsolution, then by textural analogy, that displayed by pyrrhotite and chalcopyrite in the cubanite specimens of the Eustis is also due to exsolution.

Earlier masses of pyrrhotite and later veinlets of it in chalcopyrite-cubanite intergrowths have been described from Parry Sound, Ontario, and from Fierro, New Mexico.

Schwartz describes both early and late pyrrhotite from a chalcopyrite-cubanite-pyrrhotite occurrence at Parry Sound, Ontario. The early pyrrhotite is "as grains and patches clearly of earlier formation."

1. Schwartz, G. M., Primary Relationships and Unusual Chalcopyrite in Copper Deposits at Parry Sound, Ontario, Econ. Geol. 19, p.211, 1924.

2. Schwartz, G. M. Chalmersite at Fierro, New Mexico, Econ. Geol. 18, p.275, 1923.
The later pyrrhotite occurs as veins and stringers in the chalcopyrite and cubanite; the laths of cubanite being cut off sharply by the pyrrhotite stringers indicating a somewhat later crystallization for the latter mineral. It is to be noted that Schwartz says that in the Parry Sound specimens containing the chalcopyrite-cubanite intergrowth the pyrrhotite seems to have crystallized later. He describes similar veins and stringers of pyrrhotite cutting chalcopyrite and chalmersite (cubanite) from Fierro, New Mexico. He considers such veins and stringers as later pyrrhotite. His remarks concerning the crystallization of material from an iron rich chalcopyrite solution are significant. He says, "An excess of iron and sulphur crystallized as pyrrhotite, perhaps at somewhat lower temperatures, and slightly later than the chalcopyrite-cubanite solid solu-

tion. The pyrrhotite at Fierro obviously crystallized later than the chalcopyrite-cubanite intergrowth." He apparently considers the pyrrhotite to have formed by crystallization from a solid solution, and not to have formed by later hydrothermal action.

The manner in which the pyrrhotite veinlets narrow at junctions with other such veinlets is one of the criteria mentioned by Schwartz as indicative of unmixing from solid solution. The present author has also described such a narrowing in pyrrhotite veinlets from specimens of ore from the Waite-Ackermann-Montgomery mine in Quebec; these veinlets were considered to form as the result of unmixing.

Thus, in the metamorphosed ore, there is pyrrhotite of both early and late formation; neither

2. Schwartz, G. M., Texture Due to Unmixing of Solid Solutions, Econ. Geol. 26, pp.761-762.
the early nor the late being due to hydrothermal activity, but to crystallization from an iron-rich chalcopyrite solid solution.

Cubanite:

In some polished surfaces cubanite occupies 60 to 70 per cent of the area. It is always as laths, never as irregular massive areas. The dimensions of the laths are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Average</th>
<th>Smallest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lengths</td>
<td>3.0 mm</td>
<td>.7 to 1.0 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Widths</td>
<td>.07</td>
<td>.03</td>
<td>Hair lines under highest magnification</td>
</tr>
</tbody>
</table>

The variation in widths is, of course, due to the different angles at which the plates are cut by the section which is polished.

The pattern displayed by the cubanite laths can best be described as an openly woven meshwork, with the chalcopyrite occurring between the laths in whatever spaces happen to be available. The units are more often bundles of laths of cubanite rather than individuals, although the latter do participate in the
meshwork pattern. These blades of cubanite cut across the chalcopyrite twins, suggesting that "the twinning must have been subsequent to the segregation of the cubanite. If this were not so, the cubanite would end abruptly at the twin boundaries." This is so because with the development of twinning in a crystal, a new crystal interface is produced and had the cubanite exsolved from the chalcopyrite subsequent to such twinning, it would have followed the twin, that is, the new crystal boundaries, but it does not. The conclusion is that "since the twinning is secondary, it has been caused by plastic deformation." It is to be noted, however, that it would take but a very small amount of stress to cause such twinning and this does by no means imply great post-mineral stresses.

Inasmuch as any one lath of cubanite confines itself to but one crystal of chalcopyrite, and is obviously controlled by the crystal structure of this latter; it is considered to be exsolved material from the chalcopyrite. The same situation has been observed


to have participated in somewhat the same series of events as described by Newhouse.

To further prove that cubanite formed by exsolution from chalcopyrite and not by introduction of material, two specimens were analyzed mineralogically by the method of estimating the areal proportion of each mineral in the polished surface. One specimen was of pyrrhotite, chalcopyrite and pyrite, the other this same aggregate and in addition cubanite. The sulphur, iron and copper content of each was calculated from the mineral composition. The results obtained are given in the following table:

I. Average specimen without cubanite:

<table>
<thead>
<tr>
<th></th>
<th>Per cent of mineral</th>
<th>S.</th>
<th>Fe.</th>
<th>Cu.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>2</td>
<td>1.1</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>57</td>
<td>20.</td>
<td>17.</td>
<td>19.7</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>36</td>
<td>14.3</td>
<td>21.7</td>
<td></td>
</tr>
<tr>
<td>Gangue</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>100</td>
<td>35.4</td>
<td>38.9</td>
<td>19.7</td>
</tr>
</tbody>
</table>
II. Cubanite specimen:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per cent of mineral</th>
<th>S.</th>
<th>Fe.</th>
<th>Cu.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>2</td>
<td>1.1</td>
<td>.9</td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>20</td>
<td>7.0</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>10</td>
<td>4.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Cubanite</td>
<td>63</td>
<td>23.0</td>
<td>26.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Gangue</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>100</td>
<td>35.1</td>
<td>38.9</td>
<td>21.0</td>
</tr>
</tbody>
</table>

The striking similarity in sulphur, iron and copper content of the specimen without cubanite to that with cubanite shows that there has been no resultant addition or subtraction of these elements during the formation of cubanite.

It is to be noted that the exact check indicated by some of these figures is quite fortuitous, for specimens other than that considered to be the average would have shown different mineral proportions but the aggregate sulphur, iron and copper content would have been of the same order of magnitude. Another factor which modifies the results thus obtained is the incomplete information concerning the true chemical composition of the sulfides. This is especially true
with respect to chalcopyrite which has a varying iron content dependant upon the extent to which that element has been discarded in the production of pyrrhotite or cubanite or both, from iron rich chalcopyrite. However, the magnitude of the changes introduced by using quantitatively correct chemical compositions would not materially change the similarities in iron, copper and sulphur content of the cubanite and the non-cubanite specimens.

The contribution of the investigation is that in the development of cubanite there has been no great increase or decrease in the amount of constituent elements. The system chalcopyrite, pyrrhotite, cubanite, and pyrite is, for this locality, apparently closed, and this condition lends substantial support to the idea that the development of cubanite is by exsolution from chalcopyrite.

Summary of Results Incident Upon the Intrusion of the Camptonite Dike into the Eustis Ore.

The intrusion of this dike has had the following metamorphic effects on the chalcopyrite ore body of the Eustis:
(1) The ore and country rock were heated up to a temperature of 400°C or more by the intrusion of the dike. This is deduced from the fact that in connection with chalcopyrite holding cubanite in solid solution Newhouse says that "A solid solution forms at a temperature which experimental data suggests is above 400 C."

(2) The development of anthophyllite from the muscovite and chlorite of the schist was induced by this elevated temperature.

(3) This high temperature caused some of the pyrite to go into solid solution with the chalcopyrite giving an iron rich chalcopyrite solid solution. The remaining pyrite forms the rounded grains which are now present in all specimens.

(4) When this mass cooled, the iron rich chalcopyrite purged itself of iron, giving a chalcopyrite containing less iron, cubanite and pyrrhotite. There probably was a good deal of overlapping in this process, inasmuch as there is pyrrhotite which is definitely replaced by chalcopyrite and also pyrrhotite which

exsolves from it. The chalcopyrite continued to form with the development of cubanite after most of the pyrrhotite had been developed. Marcasite also developed, this, after the pyrrhotite blebs, but before the cessation of chalcopyrite formation; this marcasite is not supergene.

(5) Replacement of the pyrite in the schist by pyrrhotite and chalcopyrite pseudomorphic aggregates.

(6) Introduction of chalcopyrite, in both disseminated masses and in transverse fractures regarded as cooling fractures. Here note the aborescent chalcopyrite in the dike. (Plate XXI, Figures 1 and 2.)

(7) Introduction of carbonate-quartz veinlets.
ORE GENESIS

The solutions responsible for the sulfide mineralization at the Eustis are considered to have been hot aqueous solutions which emanated from a magmatic source. They are not thought of as meteoric waters which had gathered their material from the surrounding rocks. The definite and constant sequence of sulfide deposition, viz: pyrite followed by sphalerite and tetrahedrite, and these by chalcopyrite and galena, suggests a varying composition of solutions according to differentiation in the source. Such constant variation would not be found in solutions which were of meteoric origin and had gathered their load from the surrounding rocks. It is also to be noted that in the sulfide ore bodies, quartz and carbonate have not been found in such abundance as they would have been in had they been deposited from meteoric waters.

In view of the close relationship of the ore body to the quartz-porphry, it is very probable

1. Hanson, George, Pyritic Deposits in Metamorphic Rocks, Econ. Geol. XV. p.608. 1920.
that the solutions came from the same source as the porphyry, namely from a magmatic reservoir. The ore bearing solutions represent the final stages of a differentiation from the magma which yielded, also by differentiation, the quartz-porphyry. The solutions deposited their load of sulfides by replacement of the porphyry, filling of open spaces being practically negligible.

The pyritic replacement deposits of Shasta County, California, and of Rio Tinto, Spain, are also considered to have been formed by deposition from solutions which arose by differentiation from the same magmatic reservoir from which the intrusives came. These intrusives have similarly been replaced by the ore bearing solutions.

Because of the apparent genetic relationship between the ore bearing solutions and the sodic quartz-porphyry, both are considered to have originated, at different times, in the same magmatic reservoir. The exact nature of this source is, however, not known.

2. Bateman, Alan M., Ore Deposits of Rio Tinto District, Spain, 22, pp. 607-611, 1921.
Polished section, pyrrhotite ore body. X 45.

Intricate replacement of pyrrhotite (dark grey) by chalcopyrite (light grey). No cubanite in this specimen.

Polished section, pyrrhotite ore body. X 130.

Similar to figure 1, islands and promontories of remaining pyrrhotite (dark grey) are more evident in the chalcopyrite (light grey).
Figure 1.
Thin-section, crossed nicols. X 55.
Abundant development of very long anthophyllite blades in the pyrrhotite ore.

Figure 2.
Thin-section, crossed nicols. X 55.
Wall rock of pyrrhotite ore, showing development of anthophyllite in patches which simulate, in shape and size, those areas of muscovite and chlorite from the schists found associated with the non-pyrrhotite ore.
Figure 1.
Polished section, pyrrhotite ore. X 45.
Leaf-like replacement of anthophyllite blades by fine strings of pyrrhotite and chalcopyrite. The one massive sulfide area represents pyrrhotite (light grey) replacing a grain of pyrite (white).

Figure 2.
Polished section of pyrrhotite ore. X 19.
Pseudomorphic pyrrhotite (light grey) after pyrite (white). Some of the pyrite cubes have been wholly replaced, and others only partially so.
Figure 1.
Polished section, pyrrhotite ore body. X 19.
Arborescent chalcopyrite (light grey) in camptonite dike. Note single line of solid chalcopyrite in centre of arborescent mass, this line is mainly filling, whereas the other is replacement of dike minerals.

Figure 2.
Polished section, pyrrhotite ore body. X 19.
Arborescent chalcopyrite similar to figure 1, but with more solid chalcopyrite, hence a larger fracture.
Figure 1.
Polished section, pyrrhotite ore. X 45.
Marcasite (the two light grey or white areas in centre of photograph) developing in pyrrhotite (dark grey)

Figure 2.
Polished section, pyrrhotite ore X 220.
Marcasite of figure 1 but magnified more. Note central veinlets in centre of each of the two marcasite areas. These veinlets consist of chalcopyrite (light grey) and carbonate (black)
Figure 1.  X 19.
Polished section, polarized light, pyrrhotite ore body.
Abundant development of cubanite laths, well twinned, with very little interstitial chalcopyrite, and a few blebs of dark grey pyrrhotite.

Figure 2.  X 45.
Polished section, polarized light, pyrrhotite ore body.
Cubanite laths which are sharply cut off by a later veinlet of very finely crystalline pyrrhotite.
Figure 1.

Polished section, plane light. X 130.

Pyrrhotite ore body.

Late pyrrhotite veinlets (dark grey) cutting off bundles of cubanite laths (light grey). Note that the pyrrhotite veinlets narrow at their intersections with one another.
Diagram showing distribution of sulfides with respect to the border of the dike. Data is from study of specimens shown by small circles in the diagram.

Legend:
- Typical ore of pyrite and chalcopyrite
- Pyrite, chalcopyrite and pyrrhotite
- Pyrite, chalcopyrite, pyrrhotite and cubanite.

Scale: 1 inch = 3 feet.
BASIC DIKES OF THE EUSTIS MINE

Regional References to Similar Dikes:

The dikes of the Eustis are all lamprophyres, but vary widely in general composition.

Late dikes of a lamprophyric nature have been widely described in the South Eastern Townships of Quebec, the adjacent regions of Vermont and New York States. In his report on the Copper Deposits of the Eastern Townships, Dresser mentions, with brief descriptions, the occurrence of camptonite, diabase and bostonite as being the chief rock types represented at various places in the southern Eastern Townships. Marsters describes in some detail the various basic dikes which occur in the immediate vicinity of the Canadian portion of Lake Memphremagog. Kemp and Marsters describe, also in great detail, the basic dikes of the Lake Champlain region.

The study of Kemp and Marsters on the trap


dikes of the Lake Champlain region forms more or less a basic paper for the study of lamprophyre dikes in the Northern Appalachian region. It is quite comprehensive and detailed in the treatment of lamprophyre dikes. The authors generalize by saying that "The dikes are formed by two strongly contrasted kinds of rock, the one, feldspathic porphyries or trachytes, which are called bostonite in this paper, the other basic rocks, which under the microscope are subdivided as diabases, camptonites, monchiquites, and fourchites. Both kinds occur closely associated in the same districts." It is to be noted that, of the dikes examined from the Eustis mine only diabases, camptonites and monchiquites were found, but that Dresser mentions bostonite as being present in the general region.

A very succinct description of the general variation in basic dikes is contained in the following quotation from Kemp and Marsters concerning the Lake Champlain dikes. "The thin-sections exhibit

a series of mineralogical mixtures extending from very typical ophitic diabase through camptonites, in which the dark silicates become idiomorphic and the feldspars recede, to aggregates of augite and hornblende lacking feldspar entirely and having comparatively little glass. Olivine is occasionally seen in a fresh condition, but in most dikes an alteration product not always satisfactory alone indicates its probable original presence. The subordinate minerals are noted in the particular description."

In the Lake Memphremagog region Marsters describes both granite and lamprophyre dikes. As belonging to the latter class he considers those dike rocks "dark grey in color, with moderately fine crystalline texture and occasional phenocrysts of dark colored silicates, sufficiently well developed to be microscopically determined. In some instances the phenocrysts were found to be pyroxene; in others the idiomorphic constituent proved to be hornblende;

while in still other instances the olivine played the same role. A number of instances were noted in which the olivine reached a diameter of one and one-half inches. It is a significant fact that the olivine phenocrysts were invariably located in the central part of the intrusive mass. On the contact the dikes were generally fine-grained and in some cases even flinty, the phenocrysts having entirely disappeared." This hand specimen description of the lamprophyre dikes as found by Marsters is given in its entirety to show the very close similarity existing, megascopically, at least, between the dikes of the Lake Memphremagog region and those of the Eustis mine.

After microscopic study in thin-section, Marsters enumerates the Lake Memphremagog lamprophyres as follows: olivine diabase, camptonite, augite camptonite, fourchite and monchiquite. It is to be noted that in the present investigation, not all these types were found at the Eustis.

1. Marsters, V. F., op. cit. p.29.
It is interesting to note the contrast between the dikes of the Eustis, Lake Memphremagog and Lake Champlain regions that is, west of the Adirondacks and those in New York State west of the Adirondacks. The dikes of the former district are characterized by an absence of brown muscovite, that is, of biotite or phlogopite, whereas the ones of the latter all have an abundance of this mica.

Smyth describes alnoites from Manheim, Syracuse, and Clintonville, New York. These dikes are characterized by an abundance of deep reddish-brown biotite; this pleochroism suggests phlogopite.

A contrast between the dikes west of and east of the Adirondacks has been also made by the authors of the New York State Museum Bulletin, 145, on the Geology of the Thousands Islands Region.

where they say, in speaking of the latter dikes, "Though they give no evidence of having been severely deformed, yet the rock of the larger dikes does show evidence of considerable pressure. Many of the feldspar crystals are distinctly bent, and both the feldspar and augite of the rock shows evidence of strain by their undulatory extinction. In this respect they contrast with the diabases of the eastern Adirondacks, which show no such strain effects. The eastern dikes also have chiefly east-west trends, differ somewhat in mineralogy, and are more numerous and widespread; and are also separated from this area by a wide region in which such dikes are absent. We seem here, therefore, to be dealing with a wholly different centre of igneous activity, and a much less extensive one than that farther east."

The author is in accord with the thought expressed above as to the cause of the difference between the dikes east and west of the Adirondacks. They are probably also of a different age, and lo-

calized by a different set of regional forces.

In composition, the basic dikes of the Eustis belong to the same series of dikes which characterizes the Eastern Townships. These latter are similar, in their definitely alkaline nature, to the intrusions which form the cores of the Monteregian Hills. It is entirely probable that all were injected at about the same time, viz.: later than Lower Devonian and probably belonging to late Devonian or early Carboniferous.

Detailed Description of the Basic Dikes of the Eustis Mine:

Distribution and Size of Dikes:

The basic dikes, similar to those briefly discussed, are widely distributed throughout the Eustis mine. There does not seem, however, to be any marked localization with respect to depth in the mine.

They vary in size from one on the 4825 level, a camptonite which is forty feet thick, to an average thickness of two feet, and then on down to mere stringers a sixteenth of an inch or less in

thickness. All the dikes invariably possess glassy selvages and fine-grained outer portions which grade, in the thicker dikes, to material very coarse grained, with phenocrysts an inch or so across.

One very noticeable feature of all the dikes is the extreme rapidity with which they disintegrate upon exposure. A very few days after having been blasted into, suffices for a dike to crumble, the back of the drift to spall and to fill with granular dike material.

After thin-section study and an investigation of the literature pertaining to basic dikes, the author has enumerated the dikes examined from the Eustis mine as follows: olivine diabase, camptonite and monchiquite.

Olivine Diabase:

In hand specimen the diabase is usually a very fine-grained to dense rock, varying with the size of the dike, showing a diabasic texture caused by numerous laths of feldspar.

In thin-section the rock consists of phenocrysts of labradorite, augite and a few olivine crystals set in a medium-grained ground mass of the same general composition.

The labradorite is as broad, idiomorphic crystals which are well and abundantly twinned; the mineral was determined as intermediate labradorite by the use of immersion oils. There are two generations of the plagioclase, one in the ground mass and one as phenocrysts; both varieties are quite free from inclusions and alterations products.

The augite, of which there are also two generations, both phenocrysts and ground mass material, occurs as allotriomorphic crystals, either packed in with the plagioclase laths or occurring as isolated phenocrysts in the ground mass. The grains of augite have a slight brownish green pleochroism.
163.

The olivine is rare and where developed is as highly altered phenocrysts, the alteration product being fibrous aggregates of serpentine which sometimes rim the less altered material and sometimes is as indefinite patches inside a crystal.

The ground mass consists of diabasic labradorite, augite, calcite and magnetite or ilmenite. These latter often form a network of needles intersecting at 90 degrees, but this arrangement bears no relation to the cleavages of the minerals in which such is found.

Because of the presence of olivine in a diabasic environment caused by plagioclase laths and in one containing augite, this lamprophyre has been called an olivine diabase.

Camptonite:

In contrast to the olivine diabase, the rocks which have been determined as camptonites, have a less diabasic and a more granitic appearance when examined megascopically.

The rocks examined from the Eustis consist of brown hornblende, plagioclase, augite, and magnetite. There are two generations of all these minerals except magnetite. It is to be noted, however, that the grains are not so far separated in size as they were in the diabase and hence the rock is much less porphyritic in texture. The hornblende, which is in greatest abundance, is quite idiomorphic. It has strong dark to light brown pleochroism, which is characteristic of barkevikite, a hornblende rich in ferrous iron and alkalis. The plagioclase is less idiomorphic than in the diabase, but nevertheless maintains its lath-like habit. The augite, which is not very abundant, amounting to only about 1 per cent, is the purplish pleochroic variety called titanium bearing augite, which is so common in alkaline rocks. Most of the augite is in the process of being altered to barkevikite. Magnetite is developed as small rounded grains in the ground mass.

For the following reasons, which are those advanced by Kemp in his discussion of the Lake Champlain camptonites, this rock from the Eustis has been
called camptonite:

(1) The rock consists essentially of brown hornblende.

(2) Ophitic textures between plagioclase and pyroxene are absent.

(3) The rock contains but a very minor amount of augite, and is, therefore, not an augite camptonite.

Monchiquite:

Dikes, which in this investigation have been termed monchiquites, are distinguishable from the camptonites only by the presence of glistening black phenocrysts of augite. They are one-quarter to one-sixteenth inches in size and are set in a finer grained ground mass.

In these rocks the ferro-magensians are the predominant constituents amounting to 75 per cent of the rock. The phenocrysts are augite and olivine. The hornblende does not appear as such; it is only in the medium grained ground mass. The augite, which is of two generations, is the purplish pleochroic titanium bearing augite, and


is quite frequently zoned. This zonal structure is more pronounced than in the camptonites; this has also been noticed by Marsters in the Lake Memphremagog dikes. The hornblende is as small idiomorphic crystals of brown barkevikite; it occurs in only the one generation. The olivine is as large phenocrysts comparable in size to the augite phenocrysts. They are much altered to serpentinous aggregates, and when thus, are as more or less granular masses. There is a very dense colorless and slightly anisotropic base to the above minerals. This may or may not be analcime; its index is lower than Canada Balsam. This enhances the possibility of its being such. Abundant fine-grained magnetite is distributed throughout the rock.

These rocks have been termed Monchiquites because of the predominance of augite, hornblende and olivine, and the fact that they are plagioclase free, which would relate them to the camptonites. Inasmuch as they contain olivine, they cannot be called fourchites, the name applied to olivine free

monchiquites, as described by Williams from Fourche Mountain, Arkansas.

Age of the Dikes with Respect to the Ore:

All the basic dikes of the Eustis are later than the ore. They transect and very often slightly displace the ore lens. Furthermore, it is to be noted that all have fine-grained to dense margins where in contact with ore as well as with country rock. This indicates that the dike borders were chilled when they came in contact with both ore or country rock; they are then later in formation than the ore.

Only one of these basic dikes, and this the largest one, metamorphosed the ore which it cut. The metamorphosing dike is forty feet thick, whereas the largest of any of the other dikes is eight feet. The ore adjacent to these smaller dikes carries neither pyrrhotite nor cubanite, nor is there any change in texture of the ore. Inasmuch as there are camptonites, comparable in composition to that

which metamorphoses the ore; amongst these smaller dikes, the composition of the dike is apparently not the factor which determines the ability to metamorphose ore.

The conclusion is, that the much greater thickness, forty feet as compared with eight feet, was needed to supply the amount of heat necessary to metamorphose the ore body as it has been.
CONCLUDING REMARKS

The main ore body of the Eustis mine is a chalcopyrite-pyrite lens, running around 4 per cent copper and 30 per cent iron. This lens averages 40 feet in thickness across the dip and 120 feet in width along the strike of the enclosing schists. It lies in the schistosity and never cross-cuts it; although it definitely replaces the schists and associated green-rock.

In addition to the chalcopyrite lens, there are three lenses with a very high content of pyrite arranged en echelon and down across the dip to the northeast of the chalcopyrite lens.

The structure responsible for the various mineralizations is considered to be a zone, made permeable to mineralizing solutions, by tension. This tension is thought to have been effected by oppositely directed forces from the northeast and northwest acting horizontally in the plane of the schist.

The rather marked mineralization features at the mine, include the following:
1. An intense carbonatization.
2. Abundant development of muscovite and quartz.
3. No marked changes in sulfide or gangue minerals over extreme length 6,050 feet of the ore lens.
4. A portion of the ore body definitely metamorphosed by a later dike.

The carbonatization of the schist to give green-rock; later in formation than the schist, has been so intense in places that much of the schist has been changed to a massive ankeritic carbonate rock containing from 25 per cent to 50 per cent of carbonate. Concomitant with or slightly later than the formation of ankerite has been that of diabantite chlorite. Neither the ankerite nor diabantite are developed elsewhere than in the green-rock, the formation of which rock was one of the first mineralization features impressed upon schists. The development of this iron carbonate and iron-rich chlorite represents the early iron-rich phases characteristic of the earlier stages of mineralization.
The more moderate mineralization is represented by abundant development both of recrystallized and introduced muscovite and quartz. There is very little muscovite in the schists outside of ores and very little coarse quartz; but within the ore zone muscovite is very predominant and most of the quartz has recrystallized to coarser aggregates.

There is a remarkable constancy in sulfide mineralization over the whole length, 6,050 feet to date (May 1934) of the ore lens. The relative proportions of chalcopyrite and pyrite remain about the same. The amounts of sphalerite and galena are so small that variation cannot be detected. However, they appear to occur in the same general quantities along the whole length of the lens. Tetrahedrite was found 1400 feet down along the incline from the surface, but also at one other place 5,800 feet down the lens. The conclusion, then, is that along 6,050 feet of a sulfide lens there has been no evident zoning of sulfides.

A rather special feature has been the
metamorphism of the ore body effected by a later camptonite dike. This has resulted in the development of pyrrhotite and cubanite. They have formed by the crystallization from a solid solution of iron-rich chalcopyrite. The solid solution, iron-rich chalcopyrite, was formed by the chalcopyrite of the ore body going into solid solution with some of the pyrite; this all being made possible by the heat supplied by the intrusion of the dike. Inasmuch as no such metamorphism has resulted from the intrusion of other dikes similar in composition but much smaller, it is concluded that only a dike of the dimensions of that on the 4825 level, forty feet or more in thickness, or larger, was capable of supplying sufficient heat to metamorphose the Eustis ore.

The last important geological phenomenon at the mine has been the intrusion of late basic dikes. They include olivine diabases, camptonites monchiquites; dikes such as are found around Lakes Memphremagog and Champlain.
BIOGRAPHICAL NOTE

Name: John Sinclair Stevenson

Born: September 21, 1908

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Education:

Bachelor in Arts...University of British Columbia, 1929

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With the Geological Survey of Canada for six summers,
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Dr. C. E. Cairnes in West Kootenay, B.C. in .... 1927 and 1928
Dr. W. E. Cockfield in the Yukon in ............. 1929
Dr. J. F. Walker in North Thompson area, B.C.... 1930
Dr. M. E. Wilson in the Noranda district, Que... 1931
Conducted a sub-party under Dr. Wilson in
the Ville Marie region, Que...................... 1932
Affiliated with the Department of Geology at the M.I.T. as
an assistant for three academic years......... 1931 to 1934

Presented to the Faculty at the Massachusetts Institute of Technology in May 1934, for the degree of Doctor of Philosophy in Geology a thesis entitled "Mineralization at the Eustis Mine, Eustis, Quebec."