GEOLOGY OF THE CANDEGO MINE

Gaspé North County, Quebec.

by

L. Wolofsky

A thesis in partial fulfilment of the requirements for the M.Sc. degree, McGill University.

April, 1954.

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ABSTRACT:

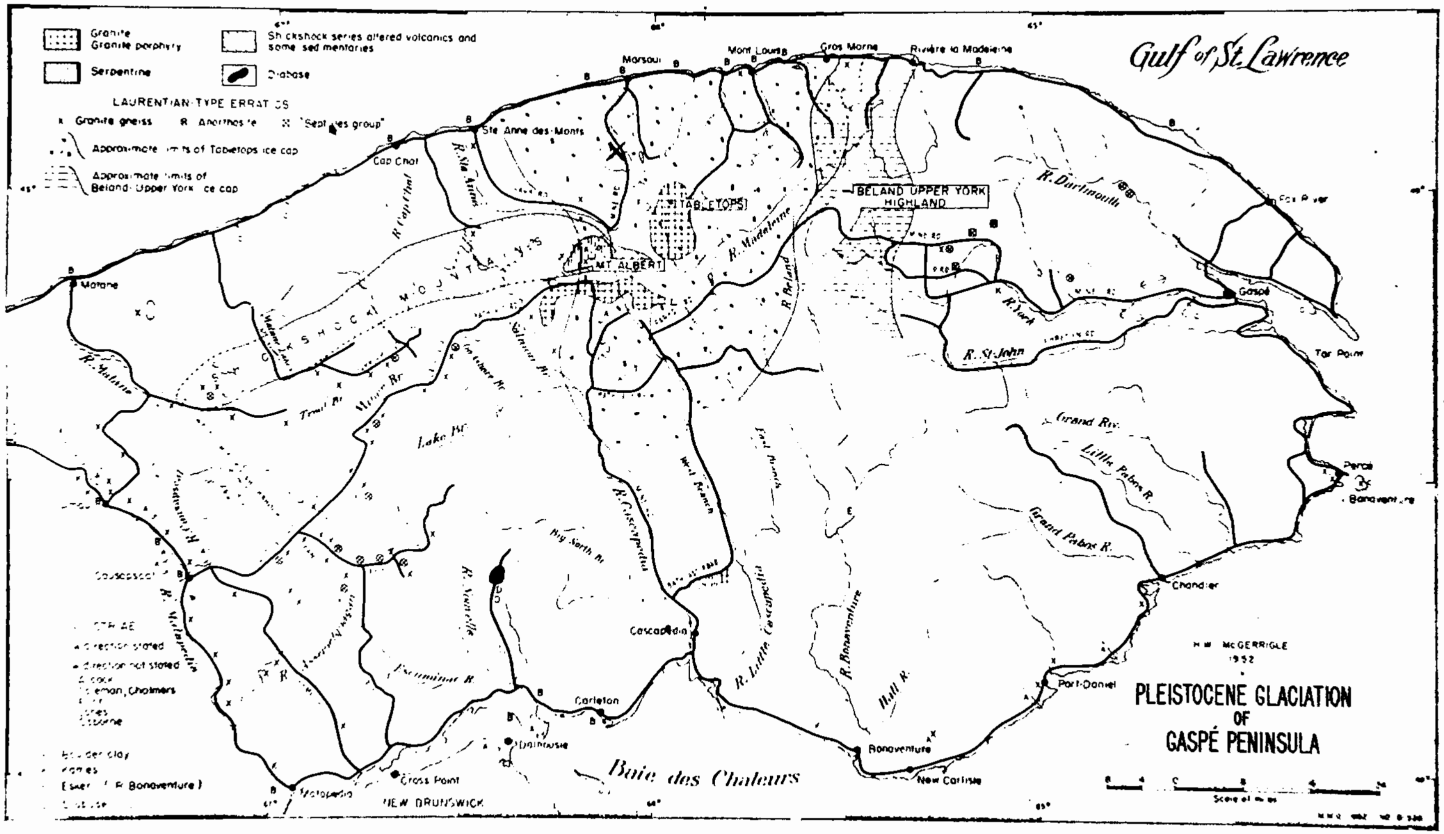
The Candego is a small lead-silver-zinc mine in the northern part of the interior of Gaspé. The ore bodies are narrow high grade shoots plunging at low angles to the west in east-west striking, steeply-dipping longitudinal strike-slip faults. These faults cut a strongly contorted zone in the Lower (?) Ordovician sedimentary rocks.

The minerals in the ore are quartz, carbonates, pyrite, galena, sphalerite, and smaller amounts of chalcopyrite, pyrrhotite, gold, tetrahedrite, arsenopyrite, bournonite, and anglesite.

LIST OF ILLUSTRATIONS

Figure 1 - Panoramic photograph of the Mine area, looking west. By H. M. Kingsbury, November 15, 1950.

Figure 2 - Gaspé Peninsula. The Candego Mine is at the cross, south of Marsoui.
From McGerrigle, 1952.



GEOLOGY OF THE CANDEGO MINE, GASPE NORTH COUNTY, QUEBEC.

INTRODUCTION

LOCATION AND ACCESS

The property of Consolidated Candego Mines Limited is in Boisbuisson and Christie Townships in the County of Gaspé North. (fig. 2) It is about 13 miles south of the village of Marsoui, which is on the north coast of the Gaspé Peninsula, about 80 miles east of the end of the railway line, at Matane. Matane is the eastern terminus of the Canadian and Gulf Terminal Railway, a short line connecting with the Canadian National Railway at Mont Joli. Provincial Highway No. 6 follows the coast of the peninsula from Matane to Marsoui and beyond. A gravel road leads from the mine, down the valley of the Marsoui River, to the coast.

Gaspé Copper Mines Limited's large copper deposit is about 25 miles east of the Candego Mine, and the Federal Metals area is about 20 miles south.

The Candego Mine was the first producing mine in the Gaspé peninsula. The Company produces lead-silver concentrates and zinc concentrates, both of excellent grade, in a flotation mill of about 65 tons daily capacity.

WORKINGS

The Mine is worked through adits driven westward into the valley slope. (fig. 3) There are six adits. Four of them, nos. 1, 2, 3, and 4 are located in one vertical zone. They are named in the order of decreasing elevation. Number 5 adit is approximately 800 feet south of this zone, at an elevation intermediate between numbers 3 and 4 adits. Number 6 adit is at about the same elevation as no. 1, and 700 feet south of it. Each of the adits contains one main drift, numbered 101, 201, 301, etc., which was driven on a vein. Drifts on other veins in the 3 and 4 adits are numbered 302 and 402. A small amount of exploration has been done by cross-cutting and diamond drilling, and stopes are present in all the adits except No. 6.

A large number of trenches were made by bulldozers for prospecting purposes. Many of these contain bedrock exposures.

Several open pits have been mined during the life of the Mine. The first and lowest was beside the river, at an elevation of about 1600 feet. (fig. 3) Others were at the present portals of nos 1 and 2 adits. A small open cut was mined above no. 5 adit.

The author's personal observations have been made in numbers 3, 4, 5, and 6 adits, parts of the old pits, and the surface trenches.

Table I, Summary of Adits. (Compare fig. 3)

Adit no.	Elevation ft. a.s.l.	Remarks
1	2320	Abandoned, inaccessible at present.
2	1920	Abandoned, inaccessible at present.
3	1860	Main production adit.
4	1760	Main haulage, some stoping and exploration.
5	1833	Inactive at present. Accessible.
6	2330	Short drift, exploration.

HISTORY

"Discoveries of lead and zinc sulphides were made at this locality as far back as 1916." (Jones, 1933a, p. 32) The early work does not appear to have been extensive, but by the time of Jones' visit in 1933 several trenches had been opened and a pit 22 feet deep had been dug. Most of this work was close to the river. The small exposures of mineralization found in this early work have not been mined. By 1944 the property had changed hands several times, and prospecting had extended farther from the river. In that year an impressive showing of galena and sphalerite was uncovered at Henley Creek (Stewart Troop, personal communication), a west-flowing stream that enters the Marsoui River about 1500 feet south of the Mine. Candego Mines Limited was incorporated in 1945, and in 1946 a high-grade ore body was found by trenching on the east bank of the river. The pit shown in figure 3 marks the location of this ore body. Trenching and pitting were continued intermittently. In 1948 a small sampling mill was installed, with an initial daily capacity of about 10 or 15 tons, and an open cut was started on the river ore body. It was felt that a mining operation was the best means of gaining information on the milling characteristics and geological nature of the ore. From February, 1948, to February, 1949, over 5000 tons of ore were milled, but mining was discontinued in this pit because of its proximity to the river, and the consequent problem of handling the water which entered the pit. In the summer of 1949 new ore was discovered high on the slope of the west mountain, and an open pit was started. Trenching was continued by bulldozer. This work traced a line of ore outcrops eastward down the slope of the mountain, and adits were started on the upper find (no. I adit, fig. 3) and on another at a lower elevation (no. 2 adit, fig. 3). These pits and adits showed the ore to be steeply dipping, and no. 3 adit was started about 60 feet below no. 2 to allow mining of this ore from a lower horizon. Numbers I and 2 adits in August and September, 1949, supplied the mill with over 1000 tons of ore averaging about 20% Pb, 15% Zn, and 18 oz. Ag per ton. (Stewart Troop, personal communication).

In October, 1949, the Company's power plant burned down and milling had to be suspended. Underground and surface exploration continued intermittently during 1950 and 1951. Number 3 adit was driven toward the west, and it intersected the downward continuation of the ore shoots (which had been projected from no. 2 adit) where they were expected. With increased confidence, another adit was started 100 feet below no. 3. This was no. 4 adit. It was originally thought that all these adits were all on the same vein, but later work showed that several mineralized veins, and many faults having attitudes similar to those of the veins, make up an ore zone on which the adits were driven.

Prospecting was extended over a wider region during the period of inactivity of the mill. A showing about 800 feet south of the main vein zone was opened by a small pit. This later became number 5 adit. (figure 3)

In February, 1952, the mill began operating again, and shrinkage stopes were opened in the ore in no. 3 adit. No. 4 adit workings were pushed to the west. No. 5 adit was started, and a small stope opened. However, the ore here is mostly sphalerite, and the price of zinc did not encourage further exploration after this shoot was exhausted. Operations in no. 5 adit were suspended late in 1952. Meanwhile, the search for continuations of the showing in the no 5 adit area led to the discovery of high grade ore on the hill-side above this adit. No. 6 adit was driven below one of these showings, but nothing of economic interest has yet been found in it.

During 1953, exploration in no. 3 adit uncovered a second ore-bearing vein. This is the 302 vein (fig. 3 and 4) which is approximately parallel to the 301, on which the earlier stopes had been driven. It is not now known whether this will prove to be a branch of the 301 or a parallel structure. At the west end of no. 4 adit, the 402 vein (fig. 3) was discovered. This is a different type of structure. It is a thick, low angle vein, as opposed to those mentioned above, all of which have steep dips.

As of October 1, 1953, the mill had treated 48,570 tons of ore. Smelter returns show a total of 5,954,049 pounds of lead, 4,840,109 pounds of zinc, 245,922 ounces of silver, and 950 ounces of gold contained in the concentrates sold up to that time. Since that date, at least 10,000 tons has been milled. (Stewart Troop, personal communication).

In 1952 the Company was reorganized and its name was changed to Consolidated Candego Mines Limited.

GEOLOGICAL WORK

<u>By others.</u>

The peninsula has received sporadic attention for many years. Intensive work did not start until 1917, seven years after the discovery of base metals deposits in the Federal area. Much of the area in the vicinity of the Candego Mine was mapped by I. W. Jones, for the Quebec Department of Mines, from 1929 to 1933. In recent years McGerrigle, also of the Quebec Department of Mines, has worked in adjacent areas and visited the many prospects.

H. M. Kingsbury served as consulting geologist to the Company for several years.

By the author.

The writer did geological work at the Candego Mine for about five months in 1953. His work included detailed geological mapping of most of numbers 3, 4, and 6 adits and examination of no. 5 adit, in addition to supervising diamond drilling, relogging some of the old drill core, and, in general, performing the duties of the mine geologist. Neither surface nor underground mapping has been completed. The Company is planning a geological mapping program for the summer of 1954. Laboratory work was done in the Department of Geological Sciences at McGill University, and consisted of optical examination of polished sections, thin sections, and powders, and qualitative chemical (especially microchemical) tests of certain specimens.

ACKNOWLEDGMENTS

Thanks are due to the Directors of Consolidated Candego Mines Limited for providing the opportunity to work at their property and permitting the preparation of this paper. Mr. Stewart Troop, Executive Vice President, has been especially helpful in encouraging the author's

work, both at the Mine and at McGill University. Mr. Troop described the history of the operation to the author, and furnished the data on production.

The Mineragraphic and Spectrographic Section of the Division of Mineral Dressing and Process Metallurgy, Mines Branch, Department of Mines and Technical Surveys, Ottawa, under the direction of M. H. Haycock, provided fifty-two polished sections of specimens from Candego. These were made for the purposes of the Division's investigation of the mineralogical and chemical properties of the Candego ore. All the mineral identifications, except that of pyrrhotite, were originally made by personel of the Mineragraphic and Spectrographic Section. Dr. Haycock and Dr. E. H. Nickel were kind enough to make their notes available to the author. Their descriptive contributions to this thesis are numerous, and are specifically acknowledged where quoted. The writer, however, accepts full responsibility for all other observations, and all interpretations.

Professor J. E. Gill of McGill University supervised the preparation of this paper and made many suggestions regarding the order of presentation of the material, which have been gratefully accepted.

The laboratory work was made possible by a scholarship provided by the Quebec Department of Mines which permitted the author to spend the 1953-54 term at the University.

The panoramic photograph (fig. 1) of the Mine area was taken by H. M. Kingsbury, and is used here by permission of Consolidated Candego Mines Limited. The print was made by Mr. L. Dille, Montreal. All other photographs were made by the author.

TOPOGRAPHY AND GLACIATION.

The Mine is situated on the west slope of the valley of the Marsoui River. (figs. 1 and 3) The river here lies at an elevation of about 1600 feet above sea level and roughly 1500 feet below the level of the adjacent upland. The general aspect of the region is that of an elevated partial peneplane, dissected by valleys with moderately steep sides. The panoramic photograph (fig. 1) shows a general view of the Marsoui River valley in the Mine Area.

There is no evidence of strong glacial erosion here. However, a few transported boulders have been seen at elevations as high as 2550 feet on the west slope of the valley. All the erratics are of rock types which occur at, or south, of the Mine. No Laurentian types were seen.

This would indicate that the region has been glaciated, and that the predominant direction of ice movement was from south to north.

Most of the soil in the Mine area is residual in origin. Extensive trenching has provided excellent profiles, in many of which the structures and quartz veinlets can be traced upward through partially-disintegrated material to the bottom of the root mat. In some places the top few inches of the profile is composed of fine silty material with irregular bedding at various angles. This is apparently fluviatile in origin. A few lenses of gravel of glacial or fluvioglacial origin were also seen. In all cases these lenses of transported material are at or near the top of the soil profile, indicating that the soil itself is preglacial. Since this unconsolidated material was not removed, the glaciation must have been relatively light.

The problem of glaciation in Gaspé has been considered by many authors. In particular, Dresser and Denis (pp. 498-504, and fig. 38, p. 508. Also pp. 518-520, and References, pp. 525-527), Coleman, and

Flint et al. have written extensively on the subject. The most recent discussion is by McGerrigle (1952). It contains a review of the previous literature, an extensive bibliography, and some stimulating ideas on the subject. McGerrigle arrived at the conclusion that there were at least five stages of glaciation in the Gaspé Peninsula. These were (p. 49)

1) Cirque or valley glaciation
2) Local ice cap
3) Laurentide ("continental") ice sheet
4) Local ice cap
5) Cirque or valley

McGerrigle's map is reproduced as figure 2 to which the location of the Candego Mine has been added. It will be seen that the area described in the present paper was covered by his local ice cap of stage 4, which left the evidence of northward-moving ice.

GEOLOGY

GEOLOGIC SETTING

The Candego deposits occur in sedimentary rocks classified by Jones (1933a, p. 21) on fossil evidence as Lower (?) Ordovician. There is a possibility that some of the rocks south and east of Marsoui may be as old as Cambrian. The series as a whole includes limestones, shales, and sandstones, mildly metamorphosed in places. It forms a strip about 15 miles wide along the north coast of the Gaspé Peninsula.

Three miles south of the Mine is the north contact of an intrusive mass of igneous rocks which underlie the highest mountains in the region, the Tabletop group. The intrusive mass is about ten miles long, in a north-south direction, by 4 miles wide. The rocks range from diorite porphyry to granite. They are generally classified as Middle Devonian in age (Jones, 1933b, p. 45). Another group of intrusive rocks outcrops at Mt. Albert, about 6 miles west of the Tabletop intrusive. These rocks are amphibolite and serpentinized peridotite. They are thought to have been intruded at the close of the Ordovician (Jones, 1933b, p. 47).

The only rock in the mine area which is younger than the Lower Ordovician is felsite or porphyritic aplite, which occurs as a dyke or possibly two dykes cutting the sedimentary rocks.

According to Jones (1933a p. 30) the major structure of the Ordovician rocks is "of the nature of an anticlinorium," whose axis passes about $1\frac{1}{2}$ miles south of the mine, with an east-west strike. The north limb of this fold, including the region of the mine, is a complex of simpler folds, some of which are of considerable dimensions. Jones observed some faults, but was unable to estimate their displacements.

The strike of bedding lies between N.65°E. and E. over a large area, except where the beds swing around the noses of plunging folds. Jones (1933a, p. 31) describes these folds as plunging gently toward the east in the eastern section of the Marsoui map area, and plunging gently west in the western section of the area. He suggests that this may result from doming of the region as a result of "upheaval along a north-south belt continuous with the similarly trending belt of intrusive rocks forming the Tabletop mountains, and this upheaval may have taken place at the time of the intrusion of the Tabletop mass". The aspect of this area would thus suggest a culmination (Billings, p. 49).

GEOLOGY OF THE CANDEGO MINE

General statement.

The Candego ore occurs as narrow high grade shoots following steeply-dipping strike-slip faults cutting folded Ordovician slates and sandstones. The faults and veins occur in a strongly contorted zone in these sediments.

The ore is composed of pyrite, sphalerite, and galena, with minor amounts of chalcopyrite, pyrrhotite, tetrahedrite, bournonite, arsenopyrite, and gold. The gangue consists of quartz and carbonates.

Sedimentary rocks.

Slates are far more abundant than any of the other rock types in the mine. They are black or dark gray, and moderately hard. Their cleavage is generally difficult to detect in underground exposures, although it can be seen in weathered surfaces and diamond drill cores.

The microscope shows that most of the slate contains quartz, sericite, graphite (?), and carbonate. Clay minerals may be present in some sections. Pyrite cubes are abundant in certain beds (figs. 5 and 6) and rare in others.

A relatively rare type is illustrated in figures 5 and 6, which are photographs of thin sections made from diamond drill core from the western part of the Mine. The two thin sections together represent a cross-section of the drill core, and are perpendicular to the bedding. Parts of seven different beds are represented. Their descriptions follow. The beds are numbered from the bottom of figure 6 to the top of figure 5.

No. 1. This bed is composed mostly of very fine clay minerals or sericite, with abundant fine pyrite, a little brown iron oxide and fine opaque material, probably carbonaceous. A faint internal banding is visible, parallel to the bedding. This is slightly offset along cleavages. Cleavage is due to slight concentrations of the fine opaque material. The trace of the cleavage makes an angle of about 45° with the bedding. No. 2 is 2mm thick. It consists mostly of very fine grains of a mineral or minerals with a micaceous habit, probably sericite. A few small quartz grains and a little iron oxide and pyrite are present. As oriented in the figure, the bottom 1/3 of the bed is much darker in colour than the remainder. This is due to an abundance of black, opaque carbonaceous material in this part of the bed. This material is concentrated in zones which are thicker near the bottom of the bed. They are at an angle of about 10° to the main bedding direction. Some of the bands are slightly curved in the vicinity of pyrite grains.

Bed number 3. This bed is 0.5 mm thick, and is similar in composition to no. 1. However, it contains much less pyrite and is more strongly cleaved than no. 1. This cleavage is visible in figure 6. Its trace is at 45° to the trace of the bedding. There has been a small amount of slip on the cleavage, in the same sense as that observed in bed 1.

No. 4 is 8 mm thick. Except for its thickness, it is very similar to bed no. 2. The bands of dark material are at about 5° to the bedding, and are slightly irregular in trend. Large pyrite grains are present in the top 2.5 mm of this bed.

No. 5 is 3.5 mm thick. It is dark coloured because of the presence of abundant carbonaceous material. The rest of the rock is carbonate, quartz and a small amount

of brown iron oxide. A few flakes, large enough to be identified as muscovite, are present. This bed is a carbonaceous and arenaceous limestone. It has no secondary cleavage, but displays a faint compositional banding.
Bed no. 6 (fig. 5) is 3.3 mm thick. It is somewhat similar to beds 2 and 4, but contains abundant coarse pyrite in its lower half, whereas the pyrite in beds 2 and 4 was concentrated in the upper portions. Some of the pyrite grains are bordered by clear areas of fine chert. Banding is pronounced, slightly irregular, and almost parallel to bedding.
Bed no. 7 occupies the remainder of the section. It is a silty slate containing quartz, fine micas (or clay minerals ?), and a relatively small amount of opaque carbonaceous material. Faint regular bedding is apparent in the lower part of the bed. The cleavage in this bed is very evident. It is due to concentrations of the carbonaceous material, some of which is recognizeably micaceous (probably graphite). The beds are not offset along this cleavage, but some of the black lines enter a short distance into the adjacent bed. A similar feature is illustrated in figure 7.

The mode of origin of the banding in beds 2, 4 and 6 is problematical. If it is due to original compositional banding, then the attitude is due to cross-bedding.

If it is a secondary feature, as it appears to be, it probably was formed by segregation or introduction of carbonaceous matter along shear planes complementary to the cleavage in the other beds.

Another unusual type is a spotted slate which occurs in large thicknesses in a few places. It is illustrated in figure 8. The structure is that of the normal slate, except for the occurrence of small (up to 3 mm, average 1 mm diameter) spots which appear gray or brown to black on the surface of diamond drill core. The mineral composition of these rocks is that of the typical slate, about 20% quartz and the remainder a fine grained aggregate of carbonaceous matter, clay-minerals and/or sericitic muscovite, and carbonate. The spots appear to consist primarily of very fine-grained carbonate, in parallel optical orientation within any one spot. The material in the spots seems similar to the rest of the rock except for the fact that the space around and between the larger quartz and sericite grains is occupied by microcrystalline carbonate. The rock cleavage is slightly disturbed by the presence of these spots, and the rock tends to break around them, rather than through them. They are thought to represent the earliest stages of metamorphism. (Harker, pp. 15, 48)

Harker does not mention carbonates specifically, but ascribes the spotted texture to the early stages of thermal metomorphism.

Very little true limestone has been recognized in the immediate vicinity of the mine. However, many of the slate and impure quartzite beds are more or less calcareous.

Thin beds of quartzite and graywacke are abundant, especially in the western section of the mine workings. Most of the beds are between one and three inches thick, but beds as thick as five feet have been seen. The thicker beds contain shaly partings.

These arenaceous rocks are gray, hard, and brittle. They consist of quartz with more or less carbonate, sericite, argillaceous material, and secondary silica. Most of the sand grains are less than $\frac{1}{2}$ mm in diameter. However, a few thin beds of fine greywacke conglomerate are present, containing rock fragments (including chert, altered fine grained igneous rocks and altered feldspar-muscovite fragments) up to $\frac{1}{4}$ inch in diameter. Figure 7 shows the bedding-cleavage relations in this type of material. One rock thin section of an individual quartzite bed displays a grain-size gradation which may indicate the original top direction. Although not megascopically visible, this feature may be of use in deciphering the structure and stratigraphy of the wall rocks.

A peculiar type of spotted material is present in several areas. It is believed to be due to the deformation of inter-bedded unconsolidated sands and muds. Fig. 9 illustrates the appearance of these rocks. Rounded fragments of sandy material are enclosed in a matrix of slate. The contacts between the fragments and the matrix are very sharp in some places and gradational in others. In the rock illustrated (fig. 9) the matrix is highly calcareous. All the fragments observed are of greywacke or sandstone composition, usually with some carbonate. They are up to several inches in diameter. In many places they appear lenticular and flattened in the plane of the bedding. Where the fragments are not noticeably elongated or flattened, the cleavage may either deviate from its general attitude to flow around them, or may cut partly through them, but in places where the fragments are flattened in the bedding direction, the cleavage flows around them, and the rock does not easily break through the fragments. For this reason this type of material is very difficult to recognize underground. However, it can easily be seen in diamond drill core.

Porphyritic aplite.

The dyke exposed in no. 6 adit is the only igneous rock in the Mine workings. A similar rock, probably the same dyke, was cut by a drill hole near no. 5 adit. The dyke is about one foot wide, and consists of two outer, chilled zones, each about one inch wide, and an inner zone. Both are porphyritic.

The rock is primarily glassy and cryptocrystalline material, the glassy type predominating in the chilled border. Phenocrysts are small. They appear to have been feldspars which have been completely altered to a fine dusty aggregate. Phenocrysts in the centre zone are larger than those in the border zone.

The relationship of this dyke to the fault in no. 6 adit is an interesting one. The adit was driven on a fault which strikes N.45°E. and dips about 40° to the southeast. The fault has been slightly mineralized with white quartz, pyrite, and a very small amount of sphalerite and galena. On approaching the dyke from the east the character of the vein material changes, and at a distance of 25 feet from the dyke the quartz leaves the fault and passes as veins into the walls, where it rapidly dies out. The fault itself can be traced a short distance further, but it seems to disappear within 5 feet of the dyke, where the slate wall rocks become harder and more massive, probably because of thermal metamorphism. West of the dyke exploration is insufficient to show if the fault continues. The dyke itself appears to have been offset at a break almost in line with the projection of the fault, but closer examination shows that the chilled border of the dyke rock extends completely around the "offset" ends. In other words, the dyke was probably introduced along a fracture which had been offset by the fault. The apparent disappearance of the fault on approaching the dyke would then be due to the fact that the dyke metamorphosed its walls sufficiently to heal the fault break. The quartz was introduced later, as is shown by the presence of thin veinlets of quartz, carbonate, and pyrite in the dyke

Ore bodies.

The ore bodies are vein-fillings which occur as shoots along steeply-dipping faults cutting the folded sedimentary rocks. Detailed discussions of the faulting and of the minerology of the ore follow, in later sections. At this point the location, attitude, and size of the ore bodies will be described.

LOCATION:

By far the largest portion of the Mine's past production has come from ore bodies above the no. 3 adit. The adit, driven as a drift along the vein, entered ore a few hundred feet west of the portal and intersected a series of ore shoots which have since been mined out at this level. Further exploration to the west disclosed several parallel or branch veins in 302 drift (figs. 3 and 4). At least two of these veins contain ore bodies, starting 40 feet above the level, which are now being stoped.

Higher up the hill, in nos. 1 and 2 adits which are in the same vertical zone of fractures as no. 3, stopes were driven on high grade ore shoots. The ore encountered in no. 3 adit extends below that level at least at the east end of the mineralized section. This is mined in a stope driven up from no. 4 adit.

One ore body was encountered in no. 5 adit, 800 feet south of this zone. The old open pit beside the river (fig. 3) was also in ore.

ATTITUDES:

All these shoots are steeply dipping. The dips range from about 85° south to 70° north. The strikes of the ore shoots are parallel to the strikes of the veins in which they occur, which range from about N.65° to 75°W. The plunges of the bottoms of the ore shoots in the no. 3 adit are all at low angles. In the old stopes near the portal of no. 3 adit this plunge is about 20° toward the N.70°W., while in the 301 vein, farther west, the bottoms of the shoots appear to be horizontal.

SIZES:

The largest single ore shoot so far encountered is in the 301 vein above the 301 drift. As of January 1, 1954, the stope in this ore body had attained an east-west length of 200 feet, and a vertical height of 90 feet in places, with the limits of the ore body not yet reached. A representative section of the breast of the stope contained ore in widths between 6 inches and 4 feet, with an average width of one foot. The average grade over this width, as determined by channel sampling at 5 foot intervals, was 39% Pb and 12% Zn.

WALL ROCK ALTERATION:

In general, there appears to have been very little alteration of the wall rocks at the time of ore formation. There is, however, a small amount of secondary silica along the borders of some quartz veinlets where these cut calcareous beds, and in certain areas in the Mine a moderate amount of graphite is present. Although graphite is present in considerable amounts in the vicinity of certain veins, it is not known whether the graphite is genetically related to the veins.

Small amounts of epigenetic pyrite, locally associated with galena and sphalerite formed by replacement of the sedimentary rocks, are present in a few places in the mine. In some places this material appears to preserve the original bedding (fig. 10), while in other places it is massive and structureless. Although the ore bodies are in veins, apparently emplaced mostly by fracture-filling, the presence of these small amounts of replacement sulphides shows that replacement of the wall rocks at least locally was possible under the conditions of formation of the ore.

STRUCTURAL GEOLOGY

The mine is located in strongly contorted sedimentary rocks. The deposits occur as shoots in steeply dipping longitudinal faults, on which the last movement has been almost wholly strike-slip. The faults form a sheeted zone up to 200 feet wide, and possibly over 800 feet wide. An exceptional structure is the 402 vein, a thick, low-angle vein with evidence of many repeated movements, which is only sparsely mineralized in the section so far explored, but which appears to have played an important part in the geological history of the deposit.

There have been several movements on these faults. Evidence of pre-, intra-, and perhaps of post-mineral faulting is present.

Complete analysis of the larger local structure is impossible at this time, but detailed structural information is now available from several sections of the mine workings, and the structure of the small area covered by these workings can be discussed.

FOLDS:

The main workings have been driven in a strongly contorted zone, striking about N.70°W., which is bounded on the north by less intensely folded beds, whose general strike is east-west. They have a moderate northerly to vertical dip.

The contorted zone consists of many small folds and wrinkles, most of which have almost horizontal axial planes, and axial lines striking east-west. Where the folds plunge, the angles range from 30°E to 30°W., the commonest plunges being between 0 to 10°W.

These plunges are roughly parallel to the bottoms of ore shoots in the adjacent veins. The reason for this is not known. In the 302 stope area, at the west end of no. 3 adit, the ore control may be a chemical-stratigraphic one. Where the ore shoot occurs, the vein is in calcareous slate, and the ore ends near the bottom of this horizon. Because the plane of the vein is an essentially vertical longitudinal section of the flat-lying folds in this area, the bottom of the ore is horizontal and parallel to the fold axial lines. In other cases, such as the 301 stopes farther east in the 3 adit, the nearest observed fold plunges west at 25° and is parallel to the bottom of the ore shoot.

There is no obvious lithologic control here.

Analysis of the fault pattern in the mine suggests that the direction of the faults is partially controlled by bedding. It is therefore probable that folds may have localized changes in the attitudes of the veins. If the ore shoots are confined to sections of the veins which have a particularly favourable attitude, then they might be expected to plunge parallel to the trace of veins on bedding, and in most cases, parallel to the folds. Detailed surveying of the stopes is planned, in order to test this possibility.

FAULTS:

There are three main sets of faults at Candego. Except for certain of the cross-faults, all appear to be pre-ore structures, but there have been both pre- and intra-mineral movements on most of them. The main faults are:

1) The ore-bearing vein-faults, striking about N.70°W., with dips from steep southerly to moderate northerly.

2) A less important group of cross-faults, striking in the northeast quadrant and dipping at moderate angles toward the northwest.

3) The 402 vein-fault, which strikes between S.70°W. and due north, and dips at very low angles toward the south and west.

Representatives of the first two types are shown on the map (fig. 4) in the pocket.

Set no. I

From the economic point of view the N.70°W. faults are the most important, because they have contained all the ore mined in the last several years. In strike, they are parallel to the fold axial lines in the zone of strong contortion of the country rock, and their dips range from about 45° north to about 60° south. The productive sections are all vertical or very steeply inclined, generally toward the north. The faults meet and branch in both strike and dip, but are roughly parallel and torm a sheeted zone of considerable width.

At least one set of strongly marked grooves is commonly present on these faults, and in many cases two or more surfaces within the vein and on its borders show similar evidence of movement. These pronounced grooves invariably have rather flat plunges, generally to the east at angles as steep as thirty degrees. Westerly plunging grooves are not steeper than 10°, and are rare. The most common plunge of the grooves is between 0 and 10° east. Early quartz and pyrite in these faults have been grooved by the movement. In addition to this post-pyrite movement, there is evidence, both microscopic and megascopic, of post-galena movement as well. The megascopic evidence is found in places where a surface of movement, showing well-developed grooves, crosses a vein from one wall to the other. Some of these 'crossovers' clearly cut the massive galena of the ore, and cleavages of the galena are sometimes parallel to the fault surface. This feature will be discussed further in the description devoted to galena.

Thin seams of fault gouge are present in many places along one or both walls of the veins.

Set no. 2

This set of faults consists of those which strike between N. 35° E. and N. 60° E. and dip toward the northwest at various angles between 35° and 55°. They are exposed in both the no. 3 and no. 4 adits, but only one has been drifted on, and this one is not a typical representative. The typical members of this set cross the mineralized vein-faults of the N.70°W. set, and offset them from a few inches to a few feet, the offsets being always in the same sense, west side south. On the other hand, the cross faults are themselves mineralized with quartz and pyrite in part.

Movement on the cross-faults has probably been of small magnitude. This is indicated by the small offsets and by the nature of the faults themselves. They consist of a $\frac{1}{4}$ inch seam of gouge in most places. In one of the faults a seam of breccia, of open structure, reaches a width of 6 inches.

The cross-fault on which some drifting was done is at the west end of the no. 3 adit workings. (fig. 4) It is exceptional in two ways - it is sparsely mineralized with quartz, pyrite, galena, and sphalerite, and it is itself cut and offset at its intersection with the 301 vein, a member of the N.70°W. set of faults. The separation is about 6 inches, south side west. Both of these observations indicate that this cross-fault is older than the ore-bearing faults, the ore, and the other cross-faults.

The cross-fault under consideration shows grooves indicating three different directions of movement.

The strike of the fault at the point where the grooves are best observed is N.35°E., and the dip is 35° northwest. The grooves are as follows: one set, the most regular, plunges at 32° westerly. The deepest grooves plunge at 30° northerly. A very faint set of horizontal grooves is also present.

402 vein-fault

This structure was discovered by diamond drilling during the summer of 1953. It is from two inches to six feet wide, about three feet being a typical figure. The vein is banded and crustified in part, with grooved surfaces forming the partings between bands. There are two ages of quartz present in this vein. The bulk of the vein is white quartz of the later generation.

The attitude of the vein is variable. Because of the very low dip, slight flexures may change the strike markedly. In the section of the vein explored up to January, 1954, the strike was between S.70°W. and due north, and the dip between 25°S and 7°W. The northerly strike and flatter dips are in the western part of the workings on this vein.

As many as nine grooved surfaces are present. All the observed grooves on surfaces within the vein strike close to N.70°W. Since the attitude of the vein varies, the plunge of these grooves is also variable, with a variation from 10°E. to 10°W. Faint sets of grooves were seen in two places on the slate hanging wall of the vein. One of these plunges at 10° toward the southwest. The other is horizontal, N.75°E. Either or both of these faint sets of grooves may be due to blasting during mining. Exploration on this vein, to January, 1954, consists of one drift, 350 feet long, a 50-foot flat raise, and a few short drill holes. This work has discovered one mineable section which measured about 50 feet along the strike direction, by 15 to 20 feet wide. This occured at the top (flattest) portion of a slight roll in the vein.

Several intersections between structures of the N.70°W. set and the 402 vein have been observed. On approaching downward toward the 402, the steep-dipping vein-faults suddenly flatten toward the north and foll into the flat vein in some places cutting through one or more bands of quartz and uniting with a surface of movement within the vein.

In other words, the steep vein-faults appear to branch from the flat one. Small patches of ore minerals are present in the flat 402 vein near most of these intersections.

So far no work, aside from a few short drill holes, has been done on the footwall side of the 402 vein. Indications so far obtained are that the individual steep vein-faults do not penetrate below the 402. Other steeply dipping veins, with the same general attitude, appear to branch downward from the 402, but these are not as numerous as the veins above that level, in the section so far explored.

The importance of the 402 vein-fault may be four-fold. It may itself be sufficiently metallized in places to be mineable, in which case it would be the first flat-lying ore body found during the writer's acquaintance with the property. Secondly, it has a dip of low angle, and is walled by seams of fault gouge, which suggests that structural traps may be present with the possibility that ore may have been emplaced under the vein. Thirdly, the 402 fault appears to have exercised a certain control over the formation of the steeply-dipping N.70°W. set of ore-bearing faults, since these appear to branch from it, and do not pass through it as individuals. Fourthly, the 402 vein-fault may have served as a channel of entry for the mineralizing solutions rising toward the ore shoots above.

MINOR STRUCTURES:

A great many fractures and sets of fractures are present. Figure 4, the map of fractures, shows only the more persistant ones. Some of them contain metallic or gangue minerals in various combinations. Only the most widespread sets are mentioned here. There are the rock cleavages, the more pronounced joint sets, and the many small quartz - or metal-bearing fractures which may be of economic importance in future and are of interest now because of their implications regarding the larger structure of the ore zone.

Cleavage.

Some mention has been made of rock cleavage under the heading of sedimentary rocks. As was mentioned in that description, the cleavage is difficult to detect underground.

In most parts of the Mine, two sets of cleavage are present. One of these is sub-parallel to bedding, even around the noses of small folds. In some places minor structures, such as small quartz veinlets, are offset along these cleavages and at bedding planes, indicating that the cleavage served as a surface of slip between beds during folding. A second set of cleavages, not as well developed, has a very variable attitude which appears to depend, in some way not as yet understood, on the lithology of the bed in which it occurs. Figures 5, 6, and 7 illustrate these features. A third set, generally visible in surface exposures but rarely in the underground workings, strikes about east-west, and is steep to vertical. This is approximately parallel to the ore-bearing faults and probably indicates that this cleavage direction is related to the same forces as those which caused those faults.

Joints.

One direction of jointing is worthy of special mention. This is in the northwest quadrant, generally N.30°W., and these joints have vertical to steep dips. They are especially prominent in the 301 drift, just west of the end of the vein, where the joints run into the north wall of the drift. (fig. 4) They are also strongly developed in part of the 302 drift. The attitude is about the same as that of certain small mineralized fractures, which will be mentioned below.

Minor Veins

A great many of these are present. There are concentrations of veinlets of quartz, carbonates, pyrite, calcopyrite, galena, and sphalerite in several areas in the mine. Noteable among these are the zone north of the 302 drift (fig. 4), where exploration is still in progress (January, 1954) and the veinlets in the walls of the old 301 stope area. Some of these structures are parallel to the joint set described above, and some are parallel to the N.70°W. vein-faults.

STRUCTURAL ANALYSIS:

Information so far available on the structure and stratigraphy of the wall rocks is not sufficient to allow detailed discussion. However, it appears that the fold structure in the immediate mine area is much more complex than the previous description (Jones, 1933a) would indicate.

Parts of the fracture pattern have been mapped in sufficient detail to warrant some tentative conclusions.

Much of the above descriptive information is summarized on figure 4, the enclosed map of a representative section of the Mine, which shows the principal fractures and patterns in part of no. 3 adit. It is thought that three sets of fractures, the N.70°W. set, the cross-faults, and the main joints, may have been formed penecontemporaneously by one set of forces which can be resolved into a compression acting in a line striking about N.30°W. and plunging slightly to the south-east. The low-angle 402 vein-fault may also be related to this compression.

Several lines of argument indicate this general direction for the maximum compressive stress. Firstly, the general trend of the Appalachian region as a whole seems to require a westward and northward thrusting force. Secondly, the direction of movement on the faults, as indicated by the grooves on the N.70°W. set and the horizontal offsets at vein intersections (south side west on the N.70°W. set and west side south on the cross-fault could both be caused by a force acting in this general direction. It should be pointed out here that only one of the cross-faults shows well-marked grooves, and that of the three directions of grooving here, the two strongest sets plunge almost in the dip line. This would indicate dip-slip movement, rather than the strike-slip which predominated at least during the last movement on the main vein-faults. However, the cross-fault which shows these grooves also contains a very faint set of horizontal grooves, and is the one cross-fault which appears to be older than the movement on the N.70°W. vein which crosses it. Therefore, it is possible that the main movement on this fault was strike-slip. When this fault was cut and offset by the 301 vein-fault, the south side of the cross-fault was moved to the west, which means that it must have been subjected to an east-west directed compression, at least locally. The dip-slip movement may have occured at this time, with the result that this younger, local movement almost obliterated the traces of the earlier movement.

If all the faults with the general attitude of the cross-faults are assumed to have been caused by the same forces, then the fact that one is older than, and the others younger than the ore-bearing veins (and the lead and zinc mineralization in the veins) suggests that all of these faults, both ore-bearing and cross-faults, must have been formed during a relatively short period of time by the same forces. If these two sets of faults are shear fractures, then the prominent joint set and the mineralized fractures parallel to it would represent tension fractures. If all three sets were caused by the same forces, their geometry should be such that the tension fracture direction contains the line of intersection of the two shear directions. The attitudes of all the fractures are very variable, so that a rigid geometric solution is impossible without unwarranted assumptions of average attitudes. However, it appears possible that this condition is fulfilled.

An objection to the above analysis relates to the geometric relations of the fractures to the supposed direction of compression, which lies in the obtuse angle between the shear fractures, rather than in the acute angle as is the case with homogeneous, elastic test pieces in laboratory experiments. However, the Candego rocks are not homogeneous or isotropic with respect to strength, since they are folded and bedded sedimentary rocks. The fact that the main direction of faulting is approximately parallel in strike to the general strike of the local bedding suggests that the direction of bedding may have controlled the direction of first failure. This would partly account for the obtuse angle facing the supposed direction of maximum compression.

Neither are these rocks completely elastic. Failure by flow is likely to have occurred before fracture. In addition, the movement continued after fracture, as is shown by the fact that there are measurable displacements, and the fractures may have been rotated to a certain extent. The effect of rotation of the faults is probably small, because the amount of movement on the faults appears to have been small, and the forces probably acted for a short time only, after failure by fracture occurred. It is believed that the sum of these three effects is sufficient to account for the observed relations.

A more serious objection is based on the relative ages of the various features. The deduction as to the probable direction of the maximum compressive stress is based on the assumption of penecontemporaneity of the N.70°W. and cross-faults, which is based on the assumption that all the cross-faults were formed as a result of the same forces, since they have similar attitudes. One of the cross-faults is older, and the others are younger, than the last movement on the ore-bearing veins they meet. In addition, one of them must be older than the ore, since it contains small amounts of galena and sphalerite, while the others are probably younger than the ore, since they have cut the ore-bearing vein and formed small amounts of drag ore at the intersections. These cross-faults contain only small amounts of white (late) quartz and pyrite. This suggests a considerable difference in age, unless the ore was introduced while the movements were still in progress. In the discussion of the mineralogy of the ore bodies, it will be shown that movement occurred on the vein-faults at at least two periods during the deposition of the ore. It is therefore possible, but by no means certain, that the ore was introduced penecontemporaneously with the faulting. If this is so, the ore and faults are probably post Lower Devonian in age, as is the very similar ore at the Federal Metals mine, twenty miles away.

With regard to the low-angle fault on which the 402 vein is locallized, only speculations are possible at this time. The direction of the last movement was essentially strike-slip. Possibly all the movements had this direction, since many grooved surfaces are present within and on the borders of the vein, and only two places show anomalous directions of grooving, both on the soft slate of the hanging wall where they may have been caused by disturbances in blasting. However, the sense of the movements is unknown. If they were due to the same forces as those which caused the other faults, the movement should have been south side (hanging wall) west. A vein-fault similar to this one was described by Jones (1933a, p. 36). It occurs in the bed of the Marsoui River, but has never been traced to the present mine workings. It may be on strike with the 402 vein, although the variable attitude of the 402 vein makes projection unsafe. Jones considered the fault to be of the normal type ("a fault with a downthrow, apparently of only a few feet displacement, on the hanging-wall side.") The general attitude of the fault suggests a thrust-fault, especially in view of the fact that its strike is approximately parallel to the front of the Appalachian ranges in this area, but the grooves in the slip-surfaces indicate strike-slip movement.

MINERALOGY OF THE VEINS

The metal-bearing minerals are pyrite, arsenopyrite, gold, sphalerite, galena, chalcopyrite, tetrahedrite, pyrrhotite, bournonite, and anglesite. Gangue consists of quartz, carbonates, and slaty inclusions of wall rocks. Between the ore-shoots, the veins have a maximum width of about one foot, and consist of quartz with smaller amounts of carbonates and pyrite and scattered patches of the other sulphides.

TABLE 2 PARAGENESIS

Quartz	—	M	—		—
Carbonates	—	O	—		—
Pyrite	—	V	—		—
Arsenopyrite	—	E			—
Gold		M	—	M	
Sphalerite	—	E		O	
Galena		N	—	V	
Chalcopyrite	—	T		E	—
Tetrahedrite				M	—
Bournonite				E	—
Pyrrhotite				N	—
Anglesite				T	—

PARAGENESIS:

A brief summary, in diagram form, of the order of introduction of the minerals is presented here (Table 2) in order to assist in clarifying the mineral relations mentioned later, in the descriptions of the several minerals. Many of the points at which deposition began and ended are conjectural. So also is the presence of the generation of quartz shown between the two periods of movement.

QUARTZ

There appear to be two types and ages of vein quartz present. One is transparent and colourless or slightly gray in colour. It occurs in euhedral crystals lining openings along the fault planes, and in masses of anhedral grains. It is euhedral against carbonates, pyrite, and later sulphides, and appears to be the first mineral of the paragenetic sequence. The second type of quartz is white or milky and is common as masses of anhedral grains. It veins and replaces some carbonate, pyrite (fig. 11), and sphalerite (fig. 12). In certain places the two types of quartz occur together. In the

402 vein, for example, bands of gray transparent quartz intergrown with pyrite have been fractured and cemented by white quartz.

CARBONATES

Both calcite and siderite have been identified (Nickle, personal communication). The siderite is pale brown to pink in colour, and the calcite is almost white. The indices of refraction indicate that both probably contain small amounts of magnesium. The carbonates occur separately or intergrown. Sometimes calcite apparently veins siderite. Carbonate veinlets were seen to cut quartz, pyrite (fig. 13) and sphalerite (fig. 13), and in one polished section a carbonate is present in the form of replacement veinlets in galena. However, most of the carbonate appears to be pre-ore in age. It is veined and replaced by all the ore minerals (see, for example, fig. 14) and by the late white quartz.

PYRITE

This mineral occurs in grains of all sizes from one-inch cubes down to the limit of microscopic resolution. Tarnished striated crystals project into vug-like openings, and appear to have been formed by the partial filling of open spaces, while finer grained pyrite has been formed by partial or complete replacement of the wall rocks. (fig. 15).

An unusual feature of much of the pyrite is its anisotropism, which is distinct and easily detected in several of the polished sections and faint in many of them. The more strongly anisotropic pyrite shows pink to bluish-green polarization colours, while the sections with weaker anisotropism give tones of gray. There is a tendency for large grains to be more strongly anisotropic than small ones, and there is also a significant difference in the strength of the anisotropism of pyrite in polished sections made at different times. The sections were made by the Mines Branch, and received by the author, in two lots. In one lot of fourteen sections, all contain pyrite which is weakly to moderately anisotropic. In the other lot, of thirty-eight sections, one contains moderately anisotropic pyrite, nine contain weakly anisotropic pyrite, and in the others the pyrite is sensibly isotropic. It is therefore possible that the conditions of polishing or mounting may be responsible for the difference in the optical properties, as the samples from which both lots were made came from all parts of the mine.

Smith (1940, p.91, and 1942, p. 12) and Schneiderhohn (reported in Schneiderhohn and Ramdohr, p. 159) have described anisotropic pyrites. Smith (1942) studied the chemical, physical and optical properties of pyrite from many sources. About half of his samples were anisotropic, and almost all were slightly deficient in sulphur. He believed the anisotropism to be due to the ordered substitution of Fe in certain of the S positions of the crystal lattice. On heating, the anisotropism disappeared, presumably because the arrangement of the excess Fe became disordered. Smith found (1942, p. 12) that small fragments lost their anisotropism more quickly on heating than did larger crystals. His experiments led him to the tentative conclusions that the heating involved in curing the bakelite of polished section mounts may destroy the anisotropism, and that anisotropic pyrites are probably formed only at relatively low temperatures (below 135°C.) At the Mines Branch, where the Candego sections were made, the temperature at the beginning of curing the bakelite is 120°C. (P. O'Donovan, personal communication), but the upper limit of temperature attained during the process is not closely controlled.

It is therefore quite possible that different lots of polished sections may be heated to different temperatures. If these contained anisotropic pyrite before sectioning, the resulting conditions would be similar to those observed in the present examination.

Schneiderhohn's specimens contained arsenic, but Smith (1942, p. 12) showed that this is not necessarily always the case. Tests of Candego pyrite have been made. Chemical tests for nickel (Short, p.92) and arsenic (Short, pp.209-210) gave negative results. A spectrographic analysis (Graham, p. 5) of a sample described as "pyrite, etc." contained strong traces of lead, silicon, and copper, traces of antimony, magnesium, and manganese, and faint traces of arsenic, aluminum, silver, and zinc. Arsenic and sulphur are said to be insensitive under the conditions of analysis.

Pyrite appears to have been deposited throughout most of the period of mineralization at Candego. Pyrite grains have been veined or partially replaced by quartz, carbonate, and all the metal-bearing minerals (figs. 11, 13, 16, 17, 18, 19, 20, 21, 22, 23) and pyrite in turn veined or replaced quartz, carbonate, sphalerite, galena, chalcopyrite blebs in sphalerite, and probably tetrahedrite (figs. 13, 24, 25).

Pyrite plays a part in several interesting types of textures. Several of these are illustrated in the figures listed above, of pyrite veined or replaced by other minerals. Resemblances can be seen to types described (Schwartz, pp. 586, 587, 589,) as brecciated, caries, core or atoll, ice-cake, and veined textures, and (by Bastin, 1950, p. 90A, Pl. II) as atoll texture. In several places pyrite has been crushed or fractured and the fractures contain carbonates, quartz, and galena. This is visible both microscopically and megascopically.

ARSENOPYRITE

A small amount of this mineral is present. It occurs in small crystals, most of which are euhedral. It is associated with the quartz and pyrite introduced early in the paragenetic sequence.

Arsenopyrite rims pyrite and projects into vug-like openings (figs. 26, 27), some of which are filled with quartz. Some grains appear to be suspended in quartz. In another place, a veinlet of tetrahedrite, cutting pyrite, encloses crystals of arsenopyrite (fig. 18).

Veinlets of arsenopyrite traverse pyrite grains. A few small rounded and apparently corroded grains of arsenopyrite are enclosed in sphalerite and galena, and others appear to have been partially replaced by pyrrhotite and tetrahedrite. Later introduction is suggested by the occurrence of a few grains enclosed in carbonate which is younger than a pyrite veinlet in sphalerite (fig. 13). To summarize, the bulk of the arsenopyrite was introduced early in the mineralization period, but deposition may have persisted until tetrahedrite was deposited.

GOLD.

Gold values in Candego ore are small. Exceptional samples, rich in fractured, fine-grained pyrite, contain as much as 0.35 ounces of gold per ton, but the run-of-mine ore averages only about 0.02 ounces. Only a few gold particles were seen in polished section. The largest (fig. 28) is about 40 microns long. All are enclosed in pyrite, and most appear to be along cracks or fractures in the pyrite. In the mill at the Candego Mine, no special effort is made to recover gold, and the ore is not ground finely enough to release particles of this size. In spite of this, most of the gold is recovered with the lead-silver concentrate, and the proportional concentration of gold is about the same as that of lead. This may be accounted for by the presence of a second gold-bearing mineral, but none has been found. It seems more likely that the fractured nature of the gold-bearing pyrite might allow it to be ground preferrentially, thus releasing the gold in spite of the relative coarseness of grind of the bulk of the ore.

The time of introduction of the gold is not known with certainty. It all appears to be associated with fractured early pyrite, and some with sphalerite (fig. 28). Probably it was introduced after the early pyrite had been fractured by renewed fault movement, but before the bulk of the sulphides was introduced.

SPHALERITE

Sphalerite forms a large part of the Candego ore bodies, but it is not as important as galena, either in quantity or in value. (In the 1952-53 fiscal year, the ratio of lead-silver to zinc concentrates produced was about 1.38 to 1, and this ratio has probably risen since that time because of selective mining and differences in the ore bodies being mined.) Most of the sphalerite is medium chocolate-brown in color, and coarse grained. A typical sample had the following composition (J.J.Brummer, personal communication. Analysed by the analysts of the Quebec Department of Mines Laboratories. Certificate no. Vg-3647).

S...........	32.34%
Zn..........	65.75%
Mn..........	0.02%
Cd..........	0.19%
Fe..........	2.46% (Total iron as Fe)
Total......	100.76

A semi-quantitative spectrographic analysis (Florian East, analyst. Information from the same source) of the same sample gave the following results:

Over 10%...............	Zn
1 to 10%...............	Fe
0.1 to 1%..............	Ca, Si, Cd
0.01 to 0.1%...........	Al, Cu, Mg, Mn
0.001 to 0.1%..........	Ga, Li, Pb, Ti, V

Another spectrographic analysis of a sample of brown sphalerite has been made by the Mines Branch (Graham). The results include Fe as a strong trace, Cd as a trace, and Si, Mn, Mg, Cu, and Ag as faint traces. This sample was presumably cleaner than that used for the Quebec Department of Mines analysis, as no Ca, Al, or Li are shown.

Both dark and light coloured sphalerites are present in the mine, but the extremes are rare. Pale amber-yellow sphalerite is found in a few veins which trend in a northerly direction, across the general strike of the ore. Qualitative microchemical tests (Short, p.198) indicate a mere trace of iron to none at all. Marmatite of a pure black colour is present in a few localities. It is relatively rich in iron.

Some of the sphalerite contains abundant small blebs of chalcopyrite, which will be discussed in a later section. Sphalerite in some of the polished sections examined can be etched in concentrated nitric acid. Such etching brings out twinning striations and grain boundaries. These features can also be seen megascopically in some hand specimens, in which the reflections from cleavage planes are visible. The lamellar twinning of sphalerite can be taken to be an indication of strain, and probably of movement on the ore-bearing fault after the formation of the sphalerite. A similar feature can be caused by "mild internal stresses such as those incident to the unmixing of solid solutions" (Bastin, 1950, p.74), but the twinning is present in Candego ore even in sections which contain few chalcopyrite blebs in the sphalerite, and in which unmixing has therefore not occurred.

Decrepitation tests have been undertaken by the Mineragraphic and Spectrographic Section of the Division of Mineral Dressing and Process Metallurgy of the Mines Branch, Ottawa, but few results are available at this time, and their significance is not fully understood. The main peaks of decrepitation are at 102, 92 and 86°C. respectively for three samples of light sphalerite, and at 217°C. for one described as dark sphalerite (M. H. Haycock, personal communication). If these temperatures are in any way related to the temperatures at which the mineral formed, they would seem to indicate either a long-continued deposition of sphalerite, during a period of changing temperature, or two generations of sphalerite. The sphalerite in all the polished sections examined is of the chocolate-brown variety which is the type described as "light" in the above tests, and there is no indication of more than one period of deposition.

All the comments below refer to the medium-brown sphalerite. It appears to have been deposited during a relatively short period, contemporaneously with some of the pyrite, but after most of the arsenopyrite. The yellow sphalerite and the black variety are not of economic importance at present, because very little of either has been found. Sphalerite is seen molded on crystal faces of quartz and replacing quartz and carbonates, partially replacing pyrite, (with well developed caries (Bastin et al, p. 602 and fig. 16) texture (fig. 17)), and probably replacing arsenopyrite. The sphalerite has been veined or replaced by all the metallic minerals, with the possible exception of arsenopyrite. Figures 10, 13, 24, 29, 30, 31, show sphalerite which is older than gangue, pyrite, galena, chalcopyrite, tetrahedrite, and bournonite.

An unusual relationship exists between some of the pyrite and sphalerite. Veinlets of pyrite are abundant in sphalerite in certain of the polished sections, but in some the pyrite veinlets are composed of grains which appear to have been rounded and corroded by partial replacement by sphalerite. An extreme case is shown in figure 32, where the pyrite has been reduced to a series of disconnected grains. Such a structure might arise through complete replacement by sphalerite of a preexistant mineral which was veined by pyrite. A second possibility is that the pyrite is younger than the sphalerite, and was deposited in its present form by replacement of the sphalerite. However, it appears indifferent to the crystal structure and grain boundaries of the sphalerite, and the contacts between the two minerals suggests that the pyrite was partly replaced by sphalerite. A third possible explanation relates to the tectonic history of the ore. It will be shown that the ore was subjected to at least one period of fault movement after the sphalerite was deposited. It is possible that this movement may have produced sufficient heat to upset the equilibrium between previously formed sphalerite and the pyrite veinlets in it. Then, for a short period of time, the sphalerite might have dissolved or replaced some of the pyrite. Such an effect could be detected only in situations like those described above, because all other pyrite-sphalerite contacts would show only the features due to replacement of pyrite by sphalerite.

GALENA

Galena is the most abundant mineral in the ore bodies, and also occurs as disseminations in the otherwise barren quartz and carbonates of the veins between shoots. Much of this low-grade material contains coarse crystals of galena with well developed cleavage. In a few places, the mineral occurs as a partial filling in vugs, and good crystal faces have developed. In the main ore bodies, however, much of the galena is relatively fine grained and is arranged in sub-parallel bands which appear to be composed of platy cleavage fragments. These bands are parallel to the walls of the veins, except in the immediate vicinity of cross-faults or places at which the vein-fault crosses from one border of the vein to the other. At such places the galena banding is approximately parallel to the nearest surface of movement. The bands are slightly curved, especially around enclosed lumps of pyrite. The cleavages of some of the galena are curved (fig. 25). All these features suggest that the galena has been subjected to stress in the solid state, and has yielded to this stress. This probably corresponds to renewed movement along the faults. It will be shown later that the chalcopyrite probably has not been subjected to this condition, and that the movement therefore must have occurred before the chalcopyrite was deposited.

Microchemical tests reveal the presence of moderate amounts of silver in the galena. Spectrographic analysis (Graham, p.5) confirms this. Faint traces of antimony, silicon, copper, and iron are also present.

The time of introduction of the galena, in relation to that of the other minerals, is fairly well defined by the microscopic relations. It completed its solidification later than most of the quartz, carbonate (fig. 14), pyrite (fig. 16), sphalerite (fig. 10) and arsenopyrite. In one case a veinlet of galena traverses carbonate which is younger than the sphalerite in the section. Small amounts of pyrite, carbonate, and perhaps of sphalerite, are younger than some of the galena. All of the tetrahedrite and pyrrhotite appear to be younger than galena (fig. 33), and a little anglesite has replaced galena in areas controlled by the galena cleavages (fig. 34).

The galena-pyrite relations are in some places similar to those described for sphalerite and pyrite. Figure 34 shows a disconnected series of grains of pyrite, which give the impression of being a vein (in some cases a network of veins), although the individual pyrite grains appear to have been corroded and partially replaced by the galena. Some of the pyrite grains contain sphalerite inclusions in rounded shapes, whereas no sphalerite occurs in the galena in the vicinity of these forms. Some of the sphalerite inclusions in pyrite contain small chalcopyrite blebs, and other rounded blebs, larger than these, are present in the galena. The explanation of these features is probably among the three possibilities suggested to explain similar forms in sphalerite. There are some significant differences, however, such as the presence of the chalcopyrite blebs, and of sphalerite inclusions in the pyrite. These suggest to the writer that the probable explanation is that galena has completely replaced sphalerite which contained chalcopyrite blebs and veinlets of pyrite.

CHALCOPYRITE

This mineral occurs as blebs in sphalerite and in larger masses. Neither type is much twinned. Both are slightly anisotropic in part. It is suggested that the two forms were not introduced at the same time.

The blebs are of all sizes up to about 0.25 mm. and down to the limit of resolution of the microscope used. Their shapes are predominantly rounded and subcircular or spindle-shaped, as seen in polished section, but many areas contain abundant blebs with a definite grometric shape. Subrectangular blebs are common, with length to breadth ratios from 1:1 to 5 or 6:1. Many areas contain triangular blebs. These facts suggest that the chalcopyrite crystal structure determined the shape of these blebs. However, in many places the blebs are oriented with their long axes parallel to sphalerite cleavages. (fig. 30) There also appears to be a relationship between the grain boundaries of the sphalerite and the abundance of chalcopyrite blebs, but the relationship differs in different polished sections. In some a zone of abundant chalcopyrite rims the grain, while in others a similar zone lies a short distance in from, but parallel to, the grain boundary. In some the presence of a pyrite or tetrahedrite veinlet in the sphalerite seems to have inhibited the formation of the blebs, while in other cases they are present only in the vicinity of such veinlets (fig. 31). In one case the blebs are present in all parts of the sphalerite, except adjacent to quartz (fig. 36).

Small areas of chalcopyrite, similar to these blebs but of larger size and without regular angular shapes, are present on some galena-sphalerite contacts and in galena near these contacts. They are probably due to segregation of the chalcopyrite content of sphalerite replaced by galena. They are associated with tetrahedrite and pyrrhotite.

The remainder of the chalcopyrite is in megascopically visible grains and veinlets. It occurs in small quantities in most of the stopes, but has never yet been sufficiently abundant to be worth recovering. It was introduced late in the sequence, and appears to be younger than all of the sphalerite, pyrite, and galena (figs. 37, 23). In a few places it is veined by a soft, non-carbonate gangue mineral (fig. 22). It appears to be partly contemporaneous with tetrahedrite, since it has veined (fig. 21) and been veined by (figs. 23, 29) this mineral. The time relation between chalcopyrite and pyrrhotite has not been established. However, the pyrrhotite is younger than tetrahedrite (see below) and therefore is probably younger than chalcopyrite.

These age relations are different from those of the chalcopyrite which occurs as blebs in sphalerite. Tetrahedrite (fig. 30) and pyrite veinlets have cut, and in some cases selectively replaced, these blebs, and many of them are spacially related to pyrite-sphalerite contacts. This suggests a sharp difference in age between the two.

The writer would suggest that the distribution of chalcopyrite blebs in sphalerite can most easily be accounted for by exsolution from sphalerite with a zoned copper content. The absence of pure copper sulphide suggests that there is sufficient iron in solution in most of the sphalerite to permit formation of chalcopyrite from the small amount of copper in the sphalerite. Selective micro-sampling or special etching methods of the sphalerite might determine whether or not the sphalerite is zoned with respect to copper content. The writer did not attempt to determine this. The apparent relation to some pyrite veinlets in sphalerite may be due to the iron contributed by the pyrite, or perhaps to higher temperature of the solutions which introduced the pyrite. A slight rise in temperature in a very limited area might permit increased mobility of the copper and iron in solution in the sphalerite, permitting them to form the chalcopyrite blebs which occur near some of the pyrite veinlets.

Because the twinning in chalcopyrite is often considered (Bastin, 1950, pp. 73-74) to be due to stress, the absence of conspicuous twinning in the Candego chalcopyrite probably means that the mineral has not been subjected to external stress, and therefore that the last movement on the ore-bearing faults took place before the chalcopyrite was deposited.

TETRAHEDRITE

This mineral is rare in the Candego ore. It has been megascopically recognized in only two places, one in the No. 3 adit, the other in the 402 vein, on the 4 adit level. It is fairly common in microscopic quantities. Microchemical sampling and testing reveal a trace of iron and a small amount of arsenic, as well as significant amounts of silver. Spectrographic analysis (Graham, p. 5) of a sample of tetrahedrite and bournonite gave As, Sb, Pb, and Cu as major constituents in about equal amounts, Ca as a strong trace, Si, Mg, Fe, Al, and Ag as traces, and V and Ti as faint traces.

Much of the tetrahedrite is in the form of small rounded to vein-like areas in galena, near and on the contacts between galena and sphalerite (fig. 33). It has also veined pyrite (figs. 19-21) and sphalerite (figs. 29, 30) and cut the chalcopyrite blebs contained in sphalerite. It was probably deposited penecontemporaneously with chalcopyrite, as indicated by the cutting relationships. Pyrrhotite has veined the tetrahedrite in several places (fig. 38).

BOURNONITE

Bournonite was observed in only one of the polished sections, where it occurs as a narrow veinlet in sphalerite (fig. 24). A previous examination (Graham, p. 4) of a specimen which contained larger amounts of this mineral indicated that it replaced chalcopyrite, galena, and pyrite, and was probably penecontemporaneous with tetrahedrite. The result of spectrographic analysis of a sample consisting of a mixture of tetrahedrite and bournonite is given in the previous section.

PYRRHOTITE

Very little of this mineral is present. All is in small veinlets or particles associated with tetrahedrite or chalcopyrite. Because of the small size of the pyrrhotite bodies, pure material for microchemical testing was not obtained, and the identification of the mineral rests on optical properties (general appearance and anisotropism), hardness, and etching characteristics in the standard reagents (Short, p. 99), and in chromic acid staining solution (Short, p. 172).

Pyrrhotite occurs in narrow veinlets in pyrite, tetrahedrite (fig. 38), galena, and sphalerite. It is also present as small blebs along the contact between galena and sphalerite grains. Like the chalcopyrite which occurs in similar situations, its presence here may be related to replacement of sphalerite by galena. If the solutions which effected this replacement were less able to transport copper and iron than zinc in solution, the copper and iron from the replaced sphalerite may have segregated at the advancing galena fronts.

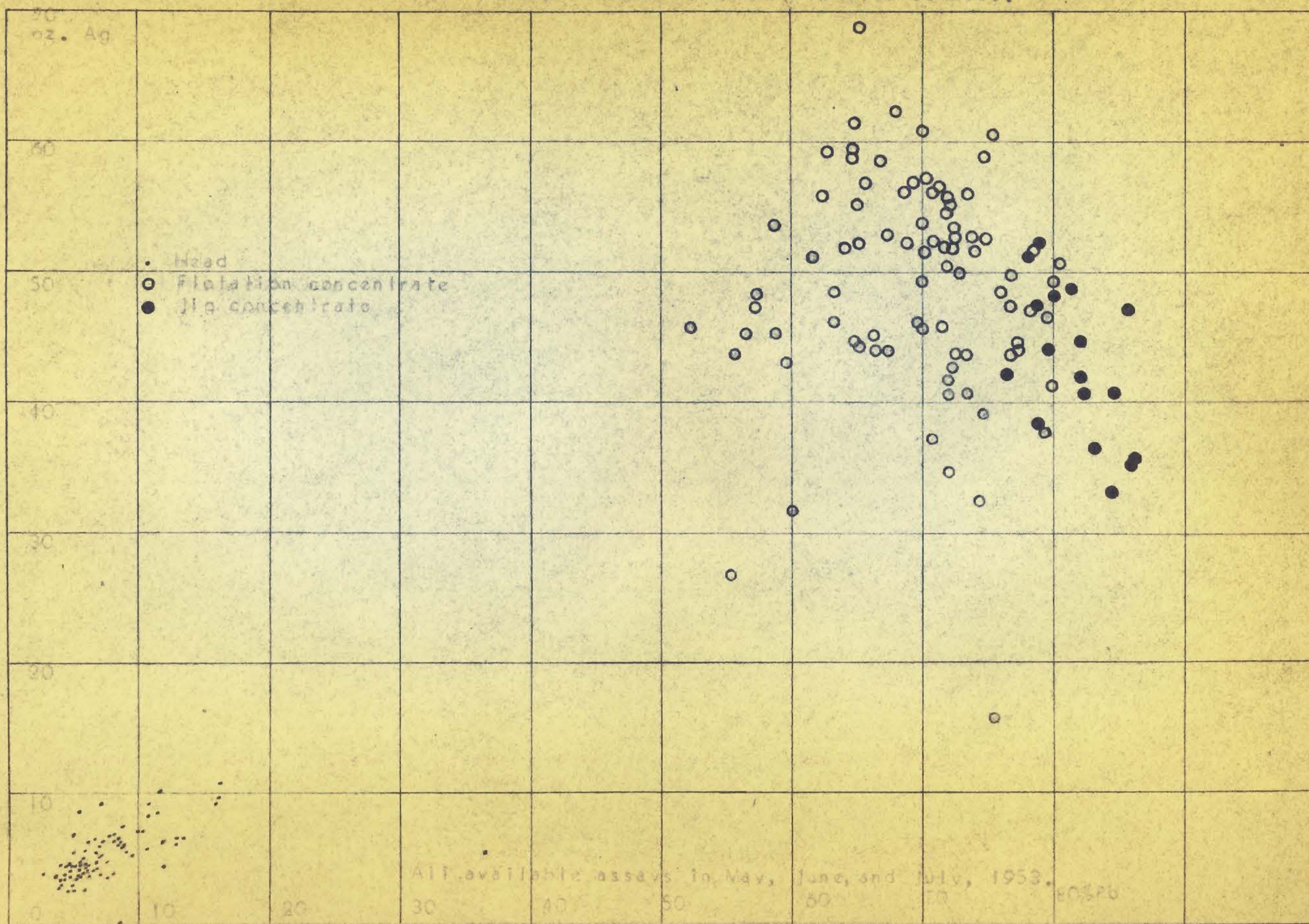
ANGLESITE

A small amount of this mineral has replaced galena in a few of the sections examined. It occurs in small areas, some of which are related to cleavage directions in the galena (fig. 34). The sulphate was identified by x-ray methods (Nickel, personal communication). It is placed at the end of the mineral sequence because it is unlikely that excess oxygen ($PbS \not+ 2O_2 = PbSO_4$) was present at any time during the deposition of the sulphide minerals. It is possible, however, that the anglesite may have formed during the period of fault movement which succeeded the formation of galena and preceded the formation of chalcopyrite. The distribution of anglesite with respect to the present erosion surface is not known.

DISTRIBUTION OF SILVER

Silver values are remarkably evenly distributed throughout the lead ore bodies. The silver content of the ore is closely related to the lead content. It averages about 0.8 oz. of silver per unit (twenty pounds) of lead, and the amount seldom falls below 0.50 oz. or rises above 1.25 oz. There has been a slight drop in the silver-lead ratio in the concentrates during the period of mining (Stewart Troop, personal communication). The relative constancy of the silver-lead ratio led to the conclusion that the silver is in solid solution in the galena. However, in the milling circuit there is a slight differential concentration of the two metals when a jig is inserted into the circuit. The jig feed is coarser material than the flotation feed, and it is found that the jig concentrate, while exceedingly rich in lead, contains less silver than the flotation concentrate. The scatter diagram (fig. 39) illustrates this. This suggests that silver is present in a mineral which is either fine grained, or has a tendency to slime, or is of lower density than the galena.

Diagram 39. Diagram of the relationship between Pb and Ag in mill samples.



None of the minerals found in the Candego ore is very rich in silver. However, appreciable amounts of silver are present in galena and in tetrahedrite. (Silver may also be expected in bournonite and gold, but these were not tested.) Since the grain size of the tetrahedrite is much smaller than that of most of the galena, and its density is considerably lower (4.4 to 5., as opposed to 7.5± , Dana, pp. 453, 416), a differential separation may be expected in the jig. The silver content of the concentrate would then be roughly related to the antimony content, but would not fall below a certain level corresponding to the amount of silver in solution in galena.

COMPARISONS WITH OTHER MINES IN GASPE

Candego, at the time of writing, remains the only producing mine in the Gaspé Peninsula. However, other mines are being explored and developed. Of these, the Federal Metals Corporation's mine, about 20 miles south of Candego, in Lemieux Township, is very similar to the Candego. Gaspé Copper Mines Ltd. are developing the very large low-grade copper ore bodies in Holland Township, about 25 miles east of Candego. This area has very different structural conditions, and much of the ore was emplaced by a different mechanism, but there are certain similarities in the ore mineralogy of the two places.

FEDERAL METALS CORPORATION

The deposits have been described (Gill and Auger, p. 910) as "sharp-walled quartz-carbonate veins and breccia fillings carrying locally, and in varying amounts, sphalerite, galena, pyrite, marcasite, chalcopyrite, and specularite." The mineralogy is thus generally similar to that at Candego, except for the absence of the arsenic and antimony-bearing minerals which are present in very small amount at Candego.

The ore in the Federal area was introduced along faults, possibly normal faults of small to moderate movement, which strike generally a little east and a little west of north and dip steeply (Gill and Auger, p. 913). The original fractures may have been tension cracks due to "average stress conditions.....represented by placing the least stress axis in a slightly tilted east-west position and the maximum stress axis (strongest compression) north-south." (Gill and Auger, p. 905).

This is approximately the attitude deduced for the forces which formed the ore-bearing and cross-faults at Candego, although these are along shear, rather than tension directions.

The Federal veins cut sediments of Lower Devonian age, which have been gently folded, domed, and intruded by dykes, sills, and small stocks of diorite and acidic porphyries. These are older than the veins. A summary (Gill and Auger, p. 918) indicates that they are also older than the faults along which the veins formed. It was shown that at Candego the one small dyke is probably younger than the nearest adjacent fault, and older than the vein material.

Wall-rock alteration is negligible in both areas.

CASPE COPPER MINES LIMITED

These deposits are vein fillings and disseminated replacements in highly metamorphosed gently folded sedimentary rocks of the Grand Grève formation of Lower Devonian age. (Bell, p. 241). There is thus no similarity to the conditions at Candego. However, many of the ore minerals are similar, and it is possible that both ores may have come from the same source. The mineralogy has been described (Douglas) in an unpublished thesis at McGill University. The "important hypogene" metallic and gangue minerals found in one or the other of the two major ore bodies at Gaspé Copper include the following (Douglas, p. 20): molybdenite, galena, pyrrhotite, sphalerite, chalcopyrite, magnetite, pyrite, quartz, and carbonates. Other less abundant minerals are covellite as an alteration product of chalcopyrite, supergene colloform iron oxide, and small amounts of cubanite and bornite. Cubanite and bornite are associated with chalcopyrite.

As at Candego, a pre-sulphide generation of quartz, in well-formed crystals, and a later generation without crystal form, are present. Chalcopyrite occurs in both properties as quartz-vein fillings and as blebs in sphalerite. At the Gaspé Copper, however, a large amount of chalcopyrite occurs disseminated in the country rocks. Pyrrhotite is closely associated with chalcopyrite in both ores, but neither cubanite nor bornite has been found at Candego. Sphalerite and galena at Gaspé Copper are associated with pyrite and chalcopyrite and appear to be younger than these minerals. This is the reverse of the relation observed in the Candego ores. All carbonate is younger than the ore minerals at Gaspe.

SUMMARY.

The sequence of events at Candego was probably as follows:

1. Deposition and compaction of the sediments during Ordovician time.
2. Folding during the Taconic revolution at the end of the Ordovician.
3. Faulting caused by maximum compressive stress acting in a slightly inclined direction, about N.30°W., probably during Middle Devonian time.
4. Soon after the beginning of faulting, introduction of the porphyritic aplite dyke.
5. During periods of quiescence, between fault movements, introduction of the ore and gangue minerals by solutions from an unknown source. This source is probably similar to that which provided the metals in the Federal area and the Gaspé Copper area.
6. Uplift, probably several times, weathering, and production of surficial material.
7. Glaciation, in several stages.
8. Deglaciation and beginning of present cycle of stream erosion.

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Figure 5

Figure 6

Figures 5 & 6 - Bedded slate, described in text, p. 21.
Ordinary light, photographic enlargements of thin sections. x4.

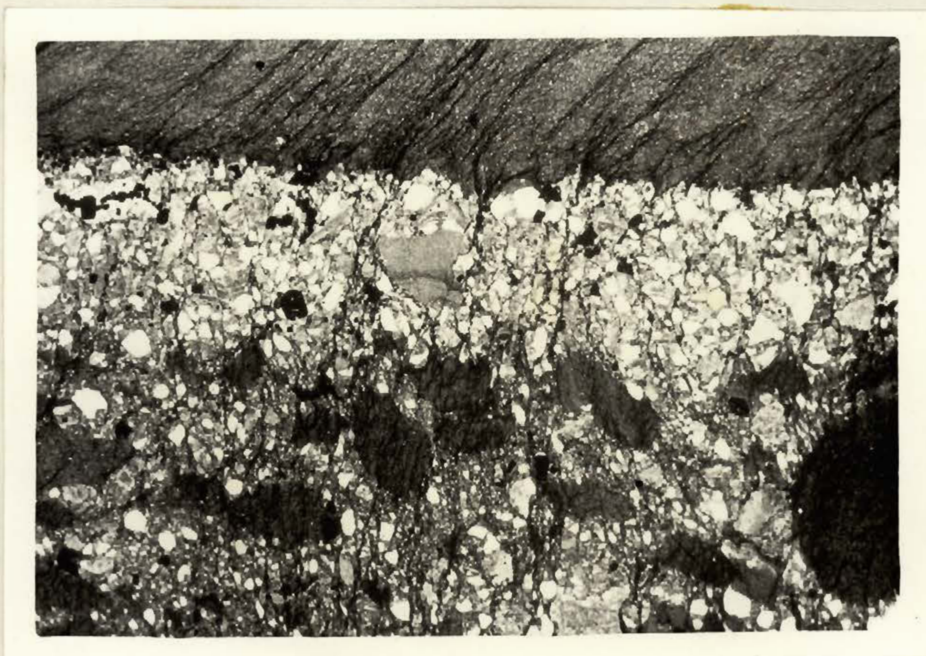


Figure 7 - Fine conglomerate and slate. Bedding runs horizontally in the photograph. Cleavage is vertical in conglomerate, inclined at 45° in slate. Ordinary light, photographic enlargement of thin section. x7.

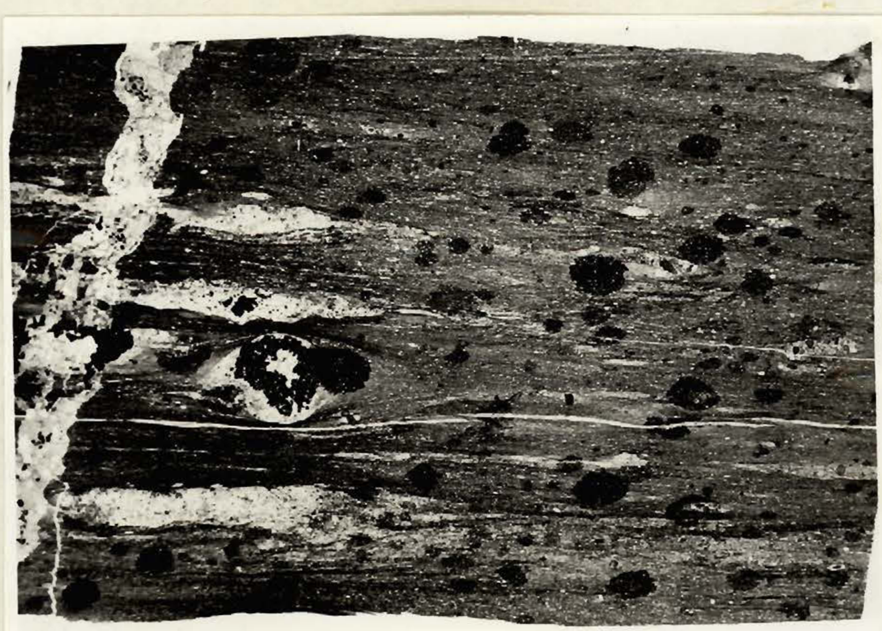


Figure 8 - Spotted slate, described in text p. 23. Ordinary light, photographic enlargement of thin section. x5.

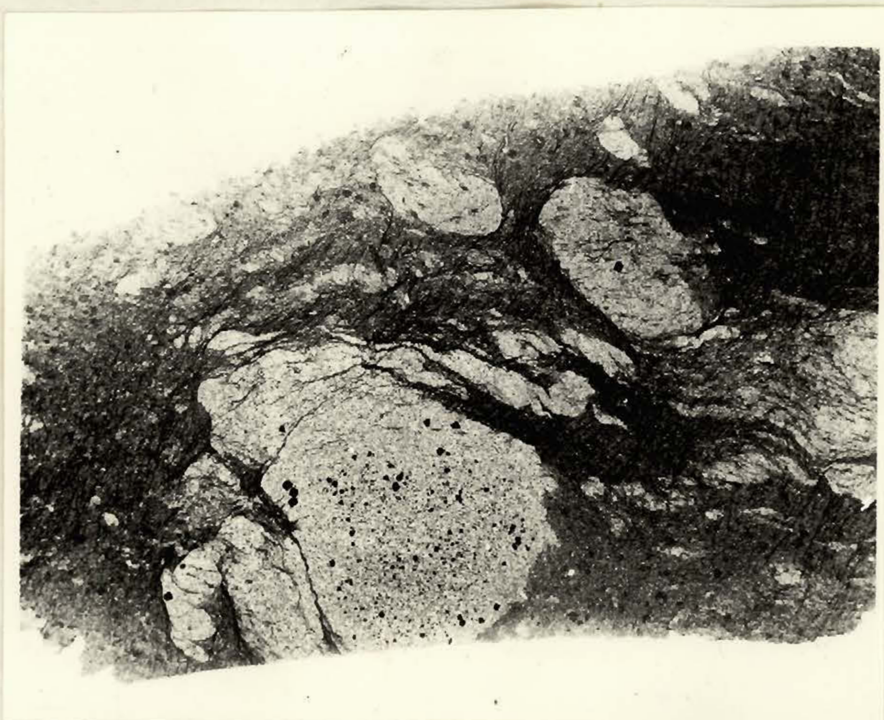


Figure 9 - Calcareous sandstone fragments in calcareous carbonaceous slate. Equant black grains in sandstone are of pyrite. Ordinary light, photographic enlargement of thin section. x7.

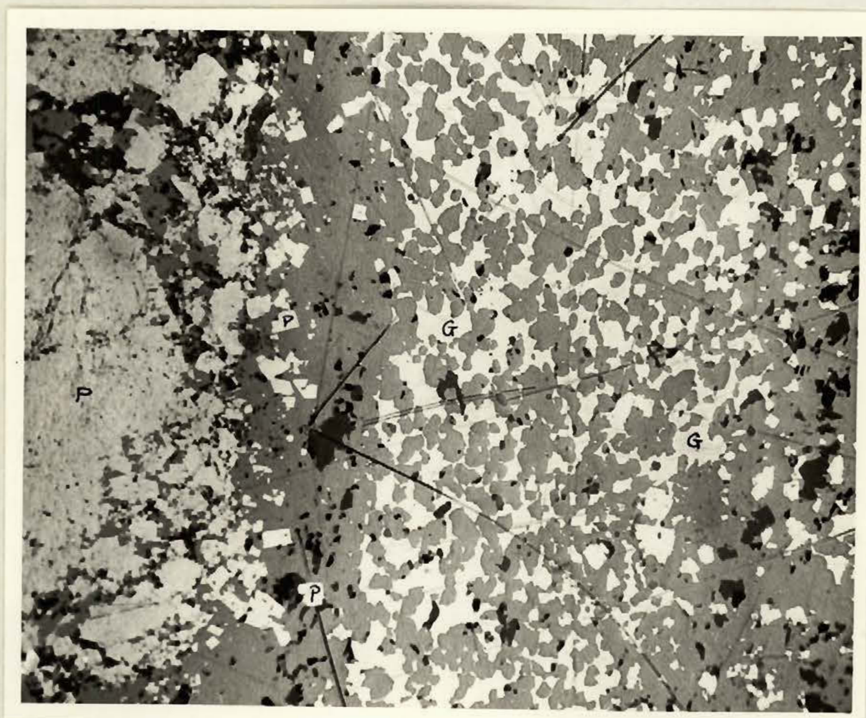


Figure 10 - Banded replacement ore. Pyrite (white), sphalerite (gray), and galena (white). The large area of pyrite at left is cut by many very fine galena veinlets. X50

Figures 10 to 38 are photomicrographs of polished sections. All except figure 27 were taken with ordinary light.

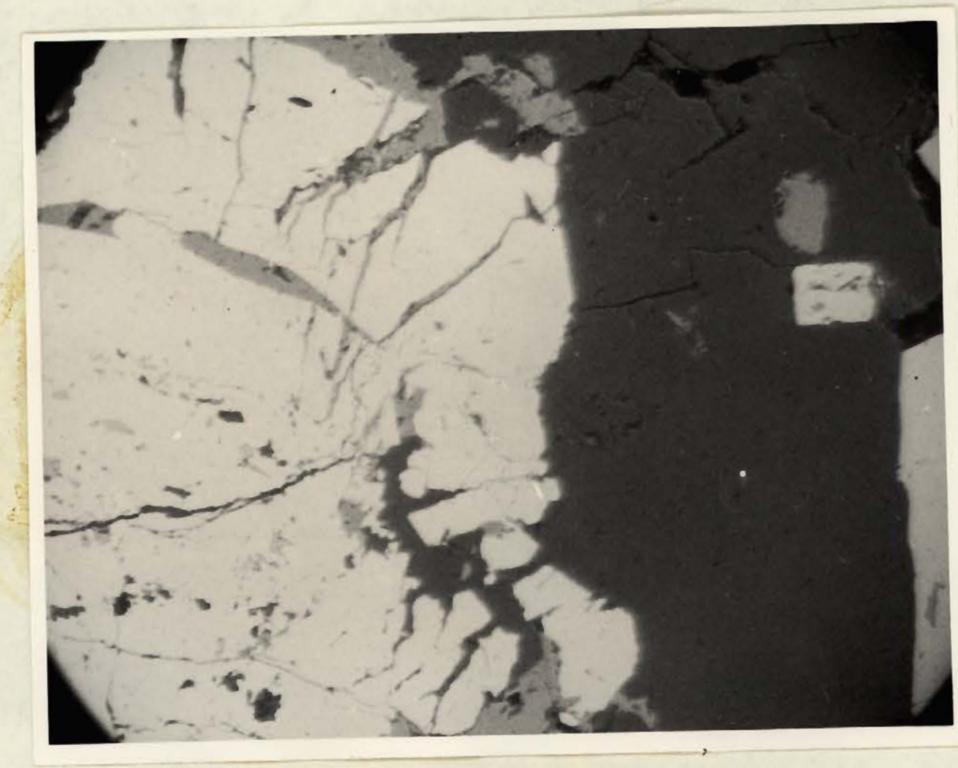


Figure 11 - Quartz (dark gray) and sphalerite (light gray) veins in pyrite (white). x140.

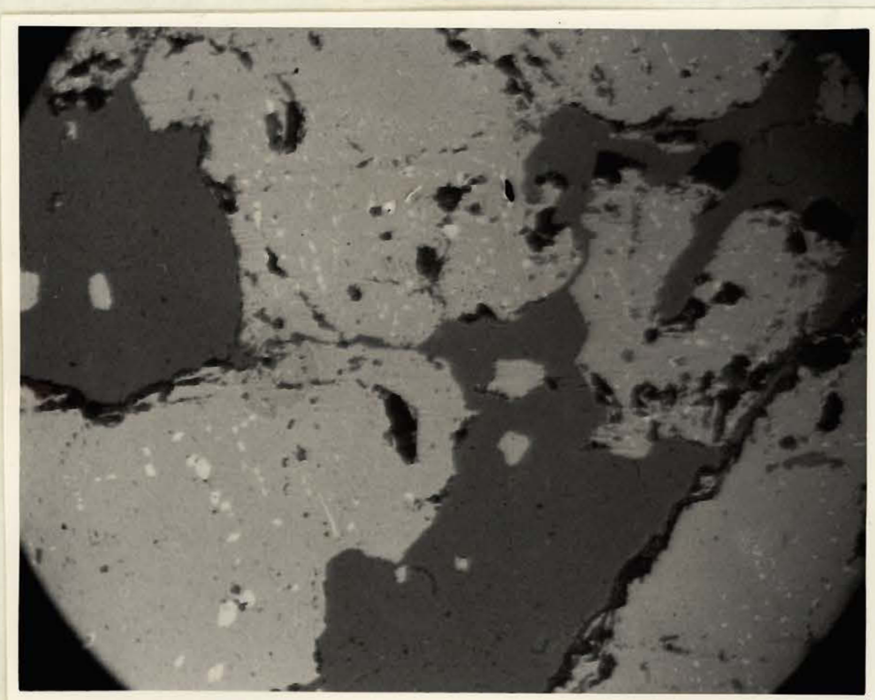


Figure 12 - Quartz (dark gray) veining sphalerite (light gray) containing chalcopyrite blebs (white). x125.

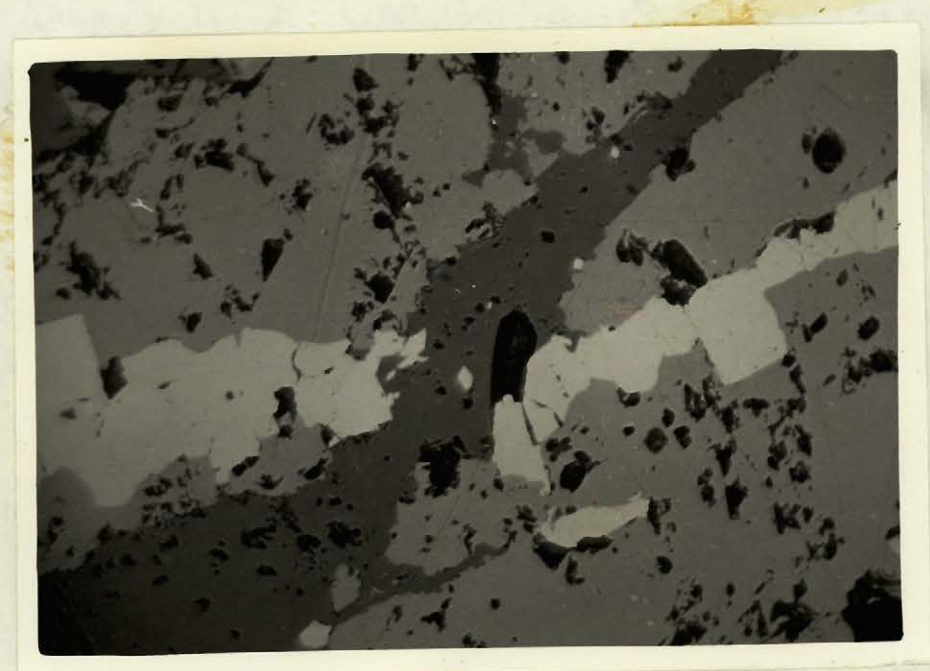


Figure 13 - Pyrite veinlet (light gray) cutting sphalerite (medium gray). Both are cut by a veinlet of carbonate (dark gray) containing small arsenopyrite crystals. x115.

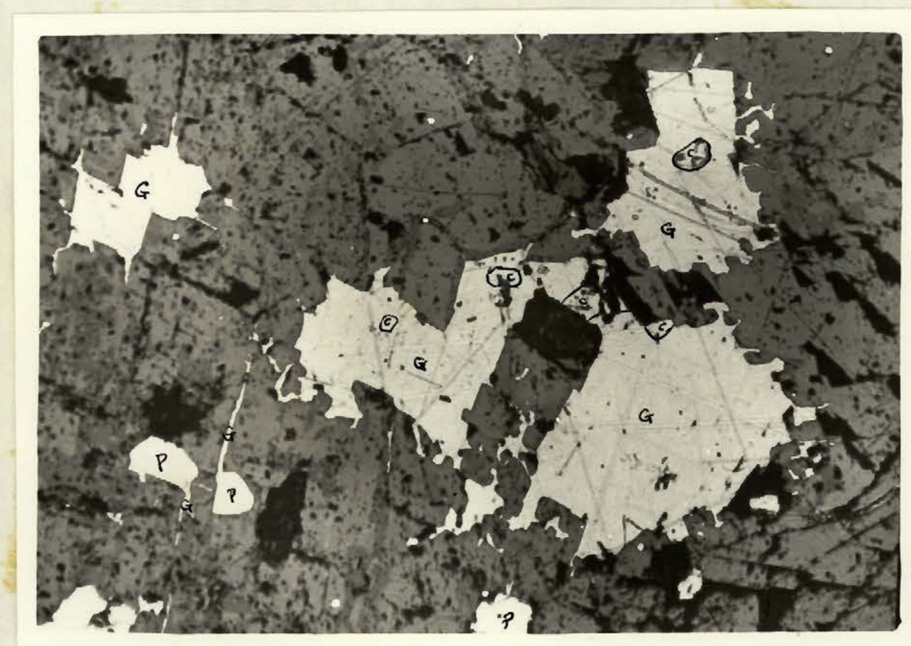


Figure 14 - Pyrite and galena (with chalcopyrite) in carbonate. Galena replacement partly controlled by cleavage of carbonate. x40

Figure 15 - Pyrite (white) replacing gangue (dark gray) x100.

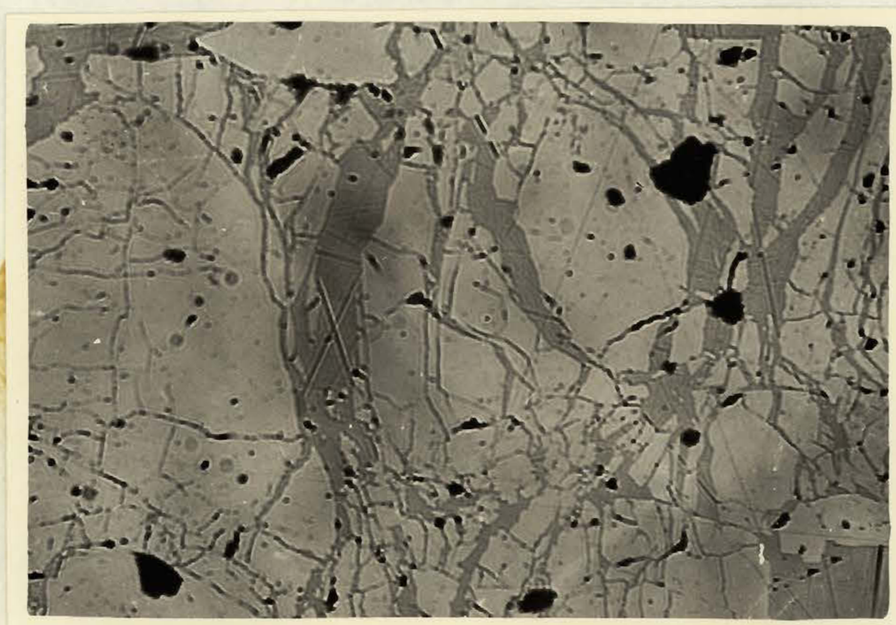


Figure 16 - Galena (medium gray) veining pyrite (lighter gray) x100.

Figure 17 - Sphalerite (dark gray) replacing pyrite(white) x160.

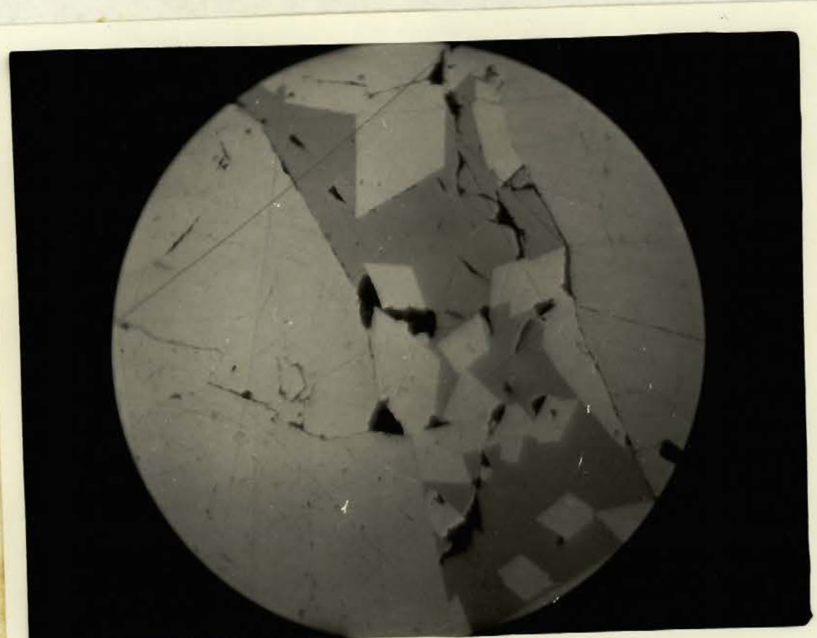


Figure 18 - Tetrahedrite veinlet (medium gray) containing rhombic arsenopyrite crystals, in pyrite (light gray) x310.

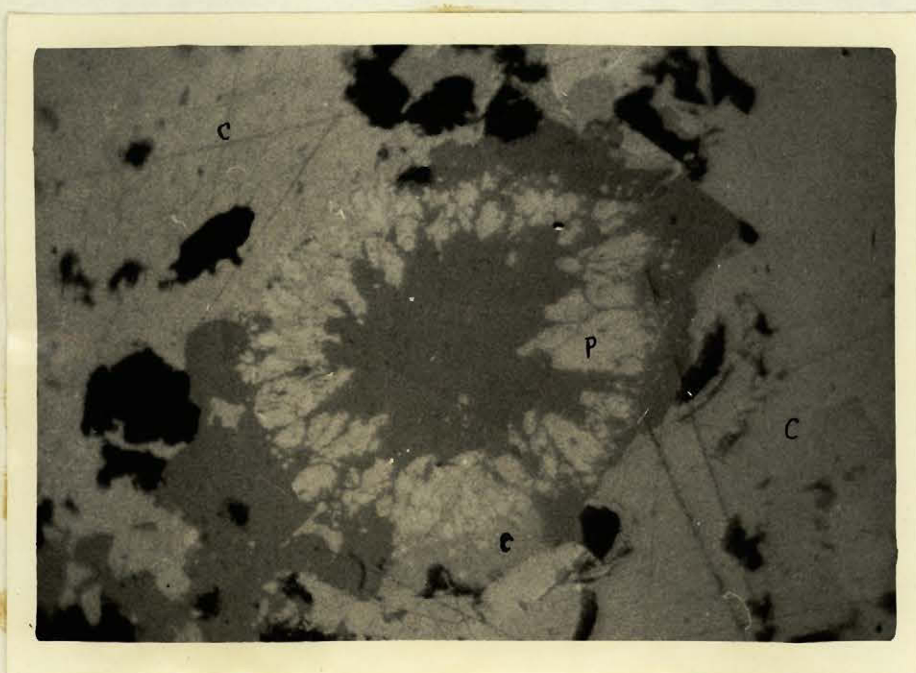


Figure 19 - Tetrahedrite (dark gray) containing and replacing a circle of irregular pyrite grains. Surrounded by chalcopyrite. x300.

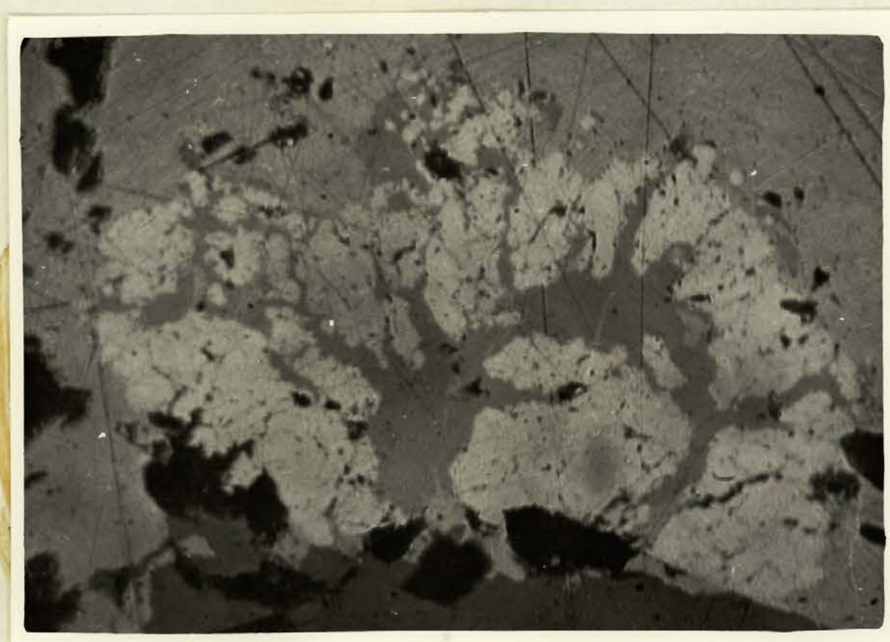


Figure 20 - Tetrahedrite (dark gray) replacing pyrite (light gray). All surrounded by chalcopyrite (medium gray). Darkest gray is bakelite. x250.

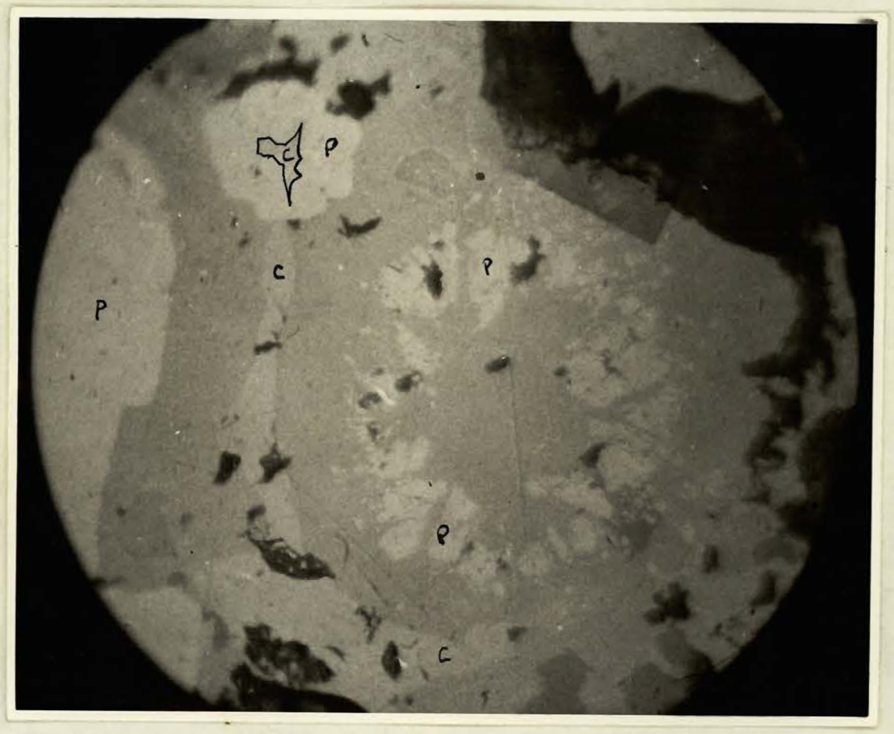


Figure 21 - Tetrahedrite containing and replacing pyrite grains. Veinlet of chalcopyrite traverses tetrahedrite. x250.

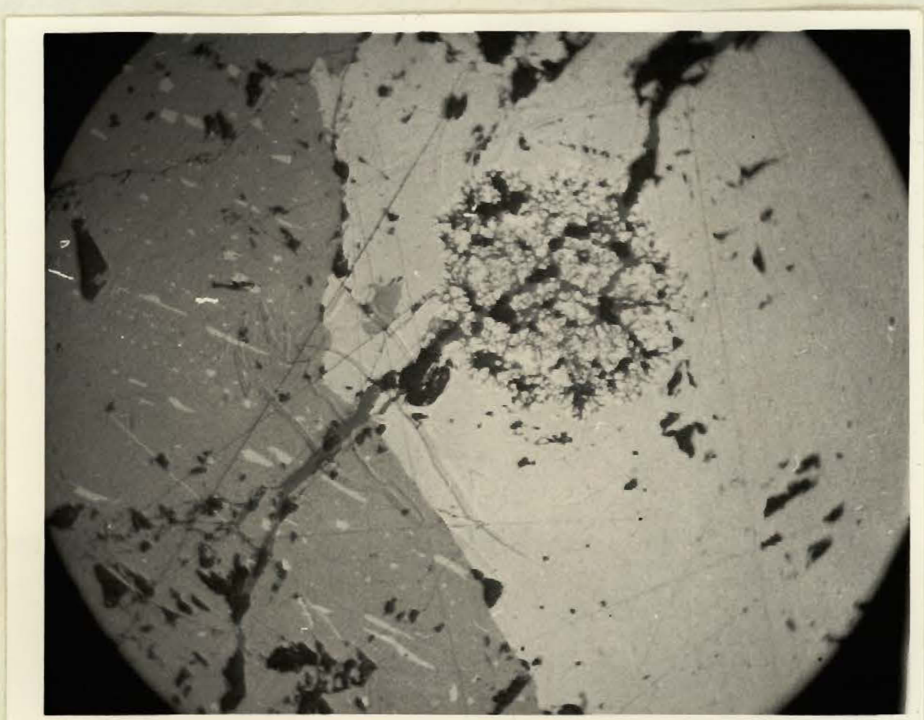


Figure 22 - Veinlet of gangue (dark gray) crosses sphalerite (medium gray) and chalcopyrite (light gray). A rounded grain of pyrite, centre, is full of ramifying veinlets of gangue. Sphalerite contains oriented chalcopyrite blebs. x100

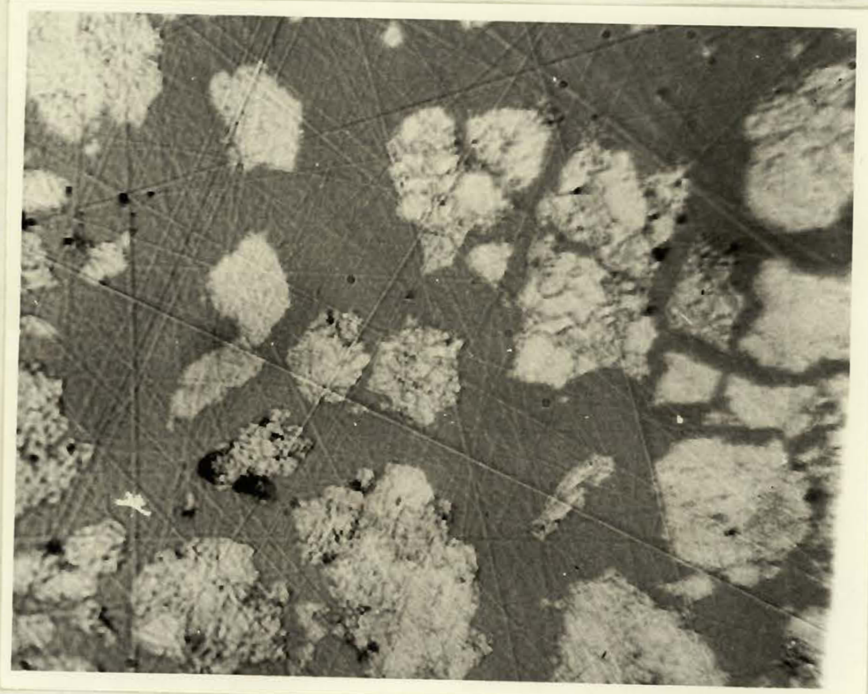


Figure 23 - Tetrahedrite (dark gray) replacing a very fine grained intergrowth of pyrite and chalcopyrite (?) oil immersion. x700.

Figure 24 - Bournonite (medium gray) and pyrite (white) veining sphalerite (dark gray) x300.

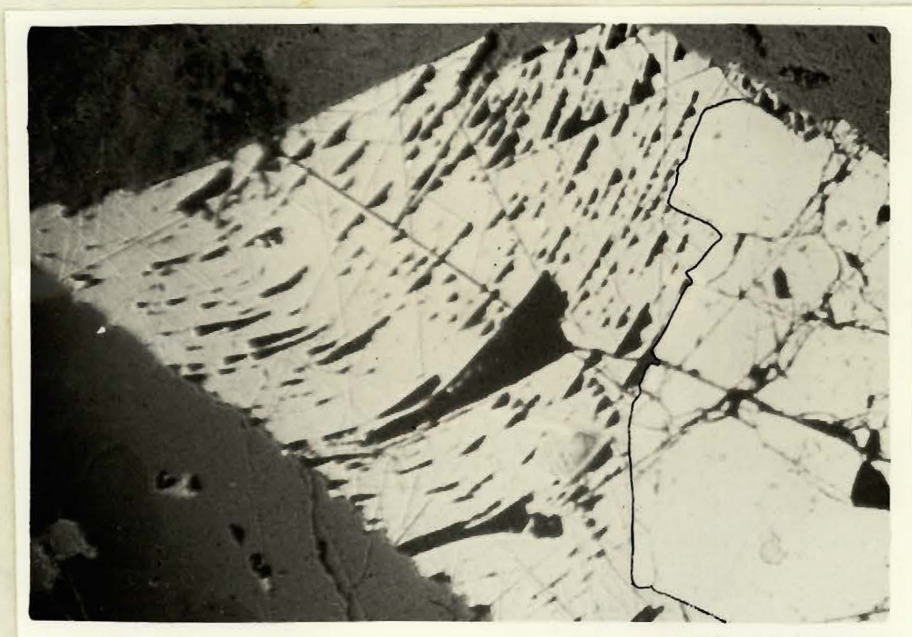


Figure 25 - Galena (white, with pits), with curved cleavage, surrounded by pyrite (right), quartz(lower left) and Bakelite (top left and right) x50.

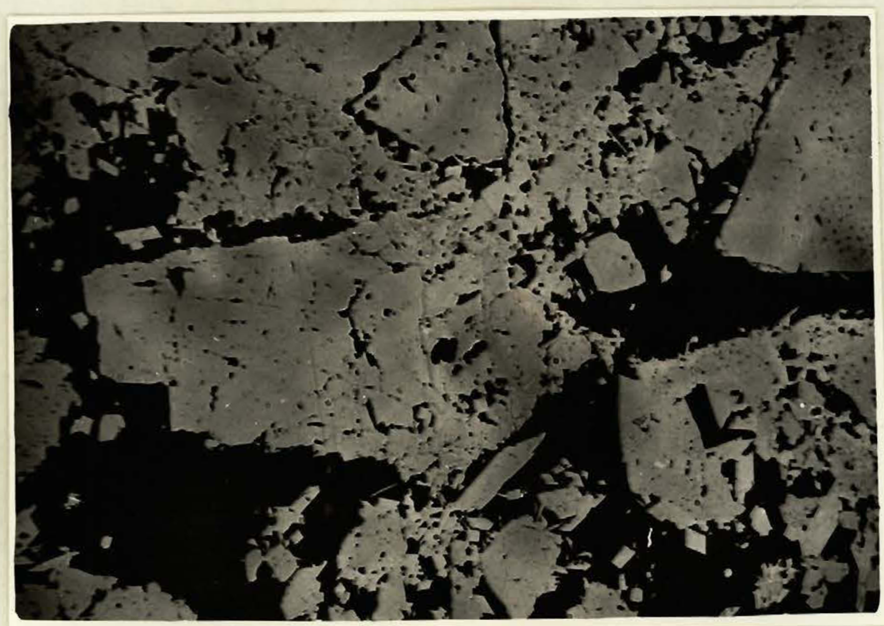


Figure 26 - Pyrite and fine rhombic arsenopyrite surrounded by quartz. Red filter. x130. See also fig. 27.

Figure 27 - Part of the field of figure 26. Photographed with crossed nicols. Veinlet of arsenopyrite cuts pyrite. x185.

Figure 28 - Small particle of gold (light gray) in pyrite (medium gray). Dark gray beside gold is sphalerite. Black line is a fracture in the pyrite. Oil immersion. x750.

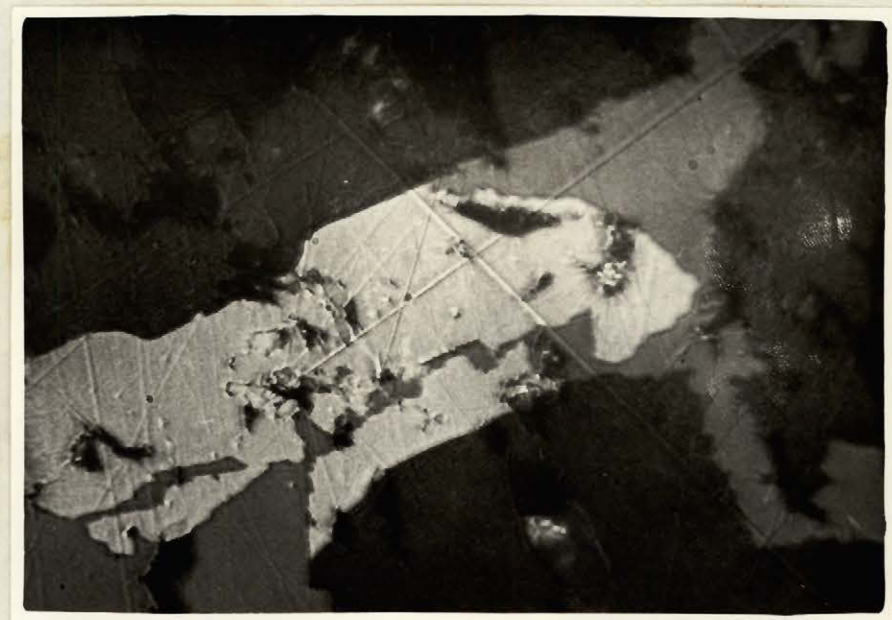


Figure 29 - Veinlet of tetrahedrite (medium gray) and chalcopyrite (white) in sphalerite (dark gray). Tetrahedrite veins chalcopyrite. Oil immersion. x850.

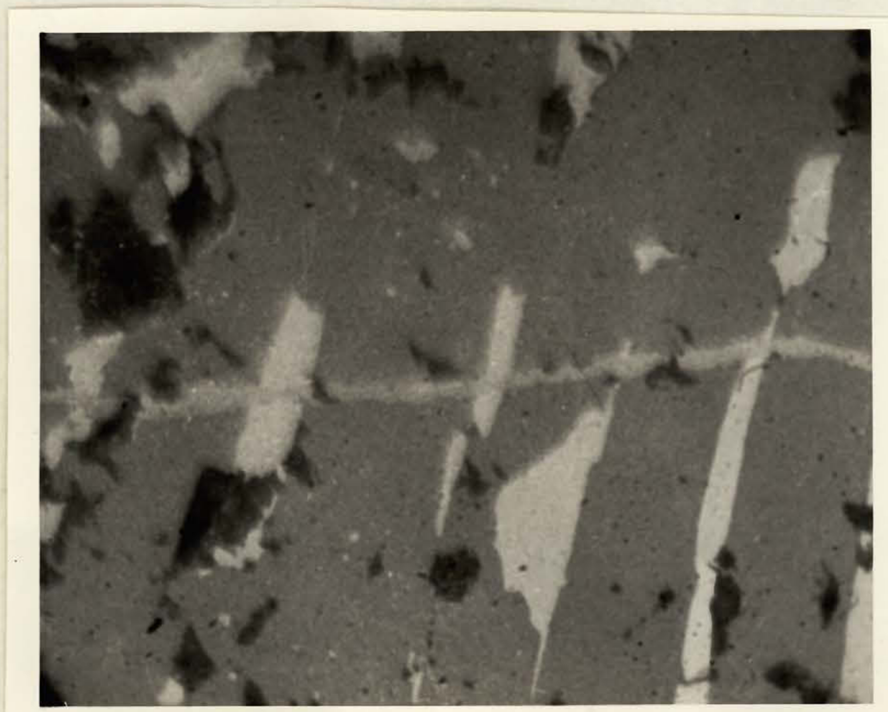


Figure 30 - Tetrahedrite veinlet (medium gray) cuts through oriented chalcopyrite blebs (light gray) in sphalerite (dark gray). The veinlet narrows slightly within some of the chalcopyrite blebs. x300.

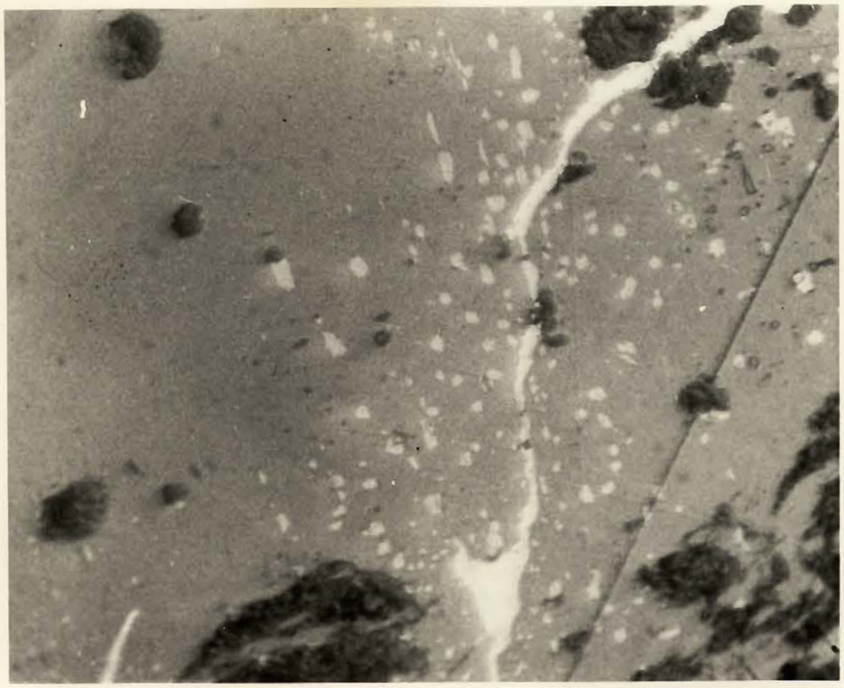


Figure 31 - Small chalcopyrite blebs (white) in sphalerite (gray), near a pyrite veinlet (white). x400.

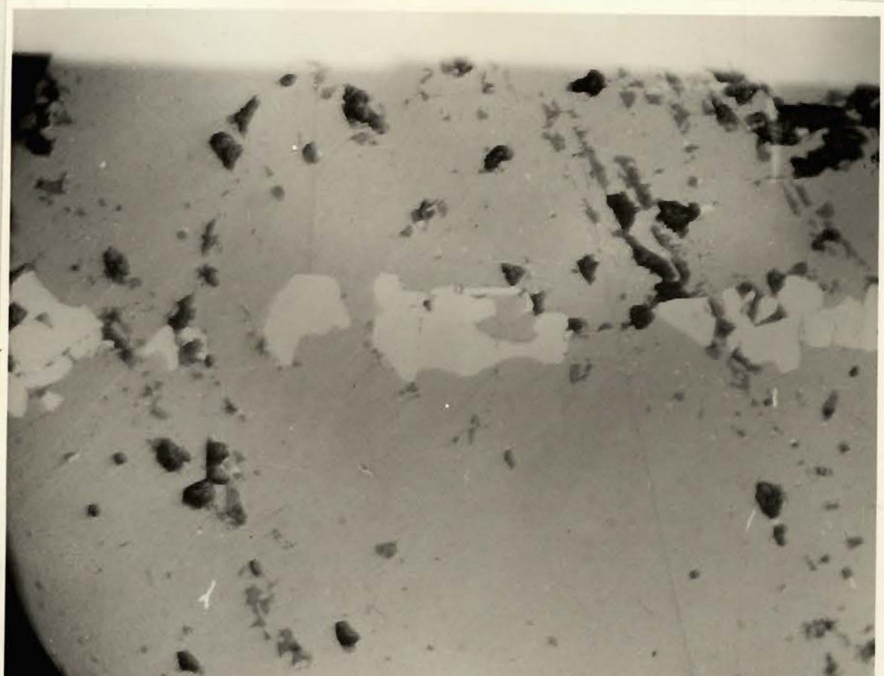


Figure 32 - Unconnected pyrite grains (white) in sphalerite (gray). Described on p. 61. x120.

Figure 33 - Tetrahedrite veinlets (medium gray) in galena (light gray) and sphalerite (dark gray) x550.

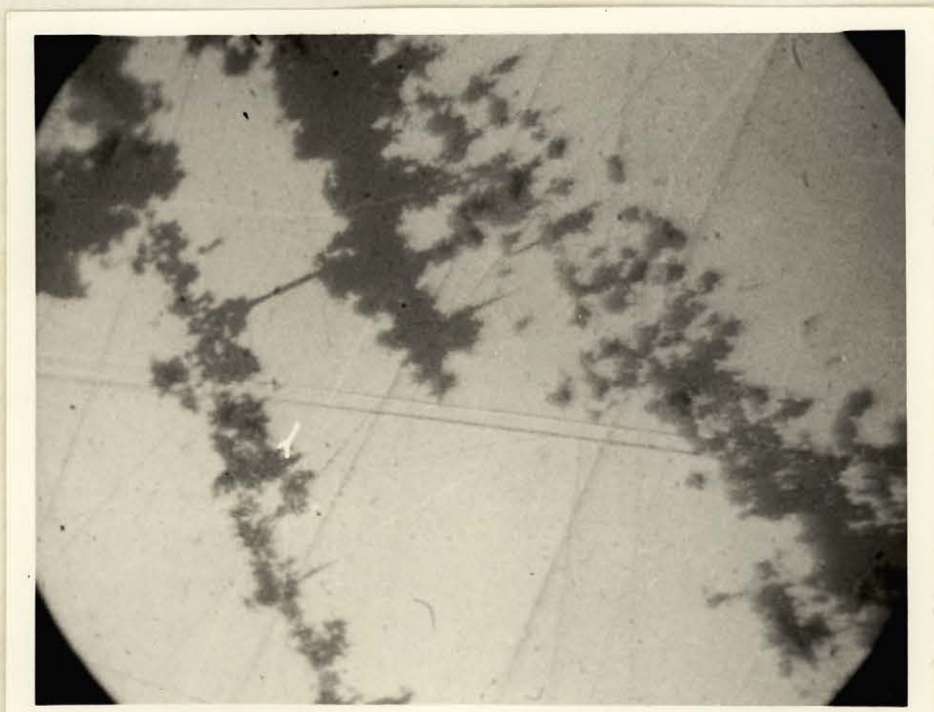


Figure 34 - Anglesite (dark) replacing galena (light) along cleavage directions. x340.

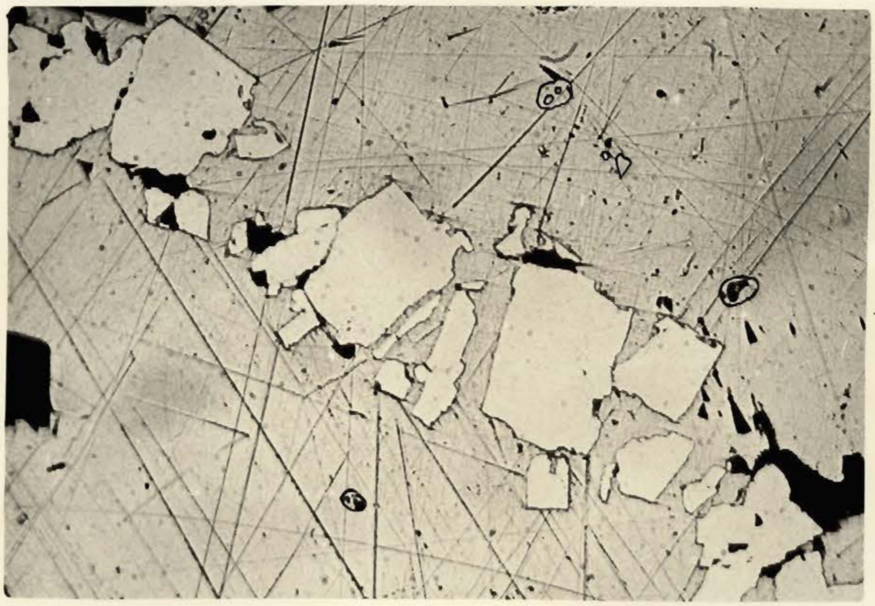


Figure 35 - Pyrite (white) in galena (gray) with chalcopyrite (outlined). Described on p. 64. x110.

Figure 36 - Sphalerite (light gray) containing chalcopyrite blebs (white), except near its contacts with quartz (darker gray). x120.

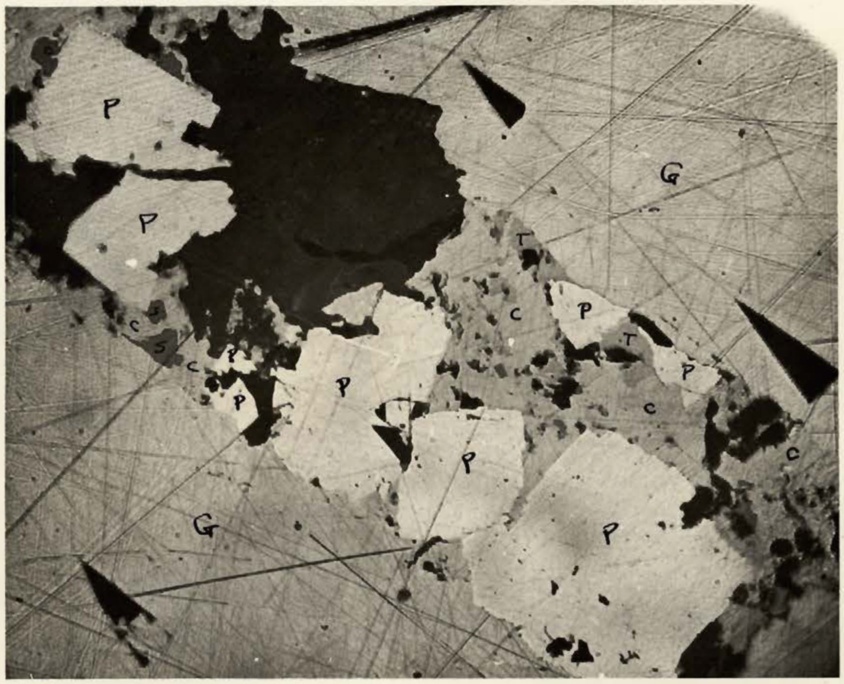


Figure 37 - Veinlet of pyrite, chalcopyrite, sphalerite, tetrahedrite, and gangue in galena. x130.

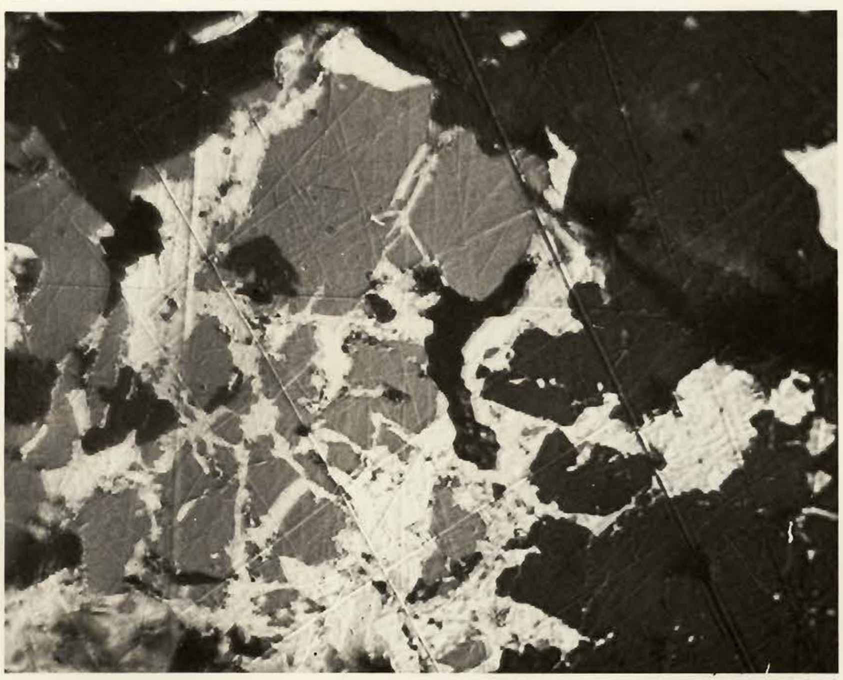
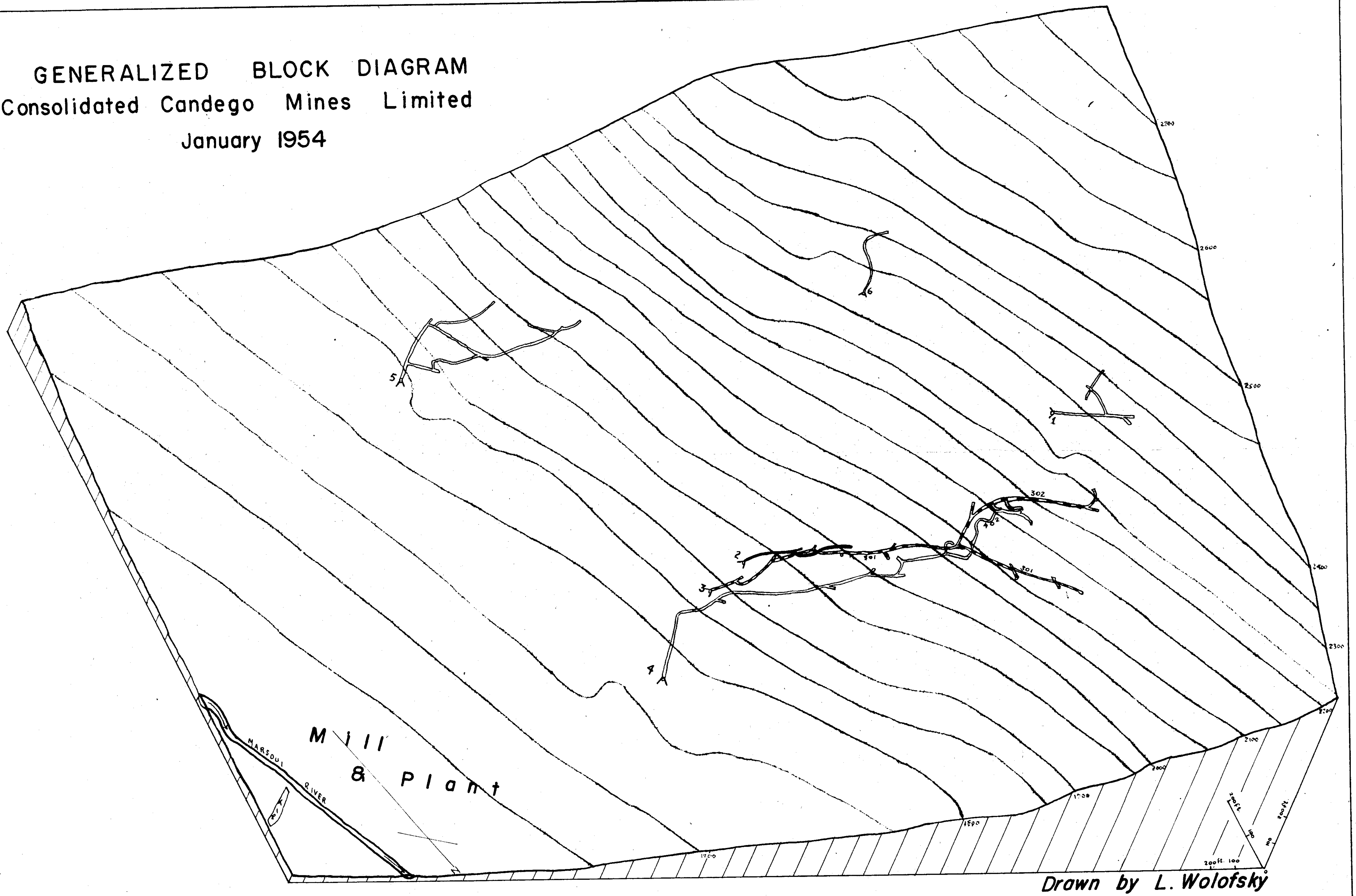


Figure 38 - Veinlets of pyrrhotite (and chalcopyrite ?) (white) in tetrahedrite (medium gray) and sphalerite (black). Oil immersion. x1000.

Fig. 4

PLAN OF FRACTURES in part of no. 3 adit CONSOLIDATED CANDEGO MINES LIMITED

GENERALIZED BLOCK DIAGRAM
Consolidated Candego Mines Limited
January 1954



Drawn by L. Wolofsky

Fig. 3