

PETROGENESIS OF THE SILICATE MINERALS
ASSOCIATED WITH COPPER ORES,
GASPE, QUEBEC.

By

D. Hope Simpson

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NOTE ON REFERENCES.

Those works to which only one reference is made are placed at the bottom of the page.

Those works that are frequently referred to are listed in the Bibliography. under the author's name, with the date of writing. In the text, the writer's name and the date are given. Note that two works were written by Winchell on the Bingham Deposits in 1924,- in February and in June.

INTRODUCTION

General Statement

Detailed geological mapping of the interior of the Gaspé peninsula has been carried on only in recent years. Logan (1) as early as 1863, however, correctly interpreted the structure of the peninsula as a great east-west trending synclinorium.

When the Federal lead - zinc and the Miller copper prospects were found just after the First World War, detailed mapping of the interior was commenced. The areal geology mapped by I.W. Jones in the district served as a basis for the study of the Miller properties.

The mineralisation of the Miller claims is pyrometasomatic but, in certain respects, it differs radically from mineralisation of other deposits of this type in Eastern North America.

In Gaspé, the grade of regional alteration of the Devonian rocks is very low, - comparable perhaps to that of the Trenton group in the St. Lawrence Lowlands. Certain rocks of Lower Devonian age, however, show contact metamorphism of a high grade over restricted areas. Mineralised skarns and porcellanites have been produced. Pyrometasomatic deposits of the skarn type in the Grenville sub-province are characteristically coarse in grain, and this and certain other features suggest that they were formed at great depths under considerable pressure. The skarns of the Miller deposits, on the other hand, are extremely fine in grain, and give evidence of shallow formation without extreme hydrostatic or tangential pressures.

(1) "Geology of Canada, 1863." Geol. Surv. Can., Atlas of maps & sections, Geological Sections, Plate 1V, Sections 10 & 11.

The two ore-bodies drilled show striking differences in country rocks and mineralisation. On Copper Mountain, the metasediments are highly siliceous, and the ore for the most part is in veinlets. On Needle Mountain, the rocks are mostly highly calcareous, and replacement is more common than vein-deposition. The chief sulphides on Copper Mountain are chalcopyrite, pyrite, and molybdenite, whereas, on Needle Mountain, chalcopyrite and pyrrhotite predominate, and pyrite and molybdenite are scarce.

The mineral associations of the metamorphic rocks are also interesting. Thus, chlorite and amphiboles are wanting, and micas are not normally abundant. Some rocks have pigeonite and sanidine, - minerals that are characteristic of the highly unusual sanidinite facies described by Eskola. These mineral associations are, in particular, the concern of this paper.

Acknowledgements.

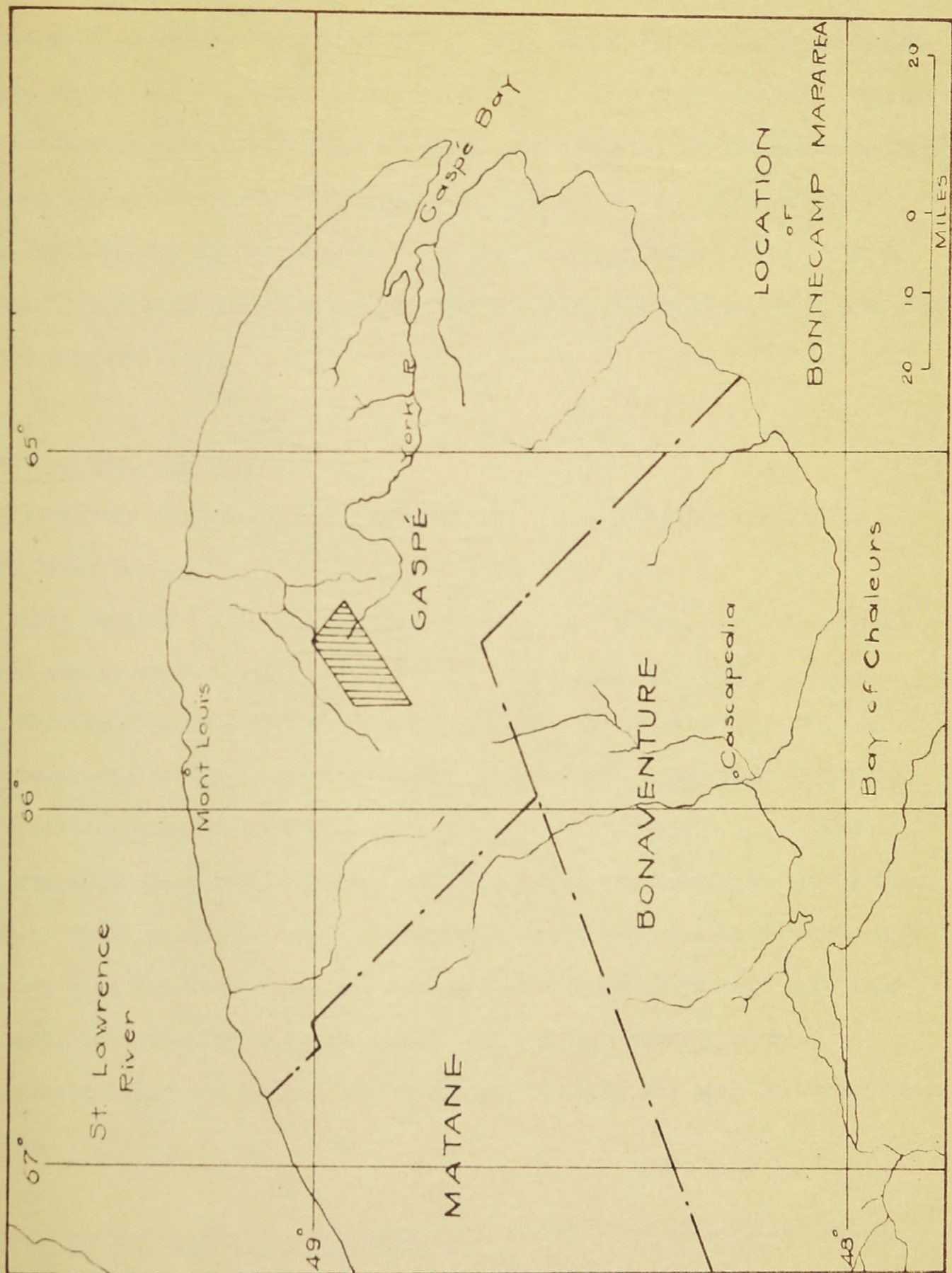
A suite of 124 slides were provided by the Quebec Bureau of Mines and were examined by the writer.

J.M. Douglas, (1941), carried out a polished section study of the ores of the Miller deposits. The writer has drawn freely at many points from this report.

Dr. F.F. Osborne supervised this study and has provided much information. The writer wishes to acknowledge his help and criticism.

Location and Accessibility.

The copper deposits are in the northwest corner of Holland township, Gaspé Nord, near the headwaters of the South Branch of the York River. A road



MAP I.

from the village of Gaspe about 60 miles to the east has recently been constructed following this river, and it provides the easiest route to the properties. Another route is by wagon road from the Federal mine some thirty miles to the west. A third route is by wagon road and trail from Mont Louis about 25 miles to the north.

The deposits are in the Bonnecamp Map Area, geologically mapped by I. W. Jones in 1931. The 49th parallel passes two miles north of the area, while meridian 65° 30' passes through it.

Previous Work and Reports

The discovery of ore-float was made in 1909 by A.E. Miller many miles down the York River Valley. In 1921, a prospecting party led by A.E. Miller discovered copper on what is now called Copper Mountain. Claims were then staked by the Millers and by others, and the Miller claims are the only ones now held.

The Noranda Exploration Company took an option on 23 of these, and diamond drilled two ore-shoots in 1939 and 1940. On Needle Mountain a low grade ore-body, containing 18 million tons of just less than 1% ore, was outlined. A considerable, but smaller, ore-body was found on Copper Mountain. 500,000,000 lbs. of copper have been outlined by drilling the two areas. The ore may run deeper than the 1000 feet drilled, and may also run underneath the unmineralised "Younger Series" that overlies on the east, the ore-bearing rocks. Work has now been discontinued.

T.C. Denis (1) spent 2½ days on the claims in 1922, the year following their discovery.

1) Que. Bur. Mines Ann. Rept., 1922, pp. 34-7.

F.J. Alcock (2) spent 5 days there in 1923 and mapped an area 2 miles by 3 miles.

I.W. Jones mapped the Bonnecamp area in 1931. The Noranda Exploration Company did much drilling, trenching, and sampling in 1939 and 1940.

H.W. McGerrigle wrote an unpublished report covering ore-values in 1940 for the Quebec Bureau of Mines. F.F. Osborne wrote a comprehensive report covering fieldwork done in 1940 that is now being printed.

(2) Alcock, F.J., York River Copper Prospects; Geol. Surv. Can. Summ. Rept., 1923, Pt. c2, pp. 6 - 12.

GENERAL DESCRIPTION OF THE BONNECAMP MAP AREA

Topography, Drainage, and Timber

The Bonnecamp Map Area, (see map 2 in the folder), is about 16 miles long and $7\frac{1}{2}$ miles wide. The country mapped extends in a north-easterly direction, and it is roughly bisected by the Rivière des Belands, which flows due north in a broad even valley. The country west of this river has, in general, a local relief of about 700 feet, which increases to 1400 feet at Mount Brown. This hill, the highest point in the Map Area, is in the south-westerly corner, and rises to a little over 3,000 feet above sea-level.

The eastern half of the area has a greater local relief, - about 1200 feet. The highest hills in this region also rise to about 3,000 feet above sea-level, and the deposits are situated among them.

The most important stream is the Rivière des Belands which rises on the south margin and flows north, reaching the Gulf of the St. Lawrence by way of the Madeleine River. The south - west corner is drained by the West Branch of the Bonaventure river, which empties south into Chaleurs Bay. The South Branch of the York River flows east from the eastern portion where the copper deposits are, to Gaspe Bay. Here, steep-sided valleys are cut deep into the plateau surface.

The region is thickly wooded with balsam fir, white and black spruce, and cedar and birch. The balsam is suitable for pulp manufacture.

Physiography and Glaciation

The summit peneplain in Central Gaspe is at about 3,500 to 4,000 feet above sea-level. Lower summit flats are found at different altitudes in the district, and the dissection of the region seems to have consisted of the

intermittent reduction of a peneplain.

The rivers occupy steep-sided valleys that appear to be too large to have been cut by streams the size of those at present occupying them. The topography, maturely dissected, was little modified by glaciation. There are a few erratics of local origin of the more resistant rocks. It seems probable that vigorous weathering has destroyed many of the less resistant. Only one erratic has been found that undoubtedly originated in the Laurentian Shield province, so that it is believed that local glaciation of the valley glacier type persisted throughout most of the latest glacial epoch. A steepening of the valley walls below 2,500 feet has been noted by several observers, and this has been considered to mark the level of the surface of the local ice-cap. There are no conspicuous cirques in the map-area, although, a few miles west, well-developed cirques abound.

Erratics of the metamorphic rocks are found north, east, and south of their point of origin.

DESCRIPTIVE GEOLOGY

General Statement of the Regional Geology

The Gaspé Peninsula is underlain by an east-west trending synclinorium, whose synclinal axis is slightly curved so that it forms an arc concave to the south. It is bounded on the north by the Taconic Logan Thrust, and on the south by the Baie de Chaleurs. The oldest rocks recognised are along the northern and southern boundaries of the region, and Ordovician rocks are included among them. Nearer the axis of the synclinorium Silurian series are found, and along the axis itself there are Lower and Middle Devonian rocks. Intrusive into the Lower but not into the Middle Devonian formations, are several stocks and dikes.

batholiths of granitic rocks, and also a few large masses of ultrabasics, of which the Mount Albert Complex is the best known.

Most of the Bonnecamp Map Area is underlain by the Lower Devonian terrane, but a part of the northern limb of the synclinorium is just included in the area mapped. The rocks were thrown into open, sub-parallel anticlines and synclines, that have strikes about $N 60^{\circ} - 70^{\circ} E$, and dips up to about 30° on the limbs. It is possible that these folds have been themselves fairly strongly folded along axes roughly perpendicular to the main strike, as anomalous strikes are rather common.

The most important Palaeozoic deformations were the Taconic, (Ordovician) and the Acadian, (Middle Devonian), to which the intrusives and ore-deposit belong. The Appalachian orogeny did not strongly affect Gaspé, and the Mississippian rocks are not much folded.

The stratigraphic section of the Bonnecamp Map Area as set forth by Osborne follows on the next page.

The Saint Alban Formation and the Gaspé sandstones are not definitely known to be represented in the area.

The Silurian Rocks are the oldest rocks exposed in the map area, and they fringe it on the northwest. The contact with the Devonian has not been seen. Fossiliferous limestones are interbedded with quartzites and siliceous limestones.

Lower Devonian rocks cover nearly all the map area, and they consist chiefly of dark-coloured siliceous limestones and siltstones, and of quartzites, and sandstones, all of them generally quite unaltered.

Structure

The Silurian and Lower Devonian rocks were folded openly, probably in early Middle Devonian time. The axes strike about $N 60^{\circ} E$ and the dips are

TABLE OF FORMATIONS

BONNECHAMP MAP AREA

MIDDLE

Gaspe Sandstones - Not cut by porphyries
(Possibly represented in the area)

Grey to Pink feldspar porphyry and quartz - feldspar porphyry.
Dark coloured diabase and syenite sills.

DEVONIAN

York Lake Series - Fine sandstones, Limestones, and Shales.
(Incl. "Younger Series"?)

LOWER

Gaspe Limestones - { Grande Grève - Calcareous siltstones with cherts
and quartzose beds.
Bon Ami ----- Soft Argillaceous Limestones.
Saint Alban - Calcareous shales.

SILURIAN

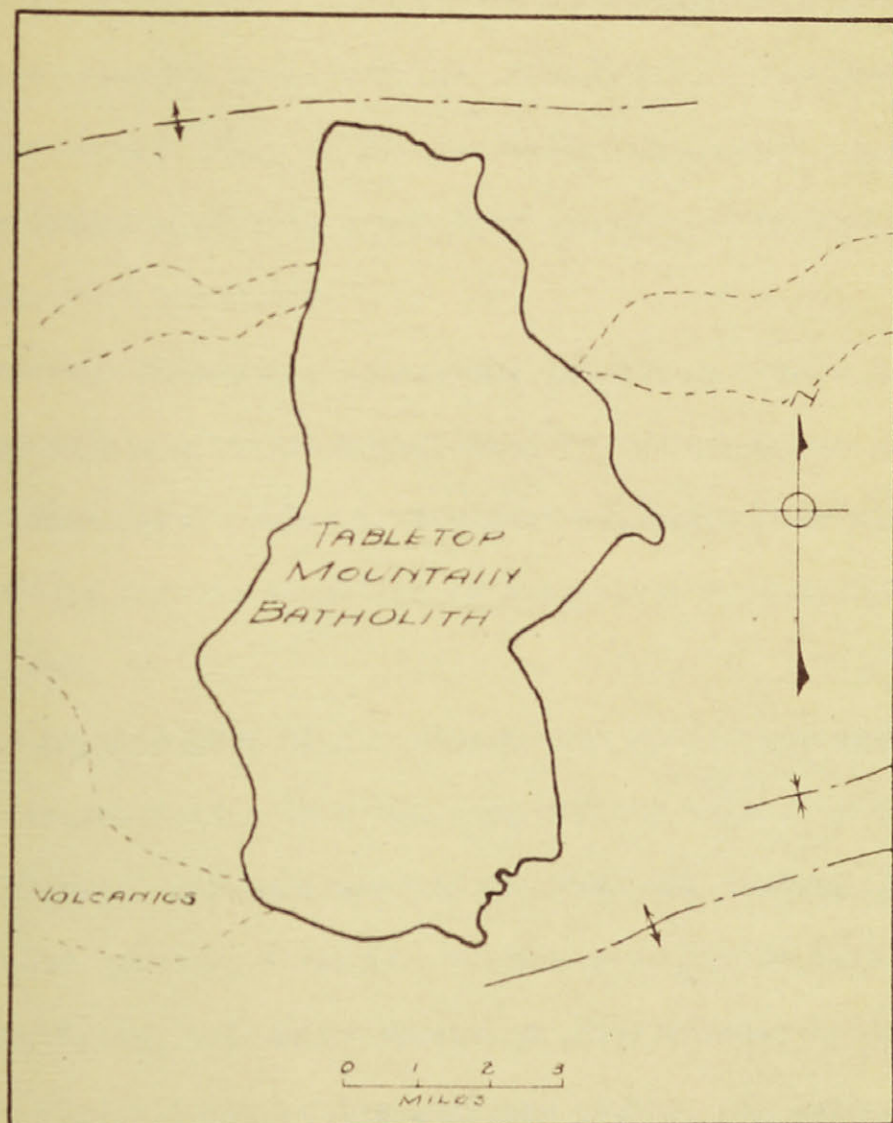
Limestones, slate and quartzite.

seldom much greater. than 30° .

The Lower Devonian and earlier rocks were intruded about this time by dykes and sills, first of diabase and associated rocks, and later of acidic porphyries, both quartzose and syenitic. It seems probable that these intrusive bodies were involved in the folding, and they are thought to be roughly contemporaneous with the ore-deposition, although no exposed igneous ^{body} is adequate to account for the pyrometamorphism. Igneous rocks have not been observed to cut the Middle Devonian formations, and are on this account believed to be earlier than they.

The diabase forms two prominent sills in the southwest portion of the area. They trend east-northeast, and lie 1 mile and $3\frac{3}{4}$ miles north of Brown Mountain. They are exposed for lengths of $3\frac{1}{2}$ and $2\frac{1}{2}$ miles respectively. The two now separate outcrops may be one sill that has been eroded. The more northerly has at its western end a potassic phase, in which the groundmass is pink orthoclase. Jones calls this the syenitic phase of the diabase. It seems to form the nose of a southwesterly plunging anticline.

A syenite porphyry sheet occurs on Brown Mountain. It is brownish to salmon-pink and is composed of small phenocrysts of felspar, chiefly orthoclase, in an orthoclase groundmass. Magnetite and chloritised pyroxene are also present. A quartz porphyry, coarse in grain and pink to grey, occurs half a mile northwest of the claims area. It may originally have been continuous with one or two other porphyry bodies exposed on Porphyry and Copper Mountains on the claims to the southeast. The bodies lie, perhaps, on either side of a synclinal axis running nearly north and south, passing just west of Copper Mountain.



MAP 3.

Metamorphism

At the headwaters of the South Branch of the York River there is an area 3 square miles in extent of highly altered rocks. The quartz porphyry sills just described are at the northern end of this area. The altered rocks are thought to be members of the Grande Grève Formation and the York Lake Series that have been changed to mineralised porcellanites and skarns. The metamorphism induced by the sills on the unaltered sediments is quite inadequate to explain the presence of this zone, even though quartz-porphyry bodies are here more numerous than elsewhere.

It seems reasonable to assume, therefore, that a cupola or stock of granite, probably similar in composition to the aschistic porphyries, occurs at no very great depth beneath. Abundant volatiles were given off, and these were responsible for the formation of scapolite, gypsum, fluorite, and various metal sulphides.

The metamorphism will be dealt with more fully below.

It is noteworthy that the long axis of this altered zone is north-northwest, that is, perpendicular to the regional strike. Many of the valleys and a joint set probably formed by tension also follow this general direction. The Table Top Batholith, which appears to have steeply dipping contacts, also seems to cut directly across the regional strike, and lies a few miles to the west, (See map 3).

COPPER - BEARING AREA

General Statement

As already indicated, the mineralised rocks are situated near the head of the York River South Branch. The metamorphic zone is about $2\frac{1}{2}$ miles long and nearly $1\frac{1}{2}$ broad, and its long axis runs about north-northwest, that is, transverse to the regional strike.

At the northeast corner of this altered zone is Porphyry Mountain, 2865 feet in height. Copper Mountain, 2615 feet, is $\frac{3}{4}$ mile to the southwest, approximately in the centre of the zone. Near the south-southwest corner is Needle Mountain, 2985 feet, 1 mile further south still, and a few hundred feet within the boundary of the altered zone. The relief is about 1000 feet.

A headwater of the South Branch crosses the zone flowing east. It is joined by two other headwaters flowing from the north-northwest, one on each side of Copper Mountain. There are Twin Lakes at the head of the more westerly tributary, at the very edge of the metamorphic area.

There are two drilled areas, one on the west flank of Copper Mountain and the adjacent flat, and the other on the north flank of Needle Mountain.

The rocks include beside the metamorphics, some pink to grey porphyry dykes and sills and irregular sheets, of syenitic or granitic composition. These are mostly at the northern end of the area, and it has been suggested that the west flank of Porphyry Mountain may overlies a centre from which mineralising solutions emanated. Porphyry Mountain is itself capped by a granite porphyry sheet.

Local Stratigraphy

The sedimentary rocks adjoining the altered zone have been assigned on the basis of lithology, structural relationships, and fossil correlations to the Grande Grève Formation of the Lower Devonian Gaspé Limestone Group.

It seems probable that most of the adjacent metamorphosed rocks also belong to this Formation. On Copper Mountain, however, another metamorphosed series occurs, apparently conformably overlying the Grande Grève. This is known on the properties as the "Younger Series". On the basis of its stratigraphic relation to the Grande Grève and its lithologic characteristics, the Younger Series has been correlated with the York Lake Series.

The rocks assigned to the Grande Grève are different in certain respects in the two drilled areas, that is on Needle Mountain and Copper Mountain, and it has been customary on the properties to refer to these two groups of rocks as the "Needle Mountain phase" and the "Copper Mountain phase" of the Grande Grève. The Copper Mountain phase is younger than the Needle Mountain phase, although the lower part of the former may grade downwards into the upper part of the latter.

The contact between the Younger Series and the highest members of the Copper Mountain phase is also gradational.

A table follows summarising apparent relationships at the Miller Properties.

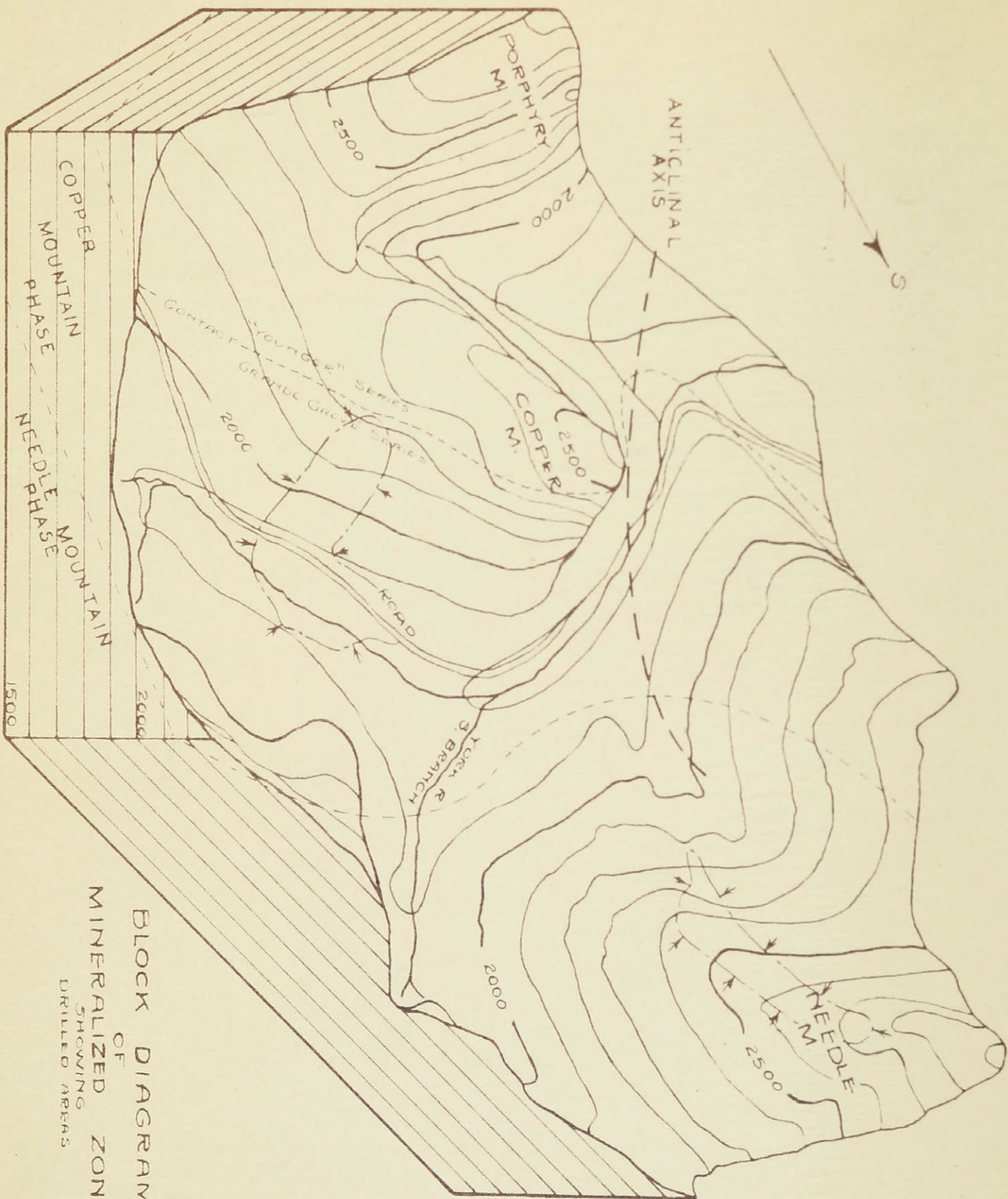
Grande Grève Formation

Jones (1931, p. 60) writes as follows of the Grande Grève and associated rocks in their unaltered state, surrounding the metamorphosed zone,

"The prevailing rocks of the region for some miles around are hard, cherty, dark grey, Lower Devonian limestones that are sometimes dolomitic. The chert occurs as small spots and lenses and in narrow bands. Associated with the limestone are beds of argillaceous limestone or slate. Coarse gritty sandstones are also found, usually grey and quartzitic." From his examination of the rocks near the property, Osborne would call many of the so-called

TABLE SHOWING STRATIGRAPHIC RELATIONS AT THE MILLER PROPERTIES

<u>AGE</u>		<u>CHARACTER BEFORE METAMORPHISM</u>		<u>THICKNESS</u>	<u>METAMORPHOSED PRODUCT</u>
EARLY MIDDLE DEVONIAN?		Pink and grey granite and syenite porphyries.			Kaolinisation.
LOWER DEVONIAN.	YORK LAKE SERIES?	Porphyry Mountain Phase.	Thin - bedded limestones and fine sandstones.	700'	Some re-crystallisation.
			Medium - grained sandstones.		Hornfels, quartzites and minor calc-silicates.
		Younger Series.	Shales, some thin limestones and sandstones.	800'	
	PART OF GASPE LIME- STONE GROUP. GRANDE GREVE FORM- ATION?	Copper Mountain Phase.	Calcareous siltstones with carbonate concretions.	1500'	Porcellanites, with garnet, diopside, and sanidine.
		Needle Mountain Phase.	Cherts and impure limestones.	1000'	Skarns and crystallised cherts. Diopside, wollastonite, scapolite rocks.



BLOCK DIAGRAM
OF
MINERALIZED ZONE
SHOWING
DRILLED AREAS

"argillaceous limestones or slates," calcareous siltstones and siltstones. He believes that the quantity of argillaceous material in the Grande Grève is not great.

In the metamorphosed area, the lowest rocks of the Grande Grève are exposed on Needle Mountain.

Needle Mountain Phase

The bottom of this phase has not been recognised, although probably a thickness of 1000 feet of rocks has been examined. These rocks consist principally of thick - bedded, fine siliceous siltstones, interbedded with impure, finely crystalline limestone. The rocks have highly variable carbonate and silica content, and are now white and porcellanous in character. The impurities have been crystallised to give skarn minerals, of which the most abundant are, wollastonite, diopside and some grossularite, ^{and members} scapolite, [^] of the epidote group. The siliceous layers are often very cherty^t, with clastic quartz less abundant than is the case on Copper Mountain. The cherts are generally crystallised. The rocks appear to have been formed fairly far from any source of coarse clastic material. They are exposed on a dome on the north ridge of Needle Mountain. This structure will be further discussed later.

Copper Mountain Phase

The Copper Mountain phase is thought to be at least 1500 feet thick. Siliceous rocks composed of diopside and clastic quartz, - now recrystallised, in most cases, to a rather even - grained mosaic, are the most abundant type here. Concretion-like masses of garnet and quartz are common in the central area. Near the southern margin of the altered zone these masses are diopside-quartz-calcite aggregates. Further south still, carbonate concretions are found with original clastic grains of quartz. It is believed that these rocks are

isochemical, and that the appearance of diopside or of garnet signifies the grade to which metamorphism has advanced. On the map entitled the "Miller Copper Prospects," in the enclosed folder these rocks of different grades are mapped as members 1B, 1C, and 1D.

It is notable that the Copper Mountain Phase lacks the considerable quantities of recrystallised limestones with skarn minerals that typify the Needle Mountain Phase, and it also lacks the argillaceous material typical of rocks assigned to the next group. The formation of garnet, which is most abundant in the Copper Mountain Phase, probably indicates however, the presence of minor amounts of argillaceous material in the Copper Mountain Phase.

The Younger Series

This series has been considered to belong to the York Lake Series for the following reasons. Its contact with the Copper Mountain Phase is gradational, and the Copper Mountain Phase is believed to include the uppermost rocks of the Grande Grève. Besides this, the Younger series is lithologically similar to the York Lake Series, - both are markedly argillaceous. Moreover, at York Lake, just to the east outside the Bonnacamp Map Area, the York Lake Series is striking directly towards Copper Mountain. A northeast plunging anticline apparently cuts the York Lake Series off at Copper Mountain, so that it does not extend any further southwest.

Assuming, then, that the Younger Series belongs to the York Lake Series, it would appear probable that the York Lake Series is, like the Grande Grève, Lower Devonian in age. Intrusives have never been seen to cut the Middle Devonian Gaspé Sandstones. At the Miller Properties, however, the Younger Series is cut by porphyries, metamorphosed, and bears minor sulphide mineralisation. It is also conformable and gradational with the Copper Mountain Phase.

It is believed for these reasons that the York Lake Series is Lower Devonian, and, further, that, when intrusion and ore-formation occurred, the land-surface was at the top of the York Lake Series. Thus, it may be mentioned in passing, at the time of ore-formation, the rocks superincumbent upon the Copper Mountain Phase probably did not exceed 2 - 4000 feet in thickness. This conclusion is supported by other considerations.

Near the top of Copper Mountain are exposed some 800 feet of dark hornfels interbedded with medium grained quartzites, and a few minor layers rich in carbonate.

On the col between Copper and Porphyry Mountains, a medium grained sandstone that is rather persistent and conspicuous overlies these dark hornfels, and is itself overlain on Porphyry Mountain by some 700 feet of rocks finer in grain and more calcareous in composition than those of the Younger Series on Copper Mountain. The rocks of Porphyry Mountain are less altered. Their top is now removed by erosion.

The Younger Series therefore, consist of 800 feet of argillaceous sediments overlain by at least 700 feet of rather more calcareous material. The prominent sandstone member separating these two phases may outcrop on the flat southeast of Copper Mountain. This sandstone occurrence and certain rocks similar to those on Porphyry Mountain, which are near the south boundary of the metamorphic area, further substantiate the structural interpretation to be described below. It is there pointed out that an anticlinal axis passes just southeast of the summit of Copper Mountain, plunging about 15° to the northeast. The southernmost occurrence of these rocks is believed to belong to the southeastern limb of this anticline.

All rocks in the metamorphic area are believed to belong to the Grande

Grève Formation, York Lake Series, or the Porphyry Intrusive series.

Plutonic Rocks

It has already been said that the acid igneous rocks were intruded into the Grande Grève before the Middle Devonian Gaspé Sandstones were laid down. If there was no great erosion after the intrusions and before the sandstones were deposited, the stratigraphic thickness of the York Lake represents the roof at that time above the Copper Mountain Phase.

Sills, dykes, and sheet-like bodies of granite and quartz porphyry, pink, buff, and grey in colour are found. Breccias with an igneous matrix are common, particularly on Porphyry Mountain. There are dykes on Copper Mountain on the mineralised area, but not on Needle Mountain. However, in the area of Younger Series rocks near the south boundary of the metamorphic zone, south of the east spur of the Needle Mountain, dykes are to be found. A few rather unsatisfactory strikes ranging from $N 50^{\circ} E$ to $N 70^{\circ} E$ have been taken on short segments of steeply dipping dykes. This direction, it may be noted, is about perpendicular to the long axis of the metamorphic zone. They may have filled tension joints opened up by an upwelling subjacent magma whose chamber was oriented with its longest dimension parallel to that of the mineralised zone.

Flow structures are not well defined but a few observations have suggested that one igneous centre is below the west flank of Porphyry Mountain.

The granite of the sill at the head of South Branch is a massive, even-grained quartz-orthoclase rock. Other masses are porphyritic, with quartz and buff, zoned plagioclases, of composition ranging from An 45 to An 5. Other varieties are whitish grey, and the proportion of quartz is highly variable in these. Some have a matrix so fine in grain that they merit the name quartz porphyry. (See plate 1).

In one slide, biotite, commonly chloritised, is found. The biotite has well developed pleochroic halos that suggest that the rocks are at least Palaeozoic in age. Jones has described a hornblende-biotite variety, and in some slides, sphene and apatite occur as accessories.

Kaolinisation of the porphyries is very prominent in some drill-holes on Copper Mountain. It is notable that molybdenite appears to be the ore most commonly associated with kaolinisation. It must be stated however, that this observation is made from the examination of very few cores. Osborne notes that kaolinisation is common near the tin deposits of Cornwall.

The contact metamorphism induced by the porphyry bodies upon the unaltered sediments is very slight. Sills thirty feet or more in thickness outside the metamorphic area have discoloured the underlying limestones only for an inch or two and overlying rocks for not more than 18 inches. Hence it seems probable that the metamorphism of the metamorphic zone was produced by volatiles from an as yet unexhumed igneous body.

"Volcanics".

Certain other minor types of igneous rocks occur. Some breccias, with a fine grained granitic mesostasis were believed by earlier writers to be volcanic. Osborne has no doubt that they are of satellitic origin. Jones writes of light-coloured volcanics which "consist almost entirely of very fine-grained quartz and orthoclase, the latter of a rather clear variety, (sanidine?) . Grains of hornblende.....may be present. These rocks have been rendered very hard and quartzose by the introduction of considerable secondary silica". In the 124 slides since examined by the writer it so happens that none have been found that contain significant quantities of

hornblende. Many slides answer to the description quoted if diopside be substituted for hornblende. No slides of this type show igneous structures, and they are frequently interbedded with other rocks of obviously sedimentary origin. There are certain members of the sanidinite facies described by Eskola, and some of the hornfelses classified by Goldschmidt that correspond perfectly to the mineralogic compositions of these rocks. Chemical analyses would settle whether these rocks are metavolcanics or not. It is significant that volcanics have not been reported from other Lower Devonian localities in Gaspe. They may have been tuffaceous sediments, but if so, one might expect them to be more aluminous than they appear to be. However, the rocks that look most like volcanics in this particular locality are of syenite or quartzless diorite composition. Such rocks would not give rise to tuffs so highly siliceous. The silica appears to be of clastic not secondary origin. In the hand specimen, the rocks might easily be taken for tuffs and "fine grained rhyolite flows," and in the absence of chemical analyses, it is impossible to estimate the ratio of quartz to feldspar. However, if volcanic material is present in rocks of this type, it seems probable that it is only in small quantities.

The most problematical type is a "trachyte", (See plate 2), that occurs in the Younger Series ^{and} in the Needle Mountain phase. It forms only narrow "flow's" or sill-like bodies, 1 to 3 inches in thickness. It is white to whitish buff in colour, the white phenocrysts of feldspar in the buff mesostasis giving it a patchy appearance. It is syenitic in composition, and some layers show very marked flow-banding, with aligned tabular feldspars forming "augen"-like patches in the finer flow-banded matrix. It is hard to conceive

of conditions under which flows so thin could be extruded. It seems more probable, perhaps, that they are sills that were intruded before the more granitic sheets in the area. Their thinness is perhaps to be explained by the high temperature of the magma and country rock which would perhaps reduce the viscosity of the magma. It is hard to explain under those circumstances, however, why the texture should be so exceptional. An aplite, pegmatitic, or normal porphyritic texture might be expected. These rocks show chloritisation of the biotite and sericitisation, and appear to have been altered to some extent either by the intruded masses of porphyry, or by the metamorphosing and ore-bearing solutions.

Modern volcanics frequently contain sanidine, and this feldspar is common in rocks of the altered zone. It might be thought that this provided strong evidence of a volcanic origin. However, the rocks that show the strongest resemblances to volcanics are not sanidine-bearing. It might be argued that only tuffs have given rise to sanidine, and this is a possibility that must be borne in mind. If so, the tuffs are far more quartzose than the trachyte flows associated with them, due perhaps to admixture of quartz of detrital origin.

The contact alteration by the Shap granite, in England, of siliceous limestones associated with acid and intermediate lavas and tuffs, is described by Harker (1891, pp. 268, 321 - 323). The conditions are rather similar to those at the Miller Properties, although alteration occurred at a far greater depth, - estimated at 14,000 feet. The only rocks among these that show close resemblances to the Miller rocks are the porcellanites derived from the clacareous siltstones, limestones, and argillites, belonging to Middle Coldwell Beds of the Coniston Flags Group. The volcanics give rise to different metamorphic derivatives, and the rhyolitic flows and ashes give feldspar-biotite

rocks with cyanite and some quartz. However, tuffaceous rocks of this nature with admixed carbonate, metamorphosed at a shallower depth might, it must be admitted, give rise to a rock with an aluminous calcium pyroxene instead of biotite and cyanite.

Whether volcanics occur in the metamorphic area or not, however, is not of great significance. It seems certain that there is no large development of flows and pure tuffs. If volcanics are present, they are of minor importance and are interstratified with the Grand Grève and Younger Series.

Local Structures

Due to the monotony of rock-type, and the lack of horizon markers, it has been difficult to decipher the local structures. Frost heaving and the lack of good natural exposures have provided additional difficulties. However, certain general structures may be noted.

There are three important structural trends near the metamorphic area. The first, and regionally the most important, is that of the rather gentle regional open folding of the Gaspé Peninsula. These folds have already been discussed, and are stated to strike about $N 70^{\circ} E$, although variation in strike is conspicuous locally.

The second trend has become apparent with the detailed mapping of the copper deposits. There are two parallel fold axes, and possibly a third, which strike in a general northeasterly direction. A northeasterly trending anticline, pitching about 15° in that direction, has been tolerably well defined; its axis runs southeast of the south spur of Copper Mountain. This broad and open structure is reflected in the trend of the outcrop of the Younger Series. The contact of this series with the Copper Mountain phase runs in a southeasterly direction on the west flank of Copper Mountain, and then apparently swings in

an easterly direction on the south flank of that mountain, and continues in a rather more southerly direction passing down the valley of the South Branch to the boundary of the area.

There is an occurrence of rocks similar to the Porphyry Mountain phase of the Younger Series, about 2 miles east of Needle Mountain. A medium grained sandstone has been recognised on the flat southeast of Copper Mountain. This rock resembles lithologically the rather persistent beds that occur between Copper and Porphyry Mountains. These occurrences have already been mentioned in connection with the stratigraphic column of the metamorphic area.

A synclinal axis roughly parallel to this anticlinal one passes about $\frac{1}{2}$ miles northwest of Copper Mountain just southeast of Twin Lakes. Jones recognised this axis in mapping the porphyries about Twin Lakes and on Porphyry and Copper Mountains. In general the Twin Lake porphyry is on the west limb of the syncline. The slopes of Copper and Porphyry Mountains are on the east limb of the syncline, (or on the west limb of the adjacent anticline).

The southeast limb of the anticline has been traced on the east slope of Needle Mountain. No well defined synclinal axis has been mapped to date in this area. Strikes tend to be irregular and dips of 45° and 50° have been recorded on the southern limb. These are abnormally steep, for elsewhere there are few dips exceeding 30° , and strikes are fairly concordant. These abnormalities may be due to local faulting.

Thus folding at the properties is simple. Fold axes pitch about 15° northeast. An anticlinal axis runs southeast of the south spur of Copper Mountain, and a synclinal axis runs just southeast of Twin Lakes. In response to this structure, the contact of the Younger Series trends southeast on the

west flank of Copper Mountain, and swings east on its southern flank. It then swings south again down the valley of the South Branch. The structure is broad and open so that the effect of the pitch is conspicuous. Dips seldom exceed 30° , except in the southeast corner where there may be faulting.

On the north shoulder of Needle Mountain there is a minor dome structure of economic importance. Osborne believes this dome is situated on the main anticlinal axis, although it seems possible that it is a minor subsidiary structure on the north west limb. Mineralisation seems to be restricted to some extent to tabular masses on the east flank of this dome.

Faulting was mentioned as a possible explanation for a few anomalous strikes on the southeast limb of the anticline. No slickensides have been seen, and in fact slickensides have been seen only at one locality in the entire Bonnecamp Map Area. At this latter locality faulting was evidently very minor and irregular. Strike faults with no topographic expression have been mapped in adjacent areas, but evidence of faulting in the Bonnecamp Map Area is lacking at the present time. It must, however, be borne in mind that outcrops are poor. Frost-heaving may account for some of the anomalous strike and dip readings.

A third structural direction is discernible in the trend of many of the river valleys, and of the mineralised area itself. This is roughly parallel to the trend of the long axis of the Table Top batholith. This direction lies a little west of north. What structure controls these orientations is not certainly known. A joint-set has been found running in this direction and it has been supposed that this set, where joints are closely spaced, controls the northerly trend of valleys. The set is perpendicular to the trend of fold axes throughout the Central part of Gaspé, and it is

in the direction in which joints would be formed under tension.

A minor topographic expression of the joint-systems is seen in the bench-like outcrops that so frequently occur on Copper Mountain. The joints usually have a steep dip, and several general trends are recognisable.

A study of joint-systems might conceivably prove of considerable interest on Copper Mountain. At this locality much of the mineralisation follows minute fractures, and the drill cores show many intersecting joints, some with one type of mineralisation, others with another type. By a study of these systems and the mineralisation associated with them, an order of ore deposition might become apparent. Some such study was attempted in a superficial way by the writer with the core-samples at his disposal, but such a treatment as was possible is quite inadequate for such a problem.

Intrusive structures have already been dealt with sufficiently earlier in this report. It suffices to remark that porphyry sheets are most abundant at the northern end of the area, notably near the Twin Lakes, on the northwest slope of Copper Mountain, and on Porphyry Mountain.

METAMORPHIC AND MINERALISING PROCESSES.

General Statement

In default of evidence to the contrary, the metamorphosing and mineralising episode in a pyrometasomatic deposit is regarded as a simple rise and fall of temperature, accompanied by various intrusions, emanations, deformations, or other more or less important incidents. In a general way, the metamorphism is produced by the rising temperature, and the minerals so formed endure in most cases after the temperature has dropped again. Most of the metallic mineralisation, on the other hand, takes place during the ensuing period of falling temperature. Some of the metamorphic minerals unstable at this stage, may be made over by the mineralising solutions. While these two processes are continuous and are scarcely separable upon logical grounds, it is perhaps convenient for purposes of description to distinguish between the minerals of metamorphism and those of the metallising epoch. The intimate relation between the two must, however, be borne in mind.

At the Miller claims the first sign of alteration borne by the calcareous siltstones is the loss of their dark colour. In rocks of this grade there is also some recrystallisation of the carbonate, but there were no new minerals formed. The quartz still retains its clastic outlines. In a general way, the area of bleached rocks may be taken as the limit both of the terrain in which copper-mineralisation may be expected, and of limestone alteration. Galena mineralisation may have been more widespread.

At an early stage, chert and clastic quartz are recrystallised to an even-grained mosaic, and all except the largest grains lose their conspicuous clastic angularity. At this grade also, the decomposition products of chemical weathering, - kaolin, phengite, etc., - are made over to feldspars

and, in the presence of calcium and magnesium carbonate, to angite and, perhaps, occasionally to epidote. The decomposition products of chemical weathering are those first rendered unstable by the rising temperature and are reconstituted to give feldspars.

The presence of even a small quantity of calcium carbonate in the sandstones of Grande Grève has a marked effect upon their alteration. The carbonate was readily silicated, and on Needle Mountain the calcareous rocks have yielded calc-silicate minerals such as wollastonite, scapolite, and some zoisite, while ⁱⁿ both the Needle and Copper Mountain phases diopside and garnet are found. On Copper Mountain, allanite and epidote seem to be more abundant than zoisite. In both phases, simple quartz-diopside rocks are abundant, and represent the alteration product of a somewhat impure sandstone. The quantity of feldspar in these rocks cannot be estimated for the colourless constituents are very fine-grained and glassy, and any feldspars present do not show twinning of any kind.

Most of the rocks of the Grande Grève are fine-grained, and are white, if no calc-silicate minerals are present, pale greenish, if they contain diopside or epidote, or pale brown, if they contain grossularite. Where epidote is particularly abundant on Copper Mountain, olive green rocks are found. Bedding is preserved as compositional banding, and is generally quite conspicuous on the drill-cores.

Thus the calcareous siltstones yield fine, white or light-coloured porcellanites, usually containing quartz, diopside, and often one or more of garnet, wollastonite, scapolite, and calcite.

The alteration of non-calcareous siltstones apparently follows a different course. These are usually more argillaceous, probably contain more

iron, and are finer grained after alteration, even, than are the fine-grained calc-silicate porcellanites. The non-calcareous siltstones are characteristic of the lower beds of the Younger Series, and are found interstratified with more calcareous beds, on the upper slopes of Copper Mountain. The calcareous beds here show much the same grade of alteration as beds of similar chemical composition lower on the mountain, so that the non-calcareous beds are also at about the same grade of alteration. In spite of their high grade, they are dark, being decolourised only along minute fissures where hot solutions could penetrate.

Under the microscope they are seen to consist of a dark, cloudy mass of minute biotite flakes, with other scaly products too fine to identify. The other minerals that are stable in a biotite hornfels, according to Goldschmidt, (See fig. 3, p. 83), are anorthite, cordierite and hypersthene. In the hornfelses less rich in $(Fe, Mg)O$, andalusite, anorthite, cordierite, and sericite form a stable association. These biotite and sericite rocks belong to different classes of hornfels, - still following the Goldschmidt classification, - from the diopsidic porcellanite hornfelses above described.

Other minerals seen in the biotite hornfelses were:- quartz, a pyroxene (?), chlorite (?), sericite (?), and a feldspar showing simple twinning.

Zones are not easily defined. However calcareous concretions are abundant in some of the limestones surrounding the metamorphic area. At the southeast corner of the area concretions of this type are found to be bleached and the carbonate is recrystallised, but associated clastic quartz grain keep their angularity. A little to the northwest, diopside appears in these, and the quartz is recrystallised, and on the west flank of Copper Mountain garnet also occurs. The silication becomes more and more complete, and in the garnet

zone only a little calcite is present. This appears to be of later introduction in many places and may have been deposited by supergene water.

Some of the features that might be expected, but that are lacking, are very interesting. Thus there is no schistosity, - only one slide showed orientation of the pyroxenes. The rocks are never more than of medium granularity. There is a complete lack of stress minerals such as cyanite, staurolite, chlorite, etc. There are almost no hydroxyl bearing minerals present in quantity, except in the biotite hornfels which is largely confined to the Younger Series, and is notable for its fine grain. There is no, or almost no, chlorite, amphibole, vesuvianite, chondrodite, etc. present. The rocks belong to the more calcareous classes in the hornfels and sanidinite facies (See fig. 3, p. 83, and fig. 4, p. 84), classified by Goldschmidt and Eskola. In general those minerals which would be unstable in such associations are absent. Thus andalusite and sillimanite are lacking, while cordierite was found by Osborne ⁱⁿ one slide only. The spinels are absent and this is to be expected in view of the excess silica present.

In the absence of chemical analyses it is difficult to estimate how much material was brought in by the metamorphosing solutions. Some of the silica may have been introduced by them, and some, introduced soda may have entered into the feldspars and scapolite, and some magnesia may have been taken up by the diopside. Small quantities of rather later epidote, chlorite, antigorite, talc (?), sericite, zeolites (?) and other minor constituents are hydroxyl-bearing and probably belong to different epochs of the metallisation. Carbonates, fluorite and gypsum also are found as late minerals.

There is another feature ^Athat perhaps can be correlated with the early phases of ore-deposition. Some of the porphyry dykes and some of the porcellanites and sills are extensively kaolinised. There seems particularly to have been deposition in the kaolinised bodies of quartz and molybdenite. The silicification occurs in veins.

Another interesting feature will be discussed later. There was a high degree of mix-crystal formation giving rise to pigeonite, - the "enstatite-augite", - and sanidine, the high temperature potash-soda feldspar.

Needle Mountain Phase.

The rocks of Needle Mountain are composed of skarns high in CaO, interstratified with more siliceous rocks. Probably, about half the rocks are simple quartz-diopside rocks with some residual carbonate which indicates that silication is not complete. The bulk of the remaining rocks contain these minerals with some of the following:- scapolite, wollastonite, a wollastonite-like mineral of unknown composition, garnet, and a fine granular mineral of high birefringence which is possibly leucocoxene. Sanidine and pigeonite are found in some of them. Since the feldspars are glassy, un-twinned, and fine in grain, it is quite impossible to estimate their quantity in each rock, or to determine the composition. Some are positive, some negative and the refractive indices are, in some slides, higher and, in others, lower than Canada Balsam. The plagioclases are probably rather anorthic in rocks as highly calcareous. (Harker, 1932, p.83, and Mäkinen, 1917, pp.146). In hand specimen, the rocks are porcellanous in appearance, and may be milky white, pearly, pale green, brown, or bluish grey in colour, and are consistently fine in grain except for a few garnetiferous and wollastonite rocks.

SUMMARY OF ALTERATION OF ROCK TYPES.

SILICEOUS	MAP UNIT	CALCAREOUS	YOUNGER SERIES
Decolourised sandstones Calcareous concretions No new minerals.	1B	Decolourisation. Recrystallisation	Sandstones, Argillites, thin bedded limestones but little altered.
Decolourised, clastic outlines retained by quartz. Some new minerals.	1C	Recrystallisation. Some Silication.	Some recrystallisation and silication in calcareous layers.
Garnet, Sanidine, Quartz, diopside Porcellanites.	1D	Complete Silication	Biotite-hornfels, Pearly Quartzite. Minor calc-silicates.

Rather conspicuous cleavage surfaces can often be seen, and they are believed to be poikiloblastic crystals of scapolite or, (less abundantly), perhaps of carbonate or feldspar. There are some rocks in which the diopside and garnet are gathered into small granular porphyroblastic aggregates or clusters. Such rocks have a spotted appearance. The ores also often look "spotty", for they are generally disseminated, the grains often being rimmed by pyroxene or zoisite (?) and, rarely, carbonate. The textures seen under the microscope are rather variable. The nearly pure quartzites and the matrix of some of the crystalline limestones usually show the simple even-grained mosaic characteristic of such rocks. The few large angular grains may represent clastic remnants. Idioblastic porphyroblasts of simple diopside crystals are common, particularly as a result of vein-wall alteration. In some slides the porphyroblasts (Plate 13) occur in groups of well-formed crystals, in others they appear as feathery groups (Plates 7-11), and in others still, particularly where diopside is not very abundant, as fine granular aggregates and rosettes (Plates 18, 20, 21). Wollastonite favours a rather feathery or radial growth in a few cases, but is usually lath-like (Plate 12). It sometimes forms a feathery mesostasis in which garnet or pigeonite form porphyroblasts. Scapolite, (Plate 16), may form idioblastic porphyroblasts, or, equally commonly, it may show a sieve-like structure, the relatively large poikiloblasts containing granules of garnet, diopside, carbonate, etc. Quartz, sanidine, and zoisite are found in many of these rocks as porphyroblasts of apparently posterior formation. Carbonate porphyroblasts are also found in the quartzose rocks and perhaps represent, in some cases, small concretions present in the original rock that escaped silification.

Certain phenomena have been noted, which suggest possible replacement although there are no definite criteria for recognition of it in most cases. Optically continuous scapolite is apparently replaced by carbonate, and in another case by carbonate and sericite. This latter case is further described below. Carbonate also apparently replaces wollastonite, diopside and feldspar. Wollastonite appears in one case to replace scapolite.

It may be mentioned that selective replacement on a small scale of bedding by the ores is not noticeable on Needle Mountain, although in a general way the carbonate beds are the most readily replaced. The dark hornfelsed siltstones of finest grain and non-calcareous in nature show no extensive mineralisation.

Interstratified with the typical rocks above described are a few, extremely fine-grained biotite-hornfelses. They are hard, dark, flinty, and have a conchoidal fracture, and are seen to consist mostly of scaly biotite, of pyroxene, and quartz porphyroblasts with, perhaps, some feldspar. There are other very fine grained rocks of which one was purplish in colour, with conchoidal fracture. It was an indeterminable aggregate of brown and colourless scaly products. Two other very fine-grained dark rocks were found under the microscope to be scapolite rocks. One contained mostly wollastonite, and lacked quartz or carbonate. Its colour appears to result from minute, greenish, cloudy granules that may be leucoxene, or an alteration product of the pyroxene. The other had porphyroblastic scapolite, carbonate and diopside with minute opaque, possibly graphitic, grains, and a few granules of mineral that was negative and that appeared to be epidote.

One other slide shows features of interest. The core-specimen from which it was made is a little coarser than usual, grey, and shows a feathery mineral, and also garnet (?) and a pale greenish mineral, - probably diopside. It shows a little kaolinisation. Under the microscope, it is

seen to have quartz, a biaxial positive (?) felspar, and the uniaxial negative sanidine variety. These clear, colourless constituents compose perhaps 15% of the whole. There is about 25% of carbonate, and the remaining 60% is composed of fibrous, colourless to greenish sericite or paragonite. A few granules of a mineral with a high refractive index occur, possibly derived from a once existent pyroxene. The mica and calcite form intergrown aggregates that suggest palimpsest porphyroblasts of scapolite. It seems as though scapolite has been pseudomorphed by these minerals. It is the only case of extensive alteration of this type seen, and probably represents a fairly local occurrence. Replacement of scapolite by calcite alone, however, is fairly common. Veins of sulphides with diopside, zoisite (?), quartz, and carbonate are abundant, although on Needle Mountain replacement of the carbonate matrix is the rule. Wollastonite also occurs in veins, and may represent pre-existing carbonate veins that have been silicated, although a quartz vein bearing galena (?) was seen to be cut in one place by a wollastonite-chalcopyrite vein, an occurrence which would suggest that there was a minor period of wollastonite-veining. Garnet is not conspicuous as a vein mineral on Needle Mountain. A characteristic wall-rock alteration is the production of diopside in the walls, with zoisite (?) in minor quantities; a mineral like leucoxene also occurs under these circumstances in minute grains.

The ores on Needle Mountain include the following sulphides, approximately in order of deposition:-

Chalcopyrite	Galena
Pyrrhotite	Molybdenite
Pyrite	Bornite
Sphalerite	

Chalcopyrite and pyrrhotite alone of these are of any importance. Diopside, scapolite, leucoxene (?), sanidine, wollastonite, quartz, zoisite, and possibly some carbonate, are gangue minerals of the earlier stages while fluorite and more carbonate apparently belong to a rather later stage of metallisation. The metallisation will be further discussed later.

The Copper Mountain Phase.

The rocks now to be described provide certain strong contrasts when they are compared with the preceeding group. The Copper Mountain phase was originally rather more siliceous than the Needle Mountain, and there are, therefore, almost no rocks containing wollastonite, of scapolite, and crystalline limestones are rare. Instead, quartz-diopside, and quartz-garnet-diopside rocks are the rule. Quartz (with felspar (?)) usually occupies 50% or more of the rock, with diopside and garnet forming the rest. Garnet is important both as a rock-forming and vein mineral. True epidote and albanite seem more usual than zoisite. Relict carbonate, if present at all, seldom exceeds 1-3%, and it appears in most cases that silication is complete, and that any carbonate present is later.

As on Needle Mountain, it is impossible to estimate the proportion of felspar present, so that it is conceivable, although improbable, that in some rocks the felspar content may exceed that of the quartz. Again the felspars include sanidine, orthoclase, and plagioclases of various compositions, some positive and some negative.

The quartz-diopside rocks are similar in all respects, including textures, (See p. 30), to those occurring on Needle Mountain, and therefore need not be described. When garnet occurs as a normal metamorphic

constituent, it does so in granular aggregates more or less mixed with a similarly occurring pyroxene. Harker suggests that irregular masses of this type are indicative of rapid cooling. There appear to be two generations of garnet; - the metamorphic type, and the vein-forming type, which is usually a little later, although they both probably were formed at nearly the same time. The formation of vein-garnet was completed before large-scale metallisation began. Idiomorphic dodecahedra are rare, generally being found only in the carbonate rocks, when the garnets are frequently anisotropic and conspicuously zoned and twinned.

Minerals of the epidote group are often present as minor constituents of the rocks, and when they are relatively abundant, - that is when they form 5% of the whole, - they lend an olive green tinge to the rocks. Both epidote and allanite are present apparently, and there are certain other minerals which resemble epidote generally, but whose optical properties do not correspond to it. The epidotes usually occur as grains or granular aggregates, and although they do not show their crystal form, they are of high crystalloblastic rank. They are often gangue minerals, and belong to a rather early stage in vein formation. The disseminated grains in the bulk of the rock bodies were very probably of pneumatolytic origin, and were formed after the main epoch of metamorphism.

Unusual rock types include the purer quartzite members. One such rock is a quartz-diopside-ankerite (?) rock in which the quartz is recrystallised and unusually coarse. The rock might be termed a fine-grained grit. One impure quartzite showed relict clastic quartz grains in a crystalline mosaic of quartz and fine scaly sericite which made up perhaps 30% of the whole slide. This rock comes from the upper most beds, and might

be classified with the Younger Series .

At the other extreme are rocks high in garnet and pyroxene. These are also unusual types. Pyroxene seldom exceeds 30%, but garnet-pyroxene rocks occur with 75% garnet. Here a little quartz with andesine (?) is found. Some masses of garnet are anisotropic and zoned, but mostly they are rather irregular, enclosing poikiloblastically diopside of normal type. A few garnets show their crystal boundaries. Rocks of this type are often a little more coarse grained than usual, and are greyish-brown in colour.

No rocks very high in carbonate were seen, - silication has been extensive on Copper Mountain. The silication of carbonate knots has been mentioned in connection with zoning.

The mineralisation of the Copper Mountain Phase is in certain respects unlike that of the Needle Mountain Phase. The more siliceous rocks of Copper Mountain were not replaced so extensively, and most of the mineralisation occurs in small fissure-stockworks delimited by the most intensive veining. The fractures are very numerous and intersect at all angles. No systems have yet been determined. Some of them are open fissures with well crystallized cavity linings, - a feature that confirms the belief that the mineralisation occurred at a rather shallow depth.

The chief metallic minerals are chalcopyrite, and pyrite, - not pyrrhotite. Molybdenite, - (rather abundant), - sphalerite, galena, bornite, magnetite, and possibly tetrahedrite have also been found in unimportant amounts. Magnetite is the only oxide and that has very seldom been seen. It seems likely that iron oxides would have been silicated if they had occurred at high temperature. Garnet, diopside, pigeonite, sanidine,

quartz, epidote, and allanite, and a little carbonate are found as rather early gangue minerals. At a later stage calcite, fluorite, and amorphous chalcedonic silica, were introduced and are found lining vugs and in the centre of crustified veins.

The most marked kaolinisation is found in the terrain of the Copper Mountain Phase, and, while it affects the porphyries most markedly, some of the quartz-diopside and garnetiferous rocks show kaolinisation. This has, in many rocks, taken place in small spots or patches, and the ordinary vitreous or porcellaneous lustre is replaced in patches by dull, white, lustreless decomposition products. Many of the smaller "spots" may represent kaolin pseudomorphs of primary feldspathic sand-grains.

Some of the porphyries have their feldspars nearly completely kaolinised and consist of a dull whitish-grey kaolin mass with rounded quartz grains embedded in it. Under the microscope the feldspars are seen to be decomposed nearly entirely to a granular translucent mass of buff-coloured, scaly material. Veins of milky-white quartz and molybdenite were seen in several sections of the core of this nature, and it is possible that they were formed during the kaolinising epoch.

Osborne suggests that if kaolinisation is sufficiently widespread in the porphyries, it may be possible to save the rock as a by-product. Drilling has shown that the alteration occurs 1000 feet down as well as at the surface. He believes the kaolinised dykes may be the channelways for the ore-solutions.

Summary of the Paragenesis of the Ores.

Douglas made a study of the ore-mineralisation from a suite of 60

polished sections. His results led him to list tentatively the relative ages of the various ores. The limitations of such a scheme are obvious. The two bodies are of several million tons each, and each has a complex and a different history. However the present writer and Douglas each tried to work out a paragenesis, and essential agreement along broad lines has been reached. Unlike Douglas, however, the writer believes that molybdenite mineralisation at least started early. He has seen a molybdenite-epidote vein cut by a pyrite vein. In another vein, there was crustification, with the same sequence ^{of minerals} lining both walls. Quartz and pyrite lined the vein on each side and then a pair of bands of dark quartz and molybdenite, and then a central zone of amorphous silica and pyrite. Another symmetrically crustified vein showed quartz on the walls, with molybdenite, and then more quartz toward the middle, with blebs of chalcopyrite forming an innermost zone.

The writer summarizes therefore the conclusions of Douglas diagrammatically in the following tables, and adds to them a few gangue minerals not considered by Douglas. The writer believes the anhydrite, and fluorite to be later than Douglas thought them to be. However, few specimens were seen, and in any case, these minerals are of academic interest only. Apart from lengthening the pyrite and molybdenite lines, and showing anhydrite and fluorite as late minerals, the writer follows Douglas closely. Naturally such a scheme cannot attempt to be rigorous.

The Younger Series.

The metamorphism of the Younger Series was apparently only intense in its lower members. The slides examined, however, are not very

PARAGENESIS - NEEDLE MOUNTAIN

Pyroxene	_____
Scapolite	-----
Lencoxene	-----
Wollastonite	-----
Sanidine	-----
Quartz	_____
Pyrite	-----
Chalcopyrite	_____
Cubanite	-----
Pyrrhotite	_____
Bornite	-----
Sphalerite	_____
Galena	_____
Carbonate	-----
Zoisite	-----
Fluorite	_____

PARAGENESIS - COPPER MOUNTAIN

Garnet	_____
Diopside	_____
Sanidine	_____
Quartz	_____
Epidote and Allanite	_____
Pyrite	_____
Magnetite	-----
Molybdenite	-----
Chalcopyrite	_____
Pyrrhotite	-----
Bornite	-----
Sphalerite	_____
Carbonate	_____
Amorph. SiO ₂	-----
Fluorite	-----

representative, and some of them come from the edge of the metamorphic zone in the Porphyry Mountain area.

Three slides of very fine, dark, banded hornstone from the basal transitional beds were found to contain quartz, biotite, and a cloudy, green, very fine material that was just possibly chlorite. In one slide there was a little very fine-grained pyroxene (?). The latter slide had a few relict clastic quartz grains a little larger or more angular than those composing the mesostasis. They were once very fine-grained, siliceous of low carbonate content siltstones. They have become decolorized only along joint-fissures.

Another slide contains largely quartz, a little carbonate, and a pyroxene (?), optically negative (?), with a rather large optic axial angle, and an extinction angle of about 22° ; it has a birefringence a little low for a normal augite. The rock is a very fine-grained, light-coloured sandstone. Another pyroxene (?) of unknown composition comes from a siliceous limestone from the calcareous Porphyry Mountain phase of the Younger Series. It resembles augite, but apparently has an extinction angle of about 12° . The rock is medium grey, very calcareous, and very fine in grain.

A decolourised limestone from the Porphyry Mountain phase showed extremely fine carbonate, a little quartz, very little pyroxene, and a little epidote (?). This is probably characteristic of the very first stages of metamorphism of a rock of this type.

A slide was made of one of the carbonate concretions from the east flank of the east spur of Needle Mountain. The knot came from the group of rocks strongly resembling those of the Porphyry Mountain phase.

It consisted largely of carbonate granules a very little quartz, a few needles of medium birefringence, probably tremolite, a little allanite (?) and possibly sericite.

The examination of these rocks was difficult. They are all very fine in grain, and dusty products that may in part be graphite, often make the rocks cloudy. They are of particular interest, however, in that there are types among them that show only the beginnings of metamorphism and that are the chemical analogues of more highly altered members of the Copper Mountain and Needle Mountain phases. It is of particular interest that nowhere has there been recognised a large-scale development of amphibole. In several slides of all formations a few minute needles were recognised that might have been tremolite, but nowhere that the writer saw, were they at all abundant, or of moderate size. Osborne and Jones report that they have seen tremolite on several occasions.

The biotite hornfels belong to a stability field more aluminous than is usual in the rocks examined. Diopside is not stable in that field. A few minute pyroxenes (?) were found in one of them, and, if the rock had attained equilibrium, the pyroxene was probably hypersthene or enstatite. The associations to be expected in a biotite hornfels include hypersthene, cordierite, and anorthite. In the rocks of coarser grain and more deeply buried, it seems that hydroxyl-bearing amphiboles and micas, if ever formed, were largely decomposed to their anhydrated equivalents. Thus tremolite, if ever formed, probably gave enstatite and diopside or pigeonite, and biotite likewise would give hypersthene and cordierite. Neither hypersthene nor cordierite have been recognised by the writer in these slides. Osborne found cordierite in only one slide, and there it

appears to be part of a metastable association. This suggests that the presence of biotite in the Younger Series is to be explained largely by the fact that the rocks of this series are more iron-rich and aluminous than are the rocks of Copper and Needle Mountains.

There is but little mineralisation in the Younger Series. It appears that the rocks were not, on the whole, sufficiently porous to allow the diffusion of the ore-solutions. This formation appears to have acted as a cap to the rising solutions. Elsewhere, it has commonly been found that extensive mineralisation has taken place beneath such a capping formation, and the solutions may have been forced to spread out laterally beneath it for a considerable distance.

Intrusives.

The intrusive rocks of the metamorphosed areas have already been described in connection with the stratigraphy, and their alteration has been mentioned under kaolinisation. Apart from rather strong kaolinisation and sericitisation of the feldspars, there is little alteration. Chlorite appears to pseudomorph hornblende in one slide, a pyroxene has replaced it in another, and biotite is often irregularly chloritised.

The porphyries contain molybdenite, chalcopyrite, ^{and} pyrite in quartz veins, and it seems probably that their alteration was produced by the ore-solutions.

Petrographic Description of the Mineral Species.

124 slides were examined. With the exception of the porphyries, they were found to be consistently fine in grain. Again with the exception of the porphyries, they are remarkably fresh, and all the feldspars are

clear and glassy. The extreme fine grain made the determination of optical properties difficult, and it was often impossible to find interference figures, accurate extinction angles, or good cleavages.

Silica

Quartz is very widespread, but it is impossible to determine optically the relative abundance of quartz and feldspar, as both are clear and glassy.

Quartz, in the diopside porcellanites, occurs most commonly as a constituent of the very fine grained mesostasis. With the diaphragm of the substage closed, this mesostasis very often has a "wetted" appearance that suggests a mosaic composed of allotrioblastic crystals of various refractive indices. However, it is quite impossible to estimate the quartz-feldspar ratio either in the mesostasis or amongst larger grains.

Occasionally, larger angular crystals are found that have an outline suggestive of their original clastic origin. In the rocks most highly silicated, however, only the larger primary sedimentary features have survived. Thus, some slides show an area of even-grained mosaic quartz and no other minerals. The rock surrounding this area may show abundant diopside or other mafic material. These areas are parts of recrystallised cherty beds or concretions.

The porphyries have a very fine-grained matrix composed of quartz and feldspar. Rare rounded quartz phenocrysts occur in them also. In hand specimen this quartz is milky white or glassy.

In the veins, quartz had a tendency to assert its crystal boundaries. It was often deposited in open fissures later filled by calcite and ore minerals. The vein quartz may be milky, clear, dark, or, rarely,

brownish.

Quartz is found, in a few slides, to have filled cavities between irregular masses of garnet. It appears to be of rather late introduction in this case. It seems likely that some silica was introduced during silication. Winchell, (June, 1924, p. 388), shows that the silication of a quartz-calcite rock may involve a volume change of more than 30%, if the original CaCO_3 and SiO_2 constituents are present in equivalent proportions. At Bingham, Utah, where he examined the silication of siliceous limestones, he concluded that there was no significant volume change during the process, and therefore that some kind of volume-for-volume replacement must take place. On the Miller Properties, no evidence has been seen of a significant change in volume during silication of the more highly silicated beds. On the other hand, there is little evidence of extensive silicification preceeding the period of ore-formation, and about contemporaneous with silication. Upon the basis of the present evidence, therefore it is not possible to state whether quartz was introduced at the time of silication or not.

In a number of slides, minute aggregates of a platy or fibrous minerals were noted. They were colourless, had a fairly low refractive index, and had a birefringence as low as quartz or perhaps lower. It has been thought possible that the mineral might be tridymite. It is of no importance from the point of view of bulk, but if the mineral is tridymite, a temperature in the neighbourhood of 870°C is required for the inversion to take place.

If such a temperature was reached, it may have been attained only locally, ^{for} traces of tridymite might otherwise have been more widespread.

Mäkinen estimates that in lavas, the stability^{range} of sanidine is from 1200° to 800°C. Sanidine is commonly found as a rock-forming and as a vein mineral in the present rocks. Under metamorphic conditions, potassic, albitic, and anorthic feldspars may form solid solutions at temperatures lower than they do in lavas, but a temperature of 800 to 900 degrees may have been approached locally, although this is believed to be a rather high temperature in all probability for a metamorphic aureole. It is possible that tridymite was formed as a metastable form below 878°C. If tridymite formed the bulk of the groundmass in some of the sanidine rocks, at the time of its reversion to quartz it may have lost its characteristic platy crystal-form. Only where tridymite showed an idioblastic relation to sanidine or some other mineral that suffered no later change, would quartz pseudomorphs show traces of the earlier, and now reverted, mineral. In this way, nearly all the traces of tridymite would be lost.

If the mineral in question is not tridymite, - or quartz pseudomorphs after it, - it may be a zeolite.

A few other fine colourless aggregates with low refractive indices could not be identified.

Feldspars

The plagioclase feldspars in the porcellanites are present in the mesostasis with quartz, and are glassy and untrapped, and, therefore, it is impossible to identify them in most cases. In one case, a grain appeared to have a composition of about An 16. In other slides, biaxial positive and negative feldspars were found, and their indices are in some slides greater, and in others less than are the indices of balsam.

Mäkinen, (1917, p. 142), states that in rocks of this type, potassic feldspars may often not be as abundant as is generally supposed. He made a study of many so-called orthoclase-bearing metamorphic rocks, and found that in many cases there was no orthoclase but that microcline and plagioclases occurred instead. Dolan found plagioclases in the aureole of Mount Royal were intermediate. (1). Harker, (1932, pp. 83), stresses that plagioclases present in a highly calcareous rock may belong to the intermediate or anorthic end of the series. The production anorthite in an impure limestone requires that "the non-carbonate part of the rock must be rich enough in alumina to yield andalusite". He continues that albite and orthoclase may be formed by the conversion of paragonite and sericite respectively. However if feldspar was produced in this manner in the Grande Greve rocks, there should be a zone outside the feldspar zone in which the reaction, $\text{mica} + \text{SiO}_2 = \text{Feldspar}$, did not take place. Here sericite should be abundant. This zone has not been recognised. Furthermore, most of the rocks are sufficiently calcareous that no alkali micas or feldspars would be formed during the course of the metamorphism. In the present case, therefore, it seems probable that any alkali feldspars present are clastic grains recrystallised.

Anorthite, on the other hand, may be derived from epidote, and these two minerals are stable products commonly formed at different grades in the more highly calcareous rocks. The hornfels and sanidinite facies diagrams show the stability relationships of the micas and anorthite with diopsidic rocks. It will be seen that the micas and diopside do not form

(1) Dolan, E.P. - "Metamorphic Zones of Mount Royal". M. Sc. Thesis, Unpublished, McGill University, 1923, pp. 24.

a stable association. The writer, therefore, believes that no alkali feldspar was formed from micas, and that the feldspars present in the diopside porcellanites are rather anorthic in most of the slides.

Grossularite is a stable phase in the hornfels facies, but should not form in rocks of the sanidinite facies. In the hornfels facies, the grossularite phase separates the wollastonite and anorthite. The Grande Greve rocks contain garnet, and, in their mineral associations generally, they very strongly resemble the hornfels facies as defined by Goldschmidt, and Eskola. In that they contain sanidine and pigeonite, however, they also resemble the rather unusual sanidinite facies of Eskola.

Some of the grossularite was presumably formed from anorthite, carbonate, and quartz.

The zoned feldspars, (Plate 1), of the porphyries have already been described and need not be discussed here.

Orthoclase has been found in several sections of the Grande Greve rocks and in the Younger Series. The mineral is invariably xenoblastic and can only be identified by its negative character and low refractive index. It is very rarely twinned but, when it is, it is according to a simple law.

The variety of potassic feldspar with a low optic axial angle known as sanidine, is fairly abundant both in veins and in the mesostasis. It probably is not as abundant as more normal potassic feldspars. Its significance will be discussed later.

Carbonates

Carbonate material was of prime importance in determining the course of alteration in these rocks. Relict carbonate is abundant in many of the

rocks that are incompletely silicated. Fine sugary granules are seen wedged between quartz grains in the richer carbonate rocks (Plate 16).

In the impure quartzite members, the carbonate may form porphyroblasts in the granular groundmass. The carbonate shows all the normal optical characters; sometimes, a lattice-like arrangement of the twinning is seen.

Carbonate is also found in veins. It is later than the quartz and appears to have been introduced later than pyrite, chalcopyrite, pyrrhotite, and molybdenite. It may, in some places, have been nearly contemporaneous with the introduction of the galena and sphalerite, and is found down the middle of veins, which have similar crustification on both walls. Carbonate is more important as a gangue on Needle Mountain than on Copper Mountain.

The mineral is frequently seen replacing zones of idiomorphic, zoned grossularite. The garnet crystal then has a centre core of early growth separated from the outer zone by a somewhat irregular "zone" of pseudomorphic carbonate, (Plate 15).

Scapolite porphyroblasts are, in a few slides, largely replaced by carbonate. The replacement occurs in such a way that the relict scapolite remains as a fibrous mass of parallel remnants embedded in the carbonate. Carbonate and sericite together replaced scapolite in another slide.

Other minerals more or less pseudomorphed by carbonate are feldspar, diopside, wollastonite and an acicular mineral that may be tremolite. In one quartz-pyroxene-scapolite slide, carbonate rims nearly all the chalcopyrite grains, (Plate 21). The reason for these reactions rims is not clear.

The composition of the carbonate is not known. The large

amount of diopside and of pigeonite in some slides makes it seem probable that some of it is probably magnesian. However, magnesia has been extensively introduced in contact zones described elsewhere. Thus at Bingham, Lindgren (1) states, the contact metamorphic rocks show an increase of 3 or 4% MgO over that of their unmetamorphosed analogues. It seems likely that the diopside is derived not only from the original $MgCO_3$ in the siltstones, but also from replacement by magnesia-bearing solutions, of calcite. Evidence for this view is provided by the occurrence of pigeonite. This mineral contains a molecular ratio of Mg:Ca that is greater than 1:1, and in pure dolomitic limestone, this 1:1 ratio can never be exceeded. There must at least have been an extensive redistribution of MgO, with a concentration of it in the pigeonite.

In a few veins a brown carbonate occurs that appears to be ankerite.

Scapolite.

Scapolite appears to be restricted to the Needle Mountain phase. In this phase, however, the mineral is of fairly wide distribution in rocks of rather various composition. It occurs in rocks high in quartz and it is found in a few crystalline limestones. In one slide scapolite occupies 50% of the field, and diopside with a little wollastonite, carbonate, and chalcopyrite, rimmed by zoisite (?), occupy the remainder. Another contains about 40% scapolite, an equal quantity of carbonate, and a little pyroxene with finely disseminated ones. No appreciable quartz or feldspar is seen in either of these slides. In the other slides, quartz is

(1) Lindgren in discussion of Winchell's paper, (Feb., 1924, pp. 900).

abundant.

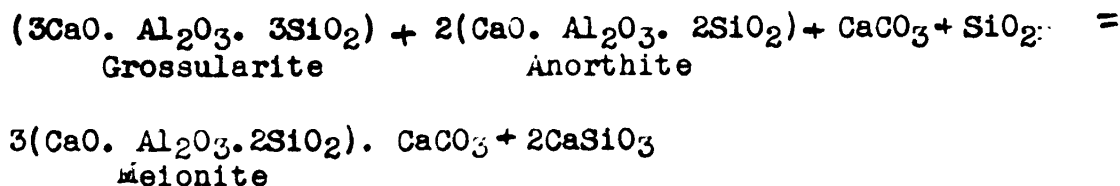
About twenty of the Needle Mountain slides contain scapolite. Only one of these also contains grossularite, and here grossularite occupies about 1% of the slide only. Five other slides contain grossularite but no scapolite. The slide containing both grossularite and scapolite is the only garnetiferous slide containing appreciable quartz that has been seen in the Needle Mountain phase. The garnet here appears to be a vein mineral, and the scapolite is partly replaced. It is possible that scapolite became unstable during vein-formation, and that it was partly made over to pyroxene and carbonate. There are not enough slides for any definite conclusions to be drawn. It seems probable that scapolite and grossularite are incompatible. The distribution of albite probably influences scapolite formation. Where albite is abundant and sodium chloride, bisulphate, sulphate, or carbonate are introduced, the marialite molecule of scapolite may be formed:-

$3\text{NaAlSi}_3\text{O}_8 + \text{NaCl} \rightarrow 3(\text{NaAlSi}_3\text{O}_8) \text{NaCl}$. Meionite is probably easily formed from anorthite:- $3\text{CaAl}_2\text{Si}_2\text{O}_8 + \text{CaCO}_3 \rightarrow 3(\text{CaAl}_2\text{Si}_2\text{O}_8) \text{CaCO}_3$.

With the present data, it is impossible to give an explanation for the apparent non-association of garnet and scapolite.

In this connection, another peculiar relation of garnet may be noted. On Needle Mountain, the mineral appears to be confined to rocks originally high in carbonate. On Copper, quartz-diopside rocks, - as well as highly calcareous rocks - often contain considerable garnet. Rocks high in silica are also likely to be high in albite, and in the Needle Mountain phase scapolite was then formed instead of garnet. When all albite is removed, garnet may become stable in the presence of scapolite.

Another question arises concerning the distribution of scapolite. If it occurs in completely silicated rocks that are raised to grade equivalent to the garnet grade of metamorphism on Needle Mountain, why is no scapolite found in the Copper Mountain phase? There is undoubtedly abundant calcite, anorthite, and albite in some of the Copper Mountain rocks. It seems possible that NaCl was lacking, - although fluorides and sulphates are found on Copper Mountain. At the greater depth of the Needle Mountain phase, the escape of volatiles may have been greatly restricted, and both the [Cl] and the [CO₂] may have been higher in the Needle Mountain rocks. In the reaction between scapolite and garnet, the formation of garnet would be repressed by the presence of chloride ion and of carbon dioxide produced during silication.



In this reaction, the superabundance of carbonate would promote the formation of meionite, in accordance with the law of mass-action.

The scapolite is usually in porphyroblasts, large when compared with the granularity of the mesostasis (Plate 16). The crystals may or may not assert their crystal boundaries so that the edge of the porphyroblast is sharp. Many of the crystals are highly poikiloblastic, containing crystals of pyroxene, quartz and feldspars. In one slide, the crystals asserted their boundaries, and were surrounded by a concentration of diopside and grossularite. Böcke and Eitel (1) point out that in the formation of scapolite, pneumatolytic soda is introduced, and iron and magnesium are

commonly taken into solution. In the present case, the latter metals were presumably redeposited close by as the temperature fell as diopside and garnet. The solutions were probably already somewhat magnesian, as previously pointed out.

Another feature of some of the scapolites is their conspicuous zoning seen under crossed Nicols, (Plate 16). The meionite and marialite molecules apparently form mix-crystals in much the same manner that the plagioclase feldspars do (2). As in metamorphic feldspars, the cores are probably sodic, and the rims calcic.

In some hand-specimens, cleavage surfaces are visible. The crystals are porphyroblastic and often show sieve-structure. The writer believes that they are scapolite, although in one case the colourless porphyroblasts appeared to be calcite. Scapolite is not easily recognisable in the hand-specimen for it is white or pale grey, and looks very like porphyroblastic quartz or feldspar.

Scapolite is easily replaced by carbonate. In many slides, fibrous, optically continuous remnants of scapolite are found. Besides carbonate, sericite was seen in one slide. The meionite molecule is decomposed by acids. Strong acid radicals were present at least toward the end of ore-deposition, for fluorite and gypsum were deposited. It is possible that the ore-bearing fluids were dilute acids, and were responsible for the partial decomposition of the scapolite. If so, the acidity of the

(1) Böcke, H.E. and Eitel, Wilhelm. - "Grundlagen der physikalischen-chemischen Petrographie." 2nd Edn. 1923, p. 3527.

(2) Ford, W.B. - "Dana's Textbook of Mineralogy." 4th Edn. p. 604.

solutions must have changed greatly before the deposition of the carbonate.

The scapolite shows the usual optical properties, and is easily recognised by its rather high interference colours, its refractive index near that of quartz, its two cleavages, characteristic tabular crystal habit, and its uniaxial negative interference figure.

Particular interest is attached to the presence of scapolite in that it signifies rather abundant chloride, sulphide and other ions that are quite probably of pneumatolytic origin. There are not many rock-forming minerals present in the rocks, which indicate large-scale pneumatolysis. The constituent elements of most of the minerals might have been present in a normal sediment. The chloride and sulphate present in scapolite are usually considered to be introduced, although evidence on this point is inconclusive. It is possible that in this deposit scapolitisation takes the place of albitisation so common in ore-deposits.

Diopside

Diopside was one of the first new minerals to be formed in the metamorphism of the Grande Greve rocks, and it persisted to the highest grades. It occurs in most slides in fine granular aggregates, colourless and transparent, but of high refractive index. Other habits are found in many slides, however, and idiomorphic porphyroblasts, radiate, and feathery groups are seen. One garnetiferous slide showed a lineation of the pyroxene crystals, - an unusual feature in the Gaspé rocks, for which there was no explanation apparent.

In hand-specimen, diopside porcellanites have a pale green tinge, often unevenly distributed. Under the microscope, a rough pyroxene cleavage

may be visible. The usual optical characters are present in the most abundant variety. Thus the birefringence is about 0.02-0.03, and the mineral is biaxial and positive. The extinction angle is usually over 35° , but cannot be accurately measured on such small and irregular grains. The optic axial angle is usually large. Schiller inclusions were seen in only one slide, and the mineral is never markedly pleochroic.

There is a diopside with a rather small optic axial angle, $-(2V \text{ from perhaps } 20^{\circ} \text{ to } 50^{\circ},)-$ that is to be found in many of the slides. In other properties, it is normal although it shows a general tendency towards a feathery habit in many of the slides. The mineral appears to be the magnesian-rich variety of diopside, variously known as pigeonite, magnesian-diopside, or enstatite-augite. Apparently diopside, and clino-enstatite at the higher temperatures, are capable of forming mix-crystals at all compositions ranging from $\text{CaMg}(\text{SiO}_3)_2$ to MgSiO_3 .

There is some variation not only in the optic axial angle, but also in the extinction angles, and in the birefringence. No constant relation was discernible in the changes in these different properties. The variations caused in the optical properties of diopside by the solid solution of MgSiO_3 were worked out by Larsen, (See Allen, White, et al. 1909 p.37) etc.) The Diopside took up 60% of its own weight of MgSiO_3 . This solution brought about a progressive reduction in the birefringence from 0.030 to 0.022. The refractive index decreased, and the extinction angle, C:X on 110, changed from 33° to $27\frac{1}{2}^{\circ}$. The optic axial also was slightly reduced from $2V=59^{\circ}$ to $2V=52^{\circ}$. The variations noted in the Gaspé pyroxenes seemed to be more marked and less regular than these. Probably solid solutions of iron, alumina, and, perhaps, other metal oxides, are in part responsible for these

variations. The properties given by Dana, (4th Ed., p. 558) for pigeonite correspond more closely to those found in the present pyroxenes. Thus he states:- "Ax. pl. perpendicular to (010) in varieties low in lime to parallel to (010) at a content of 7 to 10% CaO. Axial Angle small and variable. optically positive Z c axis varies from 22° to 45° increasing with lime content." He also states, (p. 557), that the composition of clino-enstatite "varies with iron replacing magnesium, and grades into what has been called clinohypersthene. An increasing percentage of iron is accompanied with a rise in value of indices and of the extinction angle, Z/c axis." Thus it is possible to have a pyroxene with a low optic axial angle but a fairly high extinction angle. It will be low-lime pigeonite containing iron.

Other pyroxenes occur that show somewhat ^{different} properties. One is optically positive, has a large 2V, a birefringence that is low, - from 0.017 to 0.02. It comes from a little altered rock containing 85% quartz, the rest being carbonate and a very little pyroxene; it comes from the Younger Series.

The diopside and pigeonite are not often replaced by later minerals. Embayments of calcite in the pyroxene are seen that suggest replacement in a few places, but in the absence of definite criteria it is not always certain that replacement has occurred. In one slide, a dark greenish-brown mineral, serpentine, has invaded the pigeonite along its cleavage cracks. In the same slide, optically continuous feldspar or quartz is apparently intergrown with pigeonite.

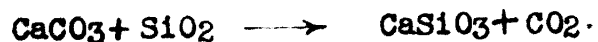
The occurrence of diopside and pigeonite raises the question of whether the MgO is introduced or not. Lindgren, as already noted, (p.49), found an introduction of a few percent of MgO at Bingham, where porphyries

have cut silicated limestones. That the metamorphosing solutions given off from a differentiated magma should be rich in MgO is surprising, as much MgO has already been removed in pyroxene formation early in differentiation. It is perhaps surprising that wollastonite and pigeonite should occur together in some of the slides. Wollastonite is found only in the most calcareous rocks, or in silicated concretions.

It has always been considered a little remarkable that amphiboles find no conspicuous development. Osborne believes that this is the result of low pressure. The water necessary for amphibole formation was able to escape. During the period of highest water-content, on the other hand, it is possible that tremolite was stable for a time, and that it later, still at a very high temperature, reverted to pigeonite, to which its formula corresponds. The writer has found no good examples of relict tremolite associated with diopside, nor has other evidence for or against this hypothesis been noted.

Wollastonite

Like scapolite, wollastonite is confined almost entirely to the Needle Mountain phase. The mineral has been formed by the silication of calcium carbonate in accordance with the equation:-



If, in the original rock, calcite and quartz were present in equivalent proportions so that, after the SiO₂ and CaCO₃ had combined, there was no excess of lime or silica left over, there would, according to Winchell, (June, 1924 p.388), have been a 30% loss of volume. There was no evidence for an extensive volume change, either in the silicated mesostasis, or in the unevenly silicated sections of drill-cores. Thus it seems certain that replacement took place approximately volume for volume, silica being introduced to just such an extent as to silicate the carbonates

without causing any volume change.

The wollastonite usually occurs in small laths or in feathery groups occupying what was formerly the carbonate mesostasis, (Plate 12). It is found in rocks that are almost completely silicated in which there is little or no excess SiO_2 after silication. Eigeonite is a common associate, but normal diopside is also found. Scapolite, garnet and , in one or two slides only, epidote (?), (Plate 12), have been seen with it. Some slides consist of some 60 or 70% wollastonite, and it seems to have been produced in those limestones relatively low in clastic quartz.

The optical properties are normal in some slides. Thus the birefringence is about 0.012 to 0.020, the mineral is biaxial negative, having its axial plane perpendicular to the best cleavage. It has positive elongation, and extinction angles about 30° or 35° . These are all the normal properties. In four slides, - numbers 35, 40, 69 and 80, - another form, apparently also CaSiO_3 , occurs. It is found replacing the carbonate mesostasis in precisely the same manner as, and intimately mixed in with, the normal wollastonite. It is similar to it in crystal habit, in that it also occurs in laths and plumose groups. It is only upon close inspection that the second form is found to be present. It is found that the sections giving the highest interference colour give straight extinction, while some sections with a slightly lower colour show normal wollastonite extinction angles of about 30° to 35° . The other properties of the unknown mineral include a very low $2V$, (or possibly a distorted uniaxial figure), that appears to be negative (?), and the optic axial plane is, in this case, parallel to the best cleavage.

It is of great interest to note that Harker, and Marr write of the silicates produced in the metamorphism of siliceous limestones by the Shap granite as follows :- "Probably more than one lime-silicate is present. The dominant one gives the interference colours of a pyroxene, and has marked cleavage traces, parallel to which it extinguishes. This may be referred with some doubt to wollastonite. It is partly collected in crystalline patches and streaks, but smaller granules of the same or a similar mineral make up a large part of the rock This was 600 yards from the contact of the mile-wide granite body? The specific gravity of this rock was 2.874, which agrees with the identification of the chief constituent as wollastonite, Harker, (1891, p.32). The properties described correspond fairly closely to the mineral seen by the writer.

The common form of wollastonite, found as a mineral has been reproduced artificially by Allen and White, (1906, p. 90). With heating, it is found to invert to pseudo-wollastonite, the alpha-form of CaSiO_3 . This form is biaxial and positive, and has a very low optic axial angle, ($2E=0-8^\circ$). Twinning is parallel to the basal pinacoid. Fibrous, fan-shaped aggregates are common; in the experiments, the alpha-form was coarser and more granular than the Beta-form. This description also fits the unknown mineral rather remarkably. There is, however, one discrepancy; the birefringence appears to be rather too high. It is stated variously as being from 0.025 to 0.043. The lower figure would fit the present mineral. Allen and White write as follows, (p. 90):-

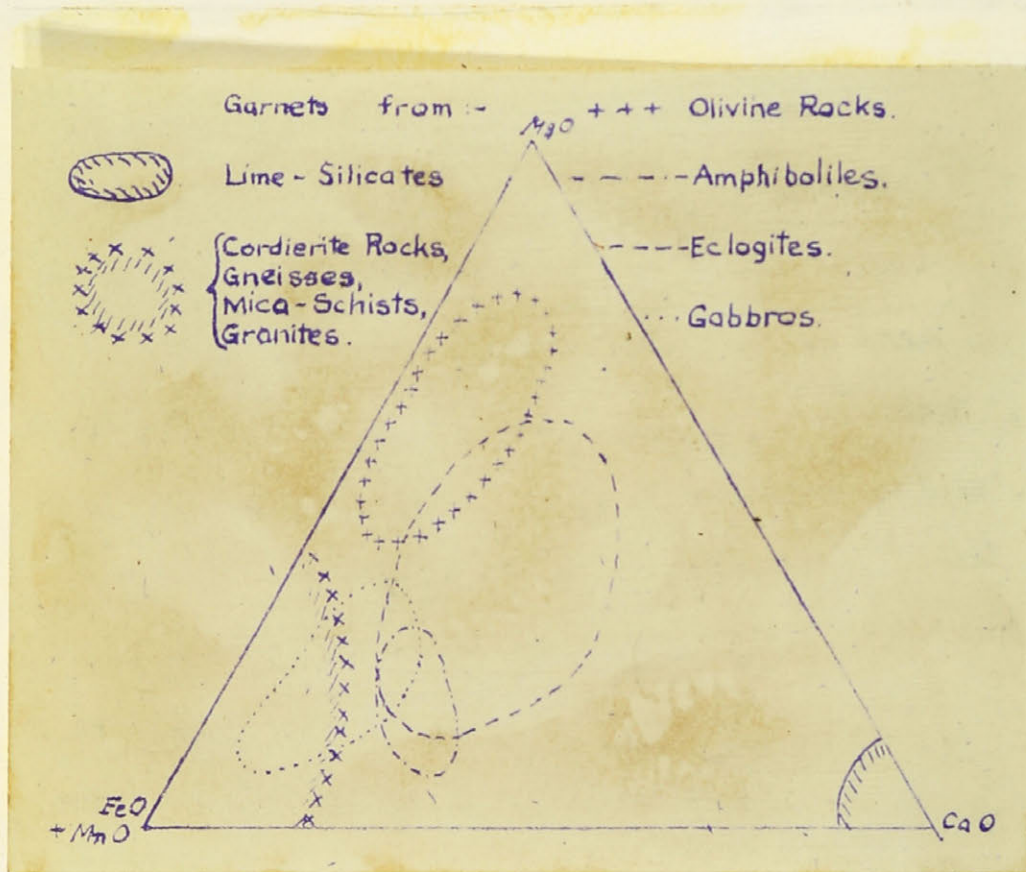
"Although the temperature at which wollastonite may crystallise from a magma is conditioned by the composition of the latter, it may be

worth while to call attention to the fact that the value of the inversion temperature as a point of reference in geology is not impaired by the varying complexity in the composition of the magma, in as much as this temperature has to do with an equilibrium between two solid states of calcium metasilicate, and has no relation to the solution out of which either form crystallises. It will of course be slightly affected by pressure in the usual way, and also to some extent by the impurities which, in small quantity, are found in the natural mineral, provided these are really dissolved in it." While this is not a case of crystallisation from a magma, there are still only the two factors above mentioned that will affect the inversion temperature. Under laboratory conditions, this temperature was 1180°C .

It seems possible that the unknown mineral here described is pseudowollastonite. So far as the present writer is aware, pseudowollastonite has seldom, if ever, been described as a rock forming mineral before. In the absence of more exact determination, therefore, the writer is hesitant to claim that the present mineral is, without doubt, $\alpha - \text{CaSiO}_3$. If the mineral is pseudo-wallastonite, possibly with a small percentage of MgSiO_3 forming a mix-crystal, it probably signifies a temperature of 1100° - 1200°C at the time of metamorphism. This is a very high temperature for contact alteration, and, in the presence of water, incipient solution of certain minerals, (as in the Laacher See sanidinites), and the widespread occurrence of pseudomorphs after trydimite might have been expected. However, the high temperature may have been of fairly short duration. Allen and White had difficulty, incidentally, in causing the reversion from the

FIGURE 1

The Proportions of Fe O, Mg O and Ca O
in Rock-Forming Garnets.



(Adapted from Eskola (1920, p.170).)

and to the Beta-form of CaSiO_3 without using solution and reprecipitation. There is therefore, some question as to the significance of this.

Garnet

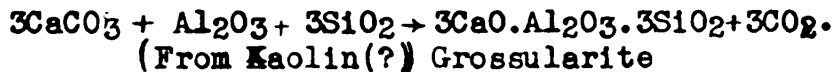
It is probable that most of the garnet is of the grossularite variety. This was indicated by a determination of the refractive index of a sample in oils, carried out by Osborne. Eskola (1920, p. 172) shows the relative proportions of FeO , MgO , and CaO in analysed rock-forming garnets. All those obtained from lime-silicate rocks contained more than 78% CaO . Most contained more than 92% CaO , and less than 8% ($\text{FeO} + \text{MgO}$), (See fig. 2). However, it appears that in some skarn deposits, the garnet is of the andradite variety, that is, rich in Fe_2O_3 rather than Al_2O_3 , according to Kemp, (Harker, 1932, p. 128). Many of the garnets are zoned, and it is probable that the zoning represents a gradation in composition between andradite and grossularite: there is however nothing to prove this.

Garnet, in the quartz-diopside porcellanites, is normally isotropic, and occurs in granular aggregates of highly variable size and shape. Diopside porphyroblasts sometimes are seen in these masses, (Plate 13).

In the Copper Mountain porcellanites, vein garnet of similar type is commonly observed to cut rock-forming garnet formed during the normal course of metamorphism: the conditions of formation of the two types of garnet were probably very similar, and their ages not very different. Here again irregular, isotropic aggregates are common, but in addition idiomorphic, anisotropic, zoned crystals are often found around the edges of the granular aggregates, (Plates 14, 15). The birefringence is a

little weaker than that of quartz. Often, calcite and, more rarely, quartz and feldspar are seen to replace some of the inner zones of garnet crystals. The outer zone and the core only of such a crystal are left. Sometimes only the outer zone is anisotropic.

The peculiar distribution of garnet and scapolite has already been discussed. Grossularite is formed more readily than anorthite in rocks low in Al_2O_3 . Thus if a little Al_2O_3 is present, the course of silication is as follows:-



The presence of quite a small amount of Al_2O_3 will greatly reduce the quantity of wollastonite formed in silication.

The garnet is often confined to narrow compositional bands and altered concretions. These are relict sedimentary structures, and in no case are they related to stress.

The Epidote Group

Minerals of the epidote group are of common occurrence, although they never make up a large proportion of a rock-mass. On Copper Mountain, these minerals are common vein-formers, and usually give the impression that they are of later introduction than the vein-garnet and diopside, although there may have been overlapping with the latter minerals. Allanite, in particular, is commonly found forming reaction-rims around the sulphides: in such cases the mineral is of quite late formation, (Plate 20).

The rimming relation is that most commonly shown by epidote minerals on Needle Mountain. In several slides, however, small, irregular

grains were observed, that showed high interference colours, and a rather irregular extinction. These grains are probably pneumatolytic in origin, for epidote is unstable in the hornfels facies,- a facies to which most of the Copper and Neddle Mountains rocks seem to correspond rather closely. Grains of similar occurrence are found on Copper Mountain. Vein-epidotes are not very common on Needle Mountain, although they are found (Plate 19).

In the hand-specimen, epidote-bearing rocks are tinged with the characteristic epidote green by the presence of the grains, which, individually, are minute, although, occasionally, masses a few millimetres in length may be seen.

Considerable difficulty was experienced in the microscopic determination of these minerals. Their properties were rather variable, the grains were often minute, and it was not very often possible to find an interference figure.

One mineral that shows unusual properties is optically positive, and has its axial plane parallel to the best cleavage: it has a high birefringence, showing colours of the third order, which excludes it from the optically positive zoisite. The mineral might possibly be the manganese epidote, piedmontite, although the mineral is said to show marked pleochroism. The mineral occurs as grains in a wollastonite-diopside rock, (Plate 10). A mineral of similar character occurs in another slide. This mineral appears to have inclined extinction, a small $2V$, and it forms rims on grains of chalcopyrite in a garnet porcellanite from Copper Mountain. Another positive epidote with a very high birefringence occurs in a kaolinised porphyry. It has a low optic axial angle, and an extinction angle near 45° .

Amongst the optically negative epidotes are various weakly pleochroic varieties, whose green colour generally masks the interference colours. They have large optic axial angles, and extinction angles from 35° to 45° . They are probably varieties of allanite, - a mineral of rather variable properties. Other negative varieties have their optic axial plane transverse to the best cleavage, and very low extinction angles. These are the normal properties of epidote. The birefringence is usually masked, although in one nearly colourless variety, it was a little higher than quartz. An abnormal smoke-blue colour, - probably the result of abnormal dispersion, - may be seen in one slide (Plate 19): the sign of this mineral can not certainly be stated, although in two or three sections it appeared to be negative. In other properties it corresponds closely to zoisite, although no cleavage was very well developed. The mineral might possibly be a vesuvianite with a rather high birefringence. Harker and Marr, (1891, p. 311), record the occurrence of this mineral with a high birefringence. They also note that Brögger found the mineral with similar properties in the Christiania district, and that a vesuvianite from Monzoni, South Tirol, shows the same property. The minute grains occur in the slide examined by the writer in a pyroxene-carbonate vein that cuts across an earlier pyroxene vein. If the mineral is vesuvianite, this is about the only slide in which it is to be seen.

It seems probably therefore, that varieties of zoisite, epidote, and allanite are all present. They are seldom normal metamorphic minerals, - at least in rocks of the highest grade. They are pneumatolytic replacement minerals that were introduced probably when the temperature had declined

somewhat from that of garnet formation. Thus they cut across garnet when they are in veins, and they form reaction rims around the sulphides, which are themselves later than the garnet, and, in most cases, later than the pyroxene.

The Micas

Minerals of this group are not common in well developed crystals in the normal rocks of the Grande Greve group. Chemically, the rocks are, normally, of such a composition that micas would not be expected as a metamorphic product; the alkali and alumina content in them is too low. However, micas occur in the porphyries and in the Younger Series rocks.

A rock from Needle Mountain a little coarser grained than usual, that has a feathery, greenish-grey mineral, is seen under the microscope to contain some 60% sericite, some palimpsest scapolite, which the sericite and carbonate have replaced, and also carbonate, quartz, plagioclase and sanidine. An unknown mineral that may be leucoxene occurs in minute grains. The rock is unusual in that it contains no pyroxene. It is notable that, in this respect, this sericitic rock conforms with the stability relations worked out by Goldschmidt for the Hornfels facies. The sericite or paragonite(?) has a high birefringence, a very low extinction angle, and is faintly greenish. It is commonly fibrous in habit. It was not possible to determine the sign.

The commonest colourless mica, however, is that found as a constituent of the impalpably fine, scaly alteration products in the kaolinised porphyry. This material may be very abundant, rendering the

feldspars buff and translucent. It may also include phengite, and possibly some other minerals, (saussurite?).

An impure quartzite from Copper Mountain contains a fine mosaic of quartz and feldspars with perhaps 30% of interstitial scaly sericitic material. There is also a little biotite, epidote (?), and carbonate.

Biotite is a constituent of some importance in the porphyries. It is green or brown under the microscope, and shows a common alteration to chlorite. It shows the usual tabular or lath-like habit, pleochroism, and quasi-uniaxial negative character. It has a tendency to lie along flow bands in the "trachyte flows" and in one slide a flow-band was followed by a crustified veinlet of biotite showing comb-structure; (Plate 2 shows a biotite "trachyte").

One or two slides of dark hornfels were composed of a scaly, extremely fine, translucent mass of brown pleochroic material, in which there were quartz, pyroxene, and many minute, opaque granules. These are believed to be biotite hornfelses, (Plate 6, Breccia particle). Some of them come from the transition beds at the base of the Younger Series. It may be noted in passing that biotite and hypersthene, with cordierite, are stable in one another's presence in the hornfels facies. A similar rock was found in the Needle Mountain phase, but it is of distinctly unusual occurrence among these rocks.

Except in the porphyries, the micas are minerals of unusual occurrence in the metamorphic rocks of the Miller Porphyries. Their absence serves to emphasise the stability relations pointed out by Goldschmidt. The low pressure may have been an additional factor that

prevented their formation in chemically suitable rocks for the volatiles could readily escape. Only in those rocks where diffusion was excessively slow, would biotite be formed, - that is, in the argillareous rocks of finest grain.

Leucoxene(?)

A mineral is found in several slides as a vein mineral, with or without sulphides, or as a fine, granular metamorphic mineral that has a very high refractive index and birefringence, (Plate 4). It is a greenish-brown colour. In the case of the one grain that gave a figure, it appears that the mineral is biaxial and positive, having a low $2V$, and with $\rho > \nu$. The extinction angle appeared to be about 35° . The mineral was compared with leucoxene in a hornblende diorite from Halsbrücke in Saxony: they were almost identical in general appearance.

The mineral is invariably very fine-grained, and is never abundant. It occurs fairly consistently in the quartz-pyroxene-carbonate association, particularly on Needle Mountain.

Amphiboles

Like the micas, the amphiboles are for the most part conspicuous for their absence. However, a very few slides contain birefringent needles, that may or may not be pleochroic.

A carbonate knot from what are believed to be beds of the Porphyry Mountain phase of the Younger Series, comes from the east spur of Needle Mountain; it was seen to contain a few minute needles of fairly high index, and moderate birefringence. The carbonate knot is very little

metamorphosed, and these needles appear to be the only new minerals that have been produced. Osborne thinks they are probably tremolite.

Another fine, needle-like product has a birefringence about 0.025 and a very perfect prismatic cleavage, and appears to be actinolite. It occurs in a quite unsilicated quartz-felspar-calcite rock, on Needle Mountain.

A large number of small, strongly pleochroic green needles occur irregularly disposed in the quartz-felspar matrix of a highly metamorphosed quartz-pyroxene-garnet rocks. This is the only slide to show gneissic lineation of the pyroxenes. The absorption was greatest parallel to the elongation. The extinction angle was difficult to measure, but is at least as great as 150° , and may be greater on other sections. Actinolite and tremolite have extinction angles of 160° . The mineral has a tendency toward fibrous growth, and the elongation is positive. It can be assigned with some confidence to actinolite. The amphiboles in most other cases occur in little altered rocks.

Two other porcellanites contain needles in the quartz-felspar groundmass, that have a birefringence about 0.012. As the mineral shows straight extinction, it is very possibly sillimanite instead of an amphibole. The rocks in which they occur are not much altered. Sillimanite is, of course, unstable in the quartz-pyroxene association, and these cases may be instances of an unstable relic shielded by the enclosing quartz grains.

The general absence of amphibole is a phenomenon of great interest. As there is no amphibolite zone, it seems that at no stage during metamorphism were amphiboles formed to any extent. If they were, they were

nearly all made over to pyroxenes. The change is a monotropic one.

The low hydrostatic pressure probably favoured the escape of volatiles. A high volatile concentration would favour amphibole formation, and, conversely, a low water concentration would favour pyroxenes. Amphiboles also are stress minerals, whereas pyroxenes are readily formed under non-stress conditions. At the Miller deposits, tangential stress was very low. Finally there is abundant evidence from several sources that the temperature was high. It is difficult to estimate how high, but it may have been too high for amphibole formation at the highest grades. Allen and Clement, (1908, p. 101), state that tremolite cannot be formed above 1000° or 1100°C. It is, perhaps, rarely that conditions are such that tremolite can be formed even at considerably lower temperatures. It is nevertheless possible that tremolite was formed in some places during the stage of rising temperature, and that the mineral was later made over to pigeonite.

One other interesting occurrence is that of chlorite pseudomorphs after hornblende in one slide of the porphyry. Hornblende was seen in only one slide of these rocks.

Other Minerals

Green scaly products occur in very minute quantities in many slides. They are of no importance, and cannot be identified. The low birefringence suggests that the mineral is generally chlorite. Chlorite is also seen to replace biotite and hornblende in the porphyry. It was seen encroaching along the cleavage cracks of a pyroxene, and was found

in one core-specimen coating a slickensided surface. It is sometimes seen to be weakly pleochroic, and occasionally of radial habit.

The possible occurrence of sillimanite has already been mentioned under the amphiboles, and that of vesuvianite under the epidotes. The scarcity of vesuvianite is perhaps remarkable when these rocks are compared with other similar rocks elsewhere.

In one slide a minute needle of apatite was seen. It had the low birefringence and the basal parting that is characteristic of that mineral.

It has already been mentioned that fluorite, anhydrite, and gypsum are found in the vugs on Copper Mountain, associated with late sulphides. Fluorite was also found in one slide composing the mesostasis: it was conspicuous because of its isotropism and its rectangular cleavage. Another slide showed an isotropic mesostasis, but no cleavage was discernible. There may, at this point, have been very local fusion to a glass, or the material may be chalcedony, or some other form of amorphous silica. of very late introduction. Amorphous silica was seen in one vug.

One other group of minerals remains to be mentioned. That is the group of decomposition products formed in the kaolinisation of the porphyries. The feldspars are seen under the microscope to be more or less completely altered to a granular, translucent aggregate of buff-coloured kaolin and other products. The saussurite alteration containing zoisite does not seem to be characteristic. In the hand-specimen the rocks are greyish-white and have a chalk-like appearance.

Introduced Material.

It has been pointed out that there are marked differences both in the metamorphism and in the mineralisation of Copper and Needle Mountains. The differences in metamorphism, in the main, depend upon original differences in the bulk chemical composition of the rocks concerned. It has been shown that rocks of similar type on both Mountains have been similarly altered. It is possible, however, that there were hypogene chloride bearing solutions on Needle Mountain, and these may have been responsible for the abundant scapolite. On the other hand, the chloride may have been dissolved in the connate water present in the sediments. Not very much chloride is required in the formation of the marialite molecule, and scapolite, while of common occurrence, does not form a very large proportion of the whole rock mass. The most commonly accepted view is that the chloride in scapolite is of magmatic origin; however, there is no conclusive evidence in the present instance.

On Copper Mountain, garnet veins are commonly found cutting the more abundant rock-forming garnet. The garnets may have obtained some of their material from hypogene solutions, or it is possible that the hot water in the pore-space merely acted as a medium in which material already present came to chemical equilibrium, and the fissures often were the fortuitous loci of redeposition as the temperature started to decline. Wall-rock alterations, in which diopside is commonly introduced along the wall of a garnet vein, suggest that the solutions transported material at least from one rock type to another where equilibrium conditions were different. In the absence of a large number of rock

analyses it is difficult to determine to what extent material was introduced at this stage of metamorphic recrystallisation.

It was stated in the discussion of diopside that hypogene magnesia may have been introduced. A certain amount of hydroxyl entered into the formation of the zoisite and epidote. The former is more abundant on Needle Mountain, and the latter on Copper Mountain. The epidote minerals probably belong in part to the stage of metallisation.

On page 44, the writer stated the belief that a certain amount of silica was probably introduced from a magmatic source during the process of silication. This belief is based upon the lack of any evidence of a considerable decrease in volume during silication.

During kaolinisation there may have been some deposition of Al_2O_3 , as well as hydration. Potash, soda, and lime were dissolved by these solutions. Osborne believes the kaolinised dykes may be the channel-ways followed by the ore-solutions.

The solutions in the Needle Mountain and in the Copper Mountain ore-bodies must have been somewhat different. Pyrrhotite is characteristic of the former body, and pyrite and molybdenite of the latter body. Osborne suggests that zoning may be responsible for these differences, and believes that the Copper Mountain ore-body may be rather higher temperature, although, he says, the evidence for this is rather slender. Two other points are brought forward by him. First, pyrite has a strong force of crystallisation and is able to assert its boundaries against quartz, - something that pyrrhotite is unable to do. Idioblastic pyrrhotite would be impossible in the siliceous rocks of Copper Mountain. Pyrrhotite

might, it may be mentioned, be expected in the crustified veins if this were the controlling factor. Secondly, the disulphide was reduced by the carbonic acid that was probably far more abundant in the Needle Mountain ore-body than in the Copper Mountain one. The reaction would be somewhat as follows:-



Although the bulk of silication preceeded metallisation, this seems a probable explanation. All the possible gaseous products are common products of vulcanicity. Furthermore, the partial decomposition and replacement of scapolite may have been brought about by the presence of SO_2 and SO_3 . The mineral is decomposed by strong acids. The sulphide ion concentration may have been different in the original emanations from the subjacent magma chamber or cupola(s). There is no reason to believe that the two ore-bodies are strictly contemporaneous.

Late carbonate-sulphide veins are common in the ore-bodies, particularly in that of Needle Mountain. Winchell (Feb. 1924, p.898) has pointed out that carbonation is impossible during a period of active replacement of a carbonate mesostasis by ores, and, still more so, during the period of silication. The late magmatic solutions of acid magmas are nearly always highly siliceous. He concludes that the carbonate may be supergene, or, at least, due to a type of lateral secretion. After silication and silicification were completed, the rocks must have been saturated with mineralised water that was slowly declining in temperature. Late pyrite, galena, and sphalerite, were probably precipitated at this stage. Much carbonate dissolved at greater depths, was probably precipitated at these higher levels along with the ores. This

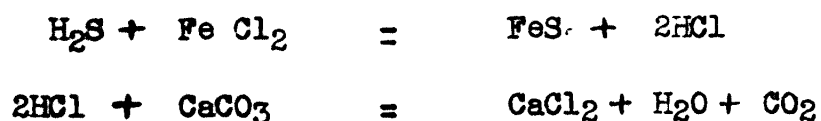
hypothesis seems more probable to the writer than that the solutions of an already differentiated acid magma, probably remarkably low in mafic minerals, should start to give off carbonate- rich solutions, after discharging for a long period, solutions that are carbonate-solvent.

Minor amounts of sulphate and fluoride radicle were introduced during the later stages of ore-deposition.

The form in which the metals were introduced is unknown.

Kemp(1) and others have suggested that they came in as chlorides. If the chloride of the scapolite was introduced, it belonged to an earlier epoqe than that of metallisation, but the presence of scapolite suggests, nevertheless, that chlorides might have been introduced in abundance.

If so, reactions of the following type would have taken place:-



The highly soluble calcium chloride would be removed and would account the complete absence of chlorides that have been introduced since the epoqe of metallisation.

(1) Kemp, J.F. - "Notes on Garnet Zones". Trans. Can. Min. Inst. Vol. XV, 1912. pp. 171-186.

Evidence of High Temperature and Low Pressure.

It has been stated on several occasions that the deposit is believed to have been formed under what Buddington has termed xenothermal conditions. It may be well to summarise the evidence for the belief that the pressure was low.

(1) There is stratigraphic evidence that the intrusion and mineralization occurred before any middle Devonian series was laid down on top of the Younger Series. The stratigraphic thickness of the latter may have been about two to four thousand feet.

(2) The veins are well crustified, and vugs are common, while some of the vugs may have been produced by later solution, most probably date from the mineralizing epoqe. That there should have been open- fissure veins is an indication of a low superincumbent load.

(3) Hydroxyl-bearing minerals are rather scarce except in those rocks of finest grain - biotite-hornfelses, etc., - and it is believed that pyroxenes rather than amphiboles were formed because water was able to diffuse through the pores of the porcellanites and to escape to the surface. Biotite and kaolin are the only very widespread hydroxyl-bearing minerals. Epidote and its relatives, although common, are never present in large bulk, and are of late metamorphic origin in most slides. Scapolite also required mineralisers, and is present in considerable bulk. This argument is not very strong one, as scapolite, the amphiboles, vesuvianite, chondrodite and one or two other minerals are the only volatile-bearing minerals that might be expected in the true porcellanites and skarns. Biotite, chlorite, and sericite would not be expected in rocks of that bulk chemical composition. The amphiboles, particularly,

are the group that are conspicuous for their absence. It is notable that tangential stress favours their development.

(4) The fine granularity and the presence of mix-crystals suggest that rapid heating to a considerable temperature was followed by rapid cooling. Rapid cooling in turn suggests a steep temperature gradient and a thin cover. The ill-formed, idiomorphic, granular rosettes of diopside, and irregular masses of garnet suggest rapid formation. Under conditions of prolonged heating, idiomorphism would have been more perfect. Some degree of unmixing of sanidine to give a microperthite might have been expected. Mäkinen, (1917), has extensively examined igneous microperthites formed by the unmixing of sanidine. It is known, therefore, that, under certain circumstances, unmixing of this kind may be expected. Besides time, temperature and the presence of water are factors of importance. If pseudo-wollastonite is present, it is perhaps surprising that it has not reverted also. In the laboratory, however, the presence of a solvent was necessary to bring about the reversion to wollastonite, (Allen and White, 1906, p. 90).

Since the hydrostatic pressure was low, there was little tendency towards the formation of dense minerals in response to pressure.

It has been frequently pointed out that tangential stress was of little importance. Thus there is only mild folding, no slaty cleavage or schistosity, and stress-minerals such as the amphiboles are absent. Staurolite, cyanite, and chloritic minerals are also absent.

There is abundant evidence of the high temperature. Decolorisation by elimination of free carbon is believed by Winchell, (Feb, 1924, P. 895), to require temperatures as high as 700° to 900°C, - the temperature at which, he believes, most of the silication occurred. The silication in many slides is complete, and grossularite was formed. Harker, (1932), remarks in one place,

PLATES

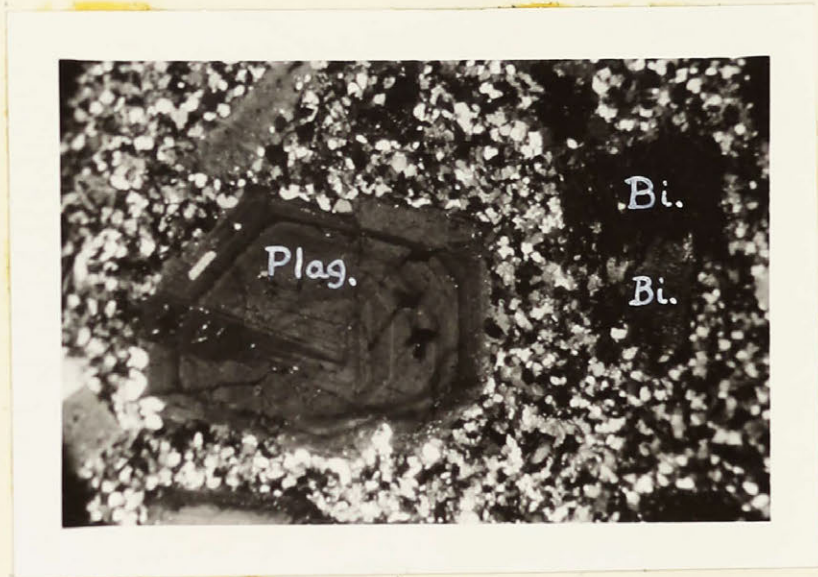
Key:-

Qu. - Quartz.	Gross. - Grossularite.
Felsp. Felspar, (Composition unknown)	Woll. - Wollastonite.
San.- Sanidine.	Ps.Woll(?). Possibly Pseudo-
Plag. Plagioclase.	● Wollastonite.
Bi. - Biotite.	Ep. - Epidote.
Pyr.- Pyroxene, probably diopside.	Zois. - Zoisite.
Disp. Diopside.	Leuc. - Lencoxene (?).
Pig.- Pigionite.	Carb. - Carbonate
Scap- Scapolite.	Ore. - Sulphide ores.

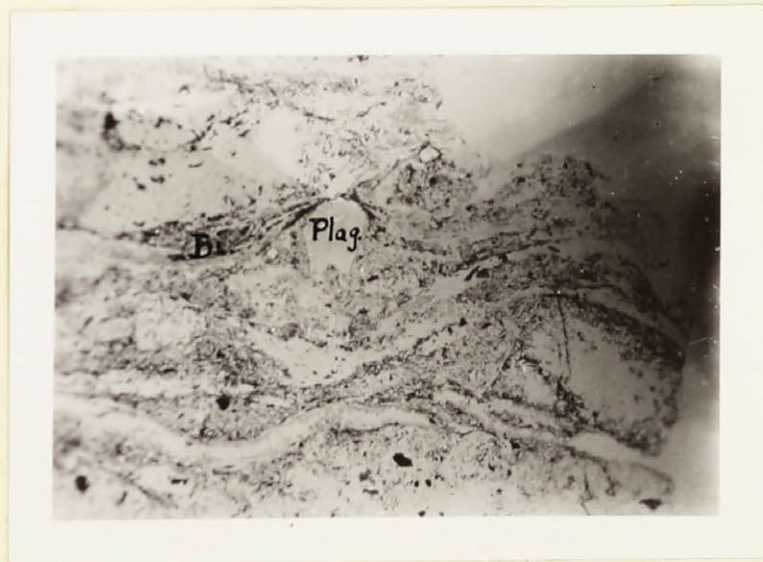
Plate 1. Grey quartz-porphyry. The quartz-felspar matrix contains a zoned plagioclase phenocryst, (An 37 - An 20), with polysynthetic twinning. The biotite is green. From Copper Mountain, Slide 114, crossed Nicols, x 24.

Plate 2. Trachyte flow or sill. Clear plagioclases are set in a quartz-felspar matrix. A little pyroxene and some scaly green biotite lie along the flow-lines. A little tremolite(?) is seen in the slide. The hand-specimen is patchy in appearance, and conspicuously flow-banded.

From the upper talus of Copper Mountain, slide 110, ordinary light, x 24.



1.



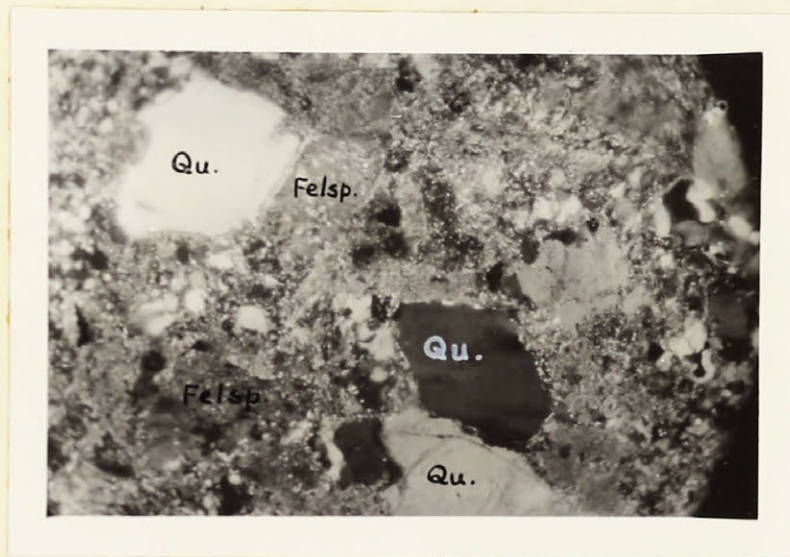
2.

Plate 3. Dark grey quartzite, very little altered. It is rather coarse and felspathic. The grains of quartz are enlarged, and there are cloudy feldspars that show polysynthetic twinning. There are also a scaly mineral, greenish brown and of interstitial habit, a little carbonate, and a very little pyroxene.

From the basal beds of the Younger Series, Copper Mountains.
Slide 112, crossed Nicols, x 68.

Plate 4. Typical quartz-pyroxene-carbonate porcellaine. It has minute dark green grains of disseminated leucoxene(?).

Needle Mountain, Slide 62, Ordinary Light, x 68.



3.



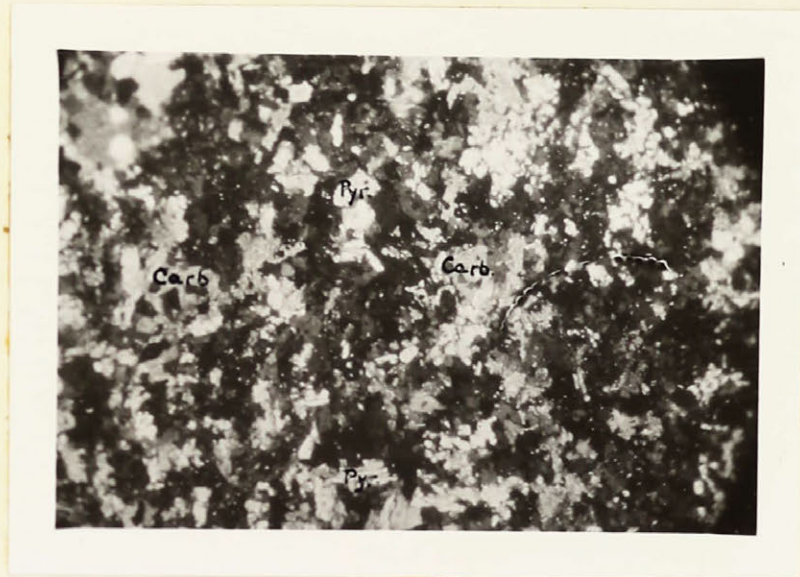
4.

Plate 5. Same as Plate 4, only with crossed nicols.

Plate 6. Part of a breccia fragment of very fine biotite(?) hornfels in a fine-grained, igneous(?) quartz-felspar matrix. The felspar in the matrix is rather highly kaolinised. The interstitial dark cloudy material is an alteration product. There is a little pyroxene and goethite present.

Probably a breccia intrusive into the Younger Series of Porphyry.

Mountain, Slide 122, Ordinary Light, x 68.



5.



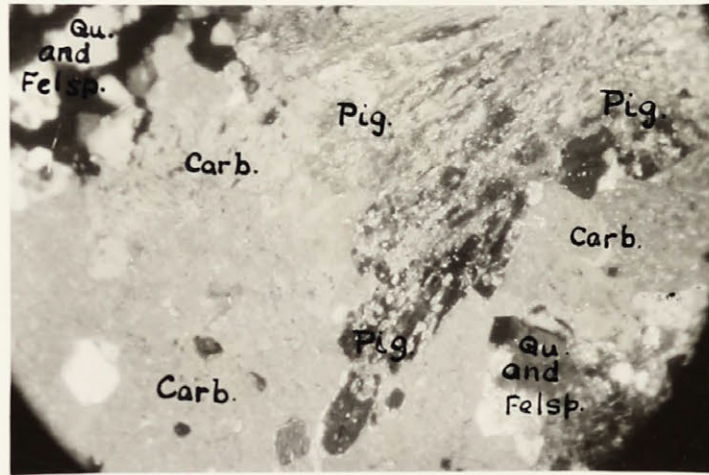
6.

Plate 7. Feathery pigeonite in a carbonate porphyroblast. Most of the slide is composed of fine quartz and felspar.

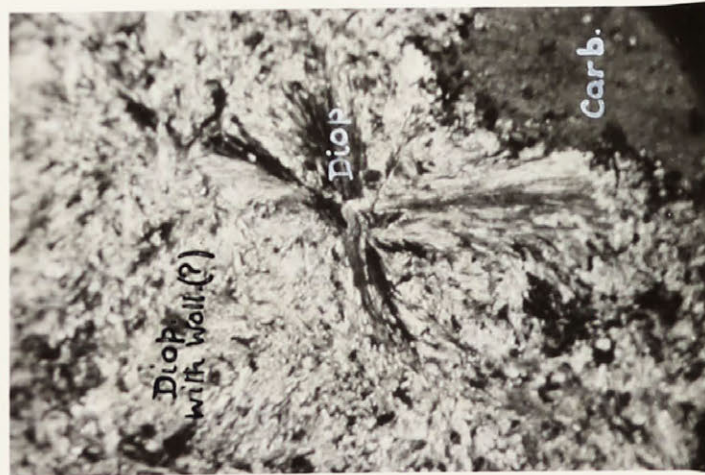
Needle Mountain, Slide 26, Crossed Nicols, x 68.

Plate 8. Feathery diopside with wollastonite and pseudo-wollastonite, Part of a carbonate porphyroblast is also seen.

Needle Mountain, Slide 66, Crossed Nicols, x 24.



7.



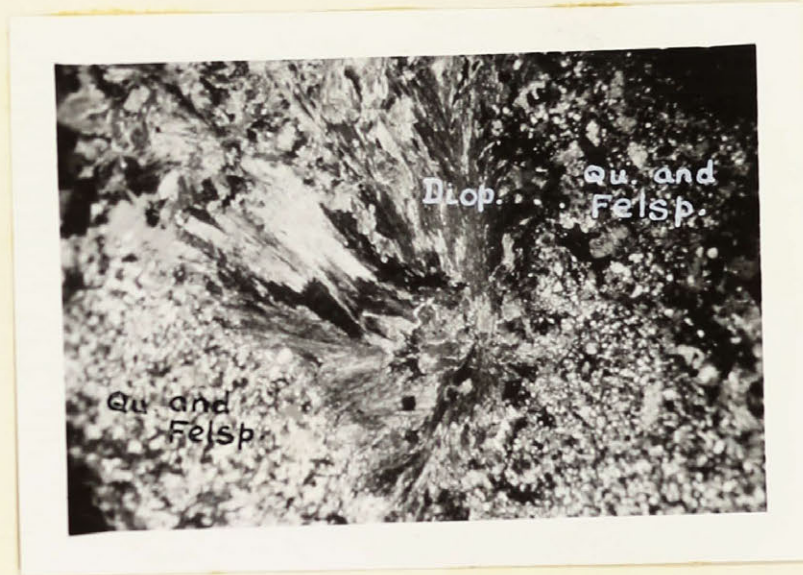
8.

Plate 9. Diopside with wollastonite in a quartz-felspar ground mass.

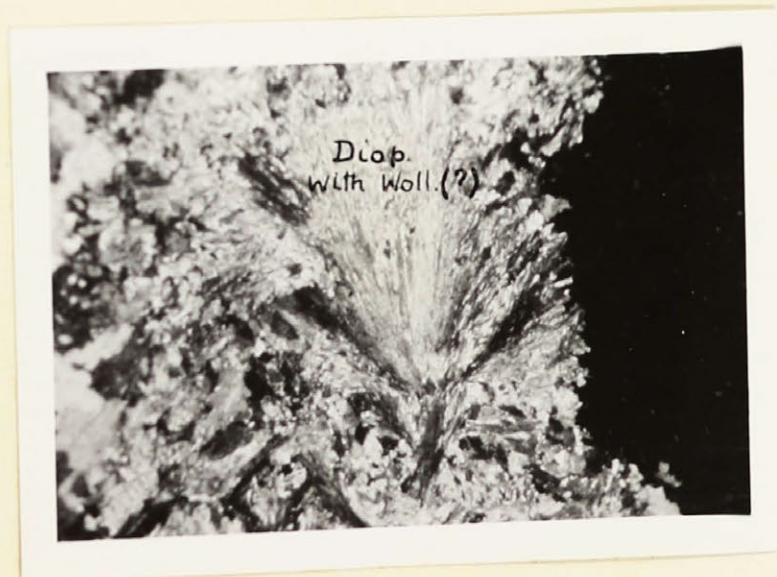
Needle Mountain, Slide 66, Crossed Nicols, x 24.

Plate 10. Diopside, with wollastonite (?).

Needle Mountain, Slide 66, Crossed Nicols, x 24.



9.



10.

Plate 11. Feathery Wollastonite and pseudo-wollastonite(?) in a wollastonite - epidote - diopside rock.

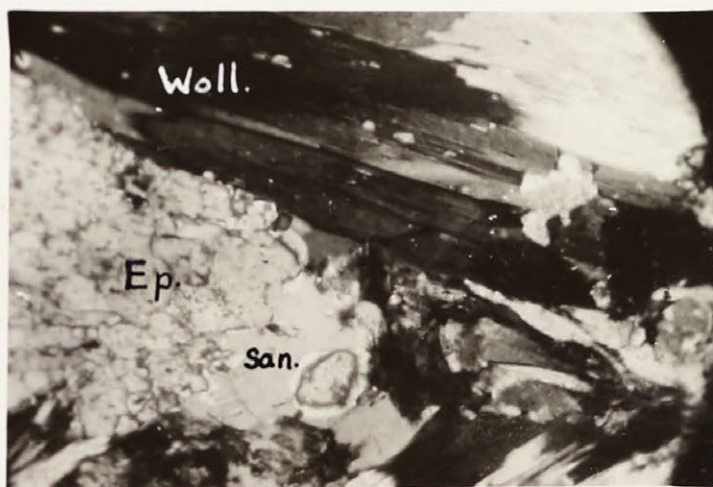
Needle Mountain, Slide 69, Crossed Nicols, x 24.

Plate 12. A mineral of the epidote type with laths of wollastonite and a little late interstitial Sanidine. From a diopside-wollastonite rock.

Needle Mountain, Slide 49, Crossed Nicols, x 68.



11.



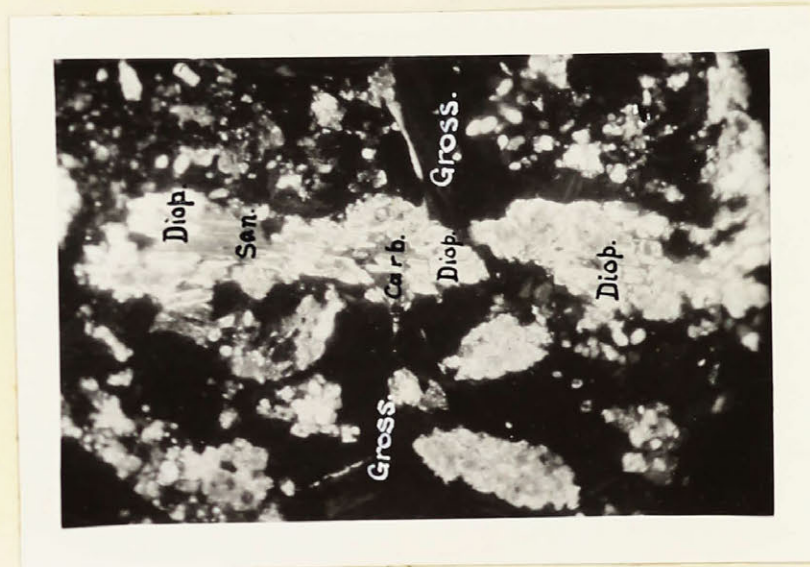
12.

Plate 13. A garnet-diopside skarn showing optically continuous pyroxene partly replaced by Sanidine and carbonate. In the Sanidine, minute needles of actinolite may be seen faintly. In places, the grossularite is weakly anisotropic.

Copper Mountain, Slide 5, Crossed Nicols, x 68.

Plate 14 Zoned anisotropic grossularite with interstitial ore and carbonate. There are a few small pyroxene grains.

Copper mountain, Slide 92, Crossed Nicols, x 68.



13.



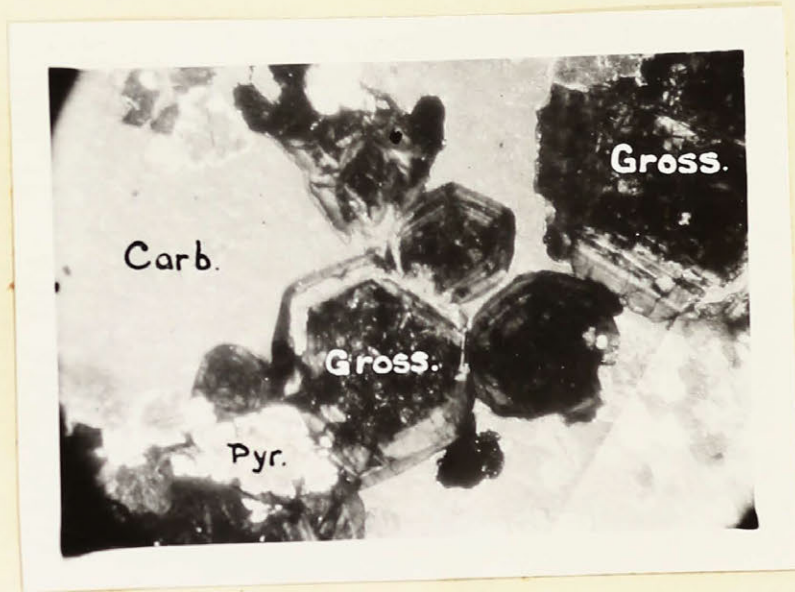
14.

Plate 15. Garnet-pyroxene-garnet rock, including, elsewhere in the slide, a little quartz. A grossularite crystal partly replaced by carbonate along a zone. A few pyroxene grains are present.

Needle Mountain, Slide 33, Crossed Nicols, x 68.

Plate 16. Zoned scapolite porphyroblasts in a fine granular carbonate ground-mass. Poikiloblastic structure.

Needle Mountain, Slide 42, Crossed Nicols. x 68.



15.



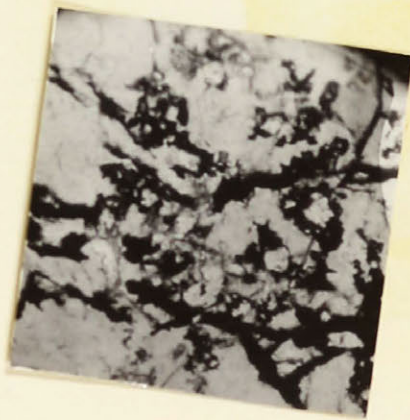
16.

Plate 17. Grossularite with interstitial ores.

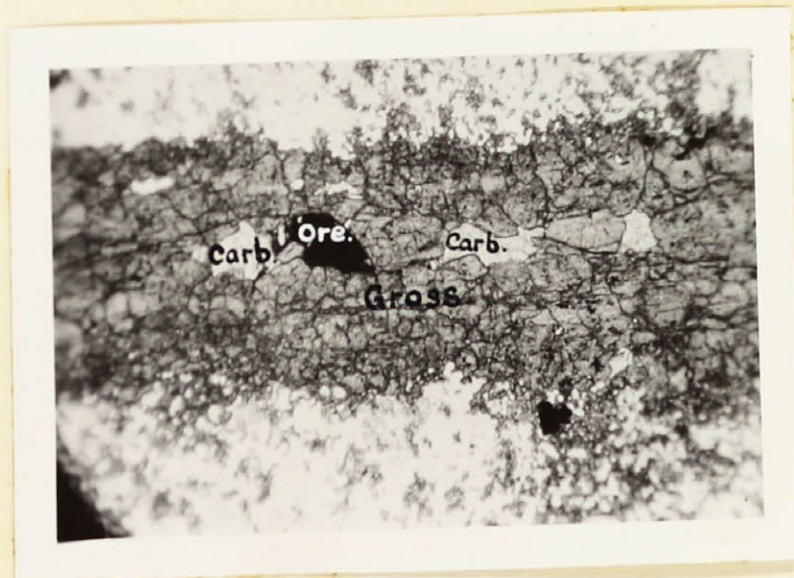
Copper Mountain, Slide 92, Crossed Nicols, x 68.

Plate 18. Typical quartz-diopside porcellanite cut by crustified garnet vein containing carbonate and sulphides.

Copper Mountain, Slide 12, Ordinary Light, x 24.



17.



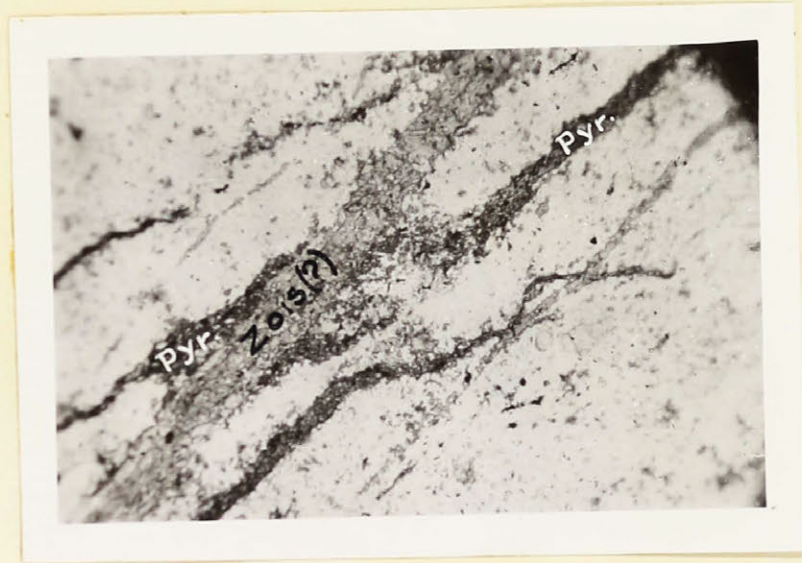
18.

Plate 19. A zoisite(?) vein cutting a pyroxene vein, in a quartz-sanidine-pyroxene porcellanite.

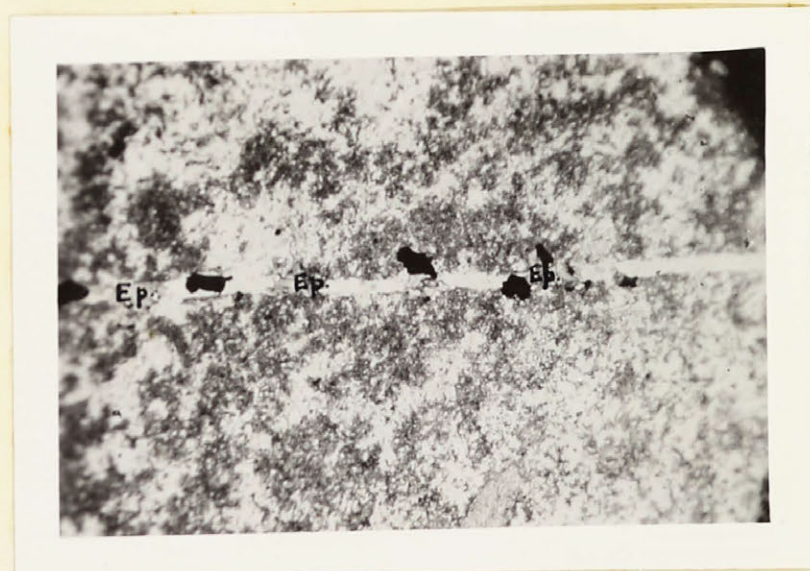
Needle Mountain, Slide 19, Ordinary Light, x 24.

Plate 20. Typical quartz-diopside porcellanite, with a quartz-epidote-sulphide vein.

Copper Mountain, Slide 109, Ordinary Light, x 24.



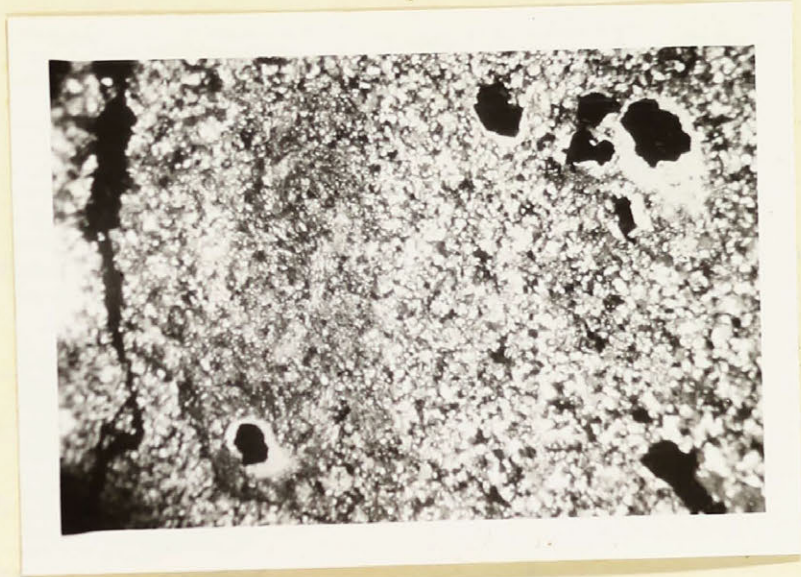
19.



20.

Plate 21. Quartz-pyroxene-carbonate porcellanite with chalcopyrite rimmed by carbonate.

Needle Mountain, Slide 32, Crossed Nicols, x 24.



21.

22.

SIGNIFICANT TEMPERATURES.

PHENOMENON	TEMPERATURE	REFERENCE
Decolorisation and silication.	About 800° C.	Winchell, (1924, P.895)
Tremolite-formation.	Below 1000 - 1100°C.	Allen & Clement, (1908, P.101).
Laboratory Inversion Point of βCaSiO_3 .	1190°C	Allen & White, (1906, P.89)
Melting Point of Dry Albite.	1128°C	
Laboratory Inversion Point, Tridymite - Quartz.	870°C	
Sanidine, - Range of stability in lavas.	800 - 1200°C	Mäkinen, (1917, P.146)
Metamorphism at Bingham, Utah.	1200 - 1500°C	Winchell, (1924, P.895).

however, that grossularite may be formed at a much lower grade of metamorphism than the almandine-spessartite garnets. The degree of solid solution is high. Tremolite, which, Allen and Clement, (1908, p.101), believe, cannot be formed above 1000° or 1100° C., is scarce; a high temperature, perhaps not as high as 1100° C. may have been in part responsible. There are present in the thin sections, substances which may be pseudo-wollastonite, tridymite and glass. The determination of each is uncertain. Pigeonite and sanidine however, provide the best evidence of extremely high temperature. Temperature estimates have been made for various of these features, and these are summarised in a table opposite.

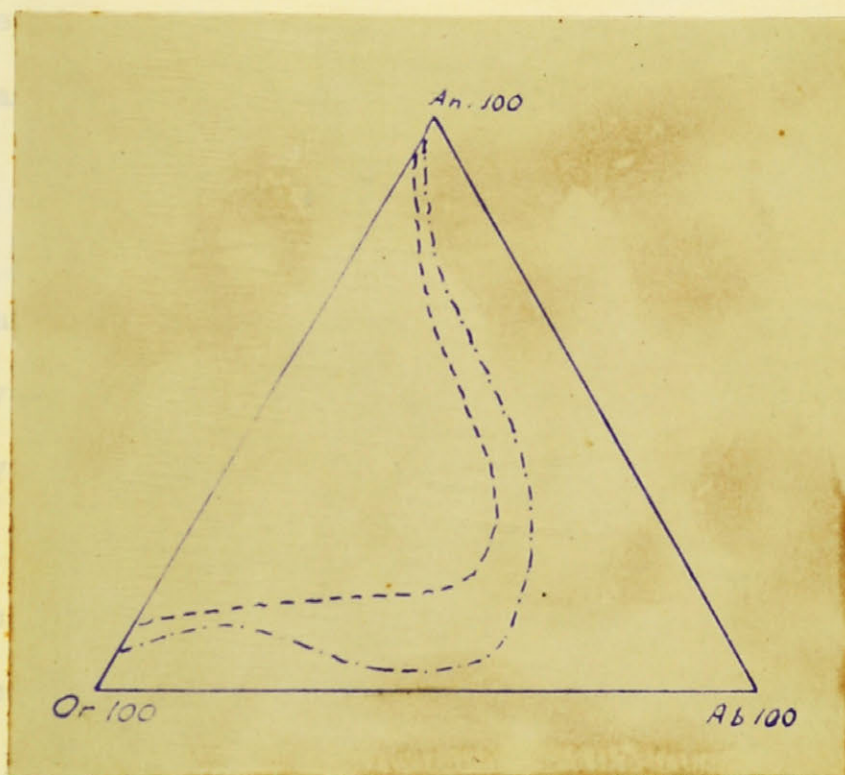
A temperature above 800° C is probably indicated by the presence of sanidine. If pseudo-wollastonite is present the temperature approached 1190° C and tridymite must have been formed, (much of it having since reverted leaving no quartz pseudomorphs). The initial melting point of the plagioclase in the presence of water would be below 1128° C, so that there would have been partial fusion as occurred in the Laacher See sanidinites. Glass need not necessarily have been formed, however. Any fused plagioclase that formed may have crystallised later with falling temperature, as high temperature conditions lasted far longer here than in the Laacher See locality, where eruption carried the pyrometamorphic rocks to the surface, and the fused feldspars and quartz formed a glassy mesostasis. Winchell's estimate for the metamorphism at Bingham, where there are no sanidinites

appears to be several hundred degrees too high.

In the absence of conclusive evidence, the writer believes that the highest temperatures reached in the metamorphic rocks were probably between 900° and 1200°C .

FIGURE 2.

Diagram showing the Degree of Solid Solution found in Lavas and in Plutonic Rocks.



Perthites and microperthites formed by unmixing were analysed and were found to be confined to the sodic side of the curves drawn.

For lavas, (temperature 1200-800°), -----

For plutonic rocks, (temperature range 900-600°), -----

Mäkinen states that in the highest temperature ranges potash-soda feldspars with more than 30% Or. crystallise as sanidine. Those with less than 30% Or. crystallise as anorthoclase. (Adapted from Mäkinen.)

Solid Solutions.

Sanidine.

This mineral is of common occurrence both in veins and in the mesostasis of the porcellanites of Copper and Needle Mountains. No accurate idea can be had, however, of the abundance of the mineral. Orthoclase and plagioclase are also found.

Mäkinen examined perthites and micro-perthites from many igneous rocks. A continuous miscibility between potash and soda feldspars was found to exist under the conditions of crystallisation for many lavas. He believes the temperature range to be $1200^{\circ} - 800^{\circ}\text{C}$. An analysis of unnixed feldspars from the plutonic rocks, showed some, but not complete, miscibility between the potash and soda feldspars. Anorthoclase, the triclinic, soda-bearing potash feldspar usually takes the place of sanidine over the range where mix-crystal formation occurs. He places the temperature range for the crystallisation of these feldspars between 900° and 600°C . presumably the stability range of sanidine in a metamorphic rock is rather similar to its range in an igneous rock, that is, at temperatures somewhat above 800°C . Sanidine, therefore, usually would have been formed with tridymite, and this is found frequently to have been the case in lavas.

Sanidine is not very common in metamorphic rocks. It has been reported by Lacroix, Brouwer, and Brauns from volcanic inclusions. For their scarcity, these sanidine-bearing inclusions have received rather much attention. The only ones described, to the writer's knowledge, that

are chemically similar to the rocks of the Miller property are some calc-silicate inclusions described by Brouwer from Java. The writer has been unable to obtain Brouwer's paper. The rocks described by Lacroix include meta-volcanics and plutonic rocks. Those described by Brauns include aluminous sediments. In all cases, the rocks were strongly heated under conditions of low pressure and stress. The volatile constituents were not confined, but were able to escape. The Laacher See rocks described by Brauns show evidence of incipient fusion. Metamorphism of this type is known as pyrometamorphism.

It must be believed then that the rocks of the Miller properties were heated in a somewhat similar way. That large quantities of volatiles were able to escape is suggested by the igneous breccias. These, however, do not show their maximum development where the exposed metamorphism is greatest, but on Porphyry Mountain. It must not be forgotten, however, that the alteration of the Grande Greve under the little altered younger series of Porphyry Mountain may be very intense.

Pigeonite, Diopside, and Wollastonite.

Solid solution between clino-enstatite and diopside has been reported from sanidinites, from xenothermal ore-deposits and also from basic and ultrabasic apophyses and flows. In all these occurrences there were high temperatures and the volatiles were, it appears, able to escape. Pigeonite is fairly common on Needle and Copper Mountains.

Allen and White, (1909, pp. 19-37.), found that in the laboratory pseudó-wollastonite forms mix-crystals with diopside to the extent of

about 3% diopside in pseudo-wollastonite. Less than 3% CaSiO_3 will form a solid solution with diopside. Pseudo-wollastonite is orthorhombic; wollastonite, which, like diopside, is monoclinic, on the other hand will form a mix-crystal to the extent of 17% diopside. The optical properties are not much affected by this solid solution. It is quite possible that this mix-crystal is present in the Miller rocks.

Classification of the Metamorphic Rocks.

Eskola, (1920), proposed a classification of igneous and metamorphic rocks based upon the association of minerals that were stable at the temperature and pressure obtaining during the principle period of formation of the rock. It was pointed out that the mineral associations depend not solely upon the bulk chemical composition of the rock, but markedly also upon the temperature, pressure, and stress conditions, and to a rather conspicuous degree upon the presence of water and various dissolved substances which may act as catalysts or a medium for certain changes and inversions. Thus if rocks of all bulk chemical compositions could be subjected to all kinds of igneous and metamorphic conditions, and if the minerals formed could reach equilibrium, the mineral associations stable for all rock compositions under manifold conditions could be defined. Goldschmidt had already attempted this in defining the stability relations among the hornfelses of the Christiana region. He pointed out that chemical equilibrium was nearly perfect. Eskola, (1920, p.145), found in the Orijärvi region a similar state of almost perfect equilibrium, ^{although} all the rocks were chemically and genetically dissimilar. Equilibrium is least perfectly attained under stress conditions, for "during stress action no true equilibria are possible. However the ideal equilibria may even here be used as norms of classification." (p. 147.)

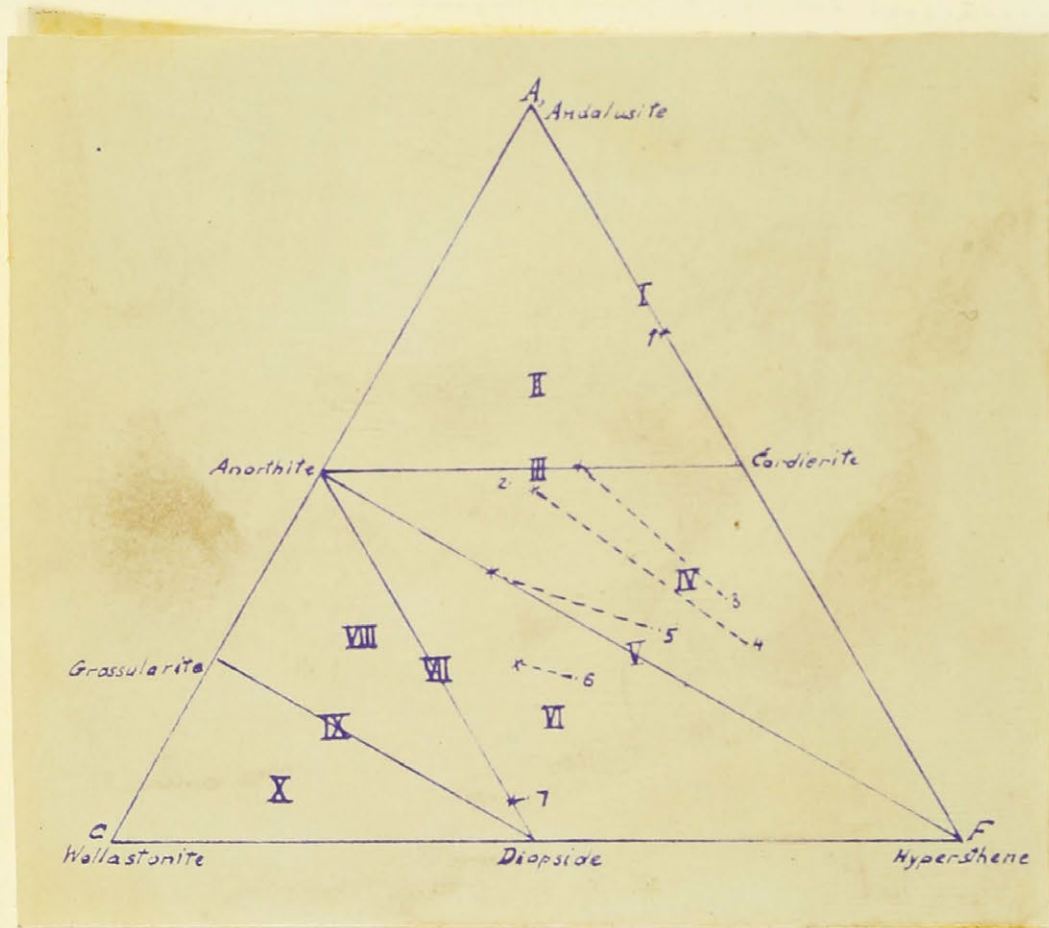
"In rocks belonging to a definite facies, the relations between their chemical and mineralogical composition may be expressed

graphically, so that the mineral associations appear directly from the diagrams based on the chemical analyses. Such a graphical solution is practicable if the number of the components controlling the mineral composition can be reduced to an extent allowing of a diagrammatic expression..... The Osann triangle..... allows only three components to be represented simultaneously, while the rocks have a much larger number. By rational choice and restriction I have, however, succeeded in finding a method of expression useful for the majority of rocks of more common composition, and having excessive silica, so that always the compounds highest in silica can be formed. In one corner of the triangle is located the alumina not combined with potash or soda, in another the lime and in the third one magnesia with ferrous iron. The minor constituents are, after subtracting the amounts of $(Al,Fe)_2O_3$, CaO and $(Mg,Fe)O$ combined in them, left out of consideration." (p. 156). A similar scheme could be worked out for the incompletely silicated calcareous rocks, in which there is a tendency for the formation of those minerals highest in CaO . That investigation can not be carried out in the present instance because of the absence of chemical analyses.

Eskola and Goldschmidt found that, when points representing rock analyses were plotted on these so called ACF triangles, on which the minerals of the mineral facies had been marked, the minerals found in the rocks analysed corresponded extremely closely to the phases predictable from the diagram.

FIGURE 3.

The A, CF - Projection of the Hornsfels
Facies.

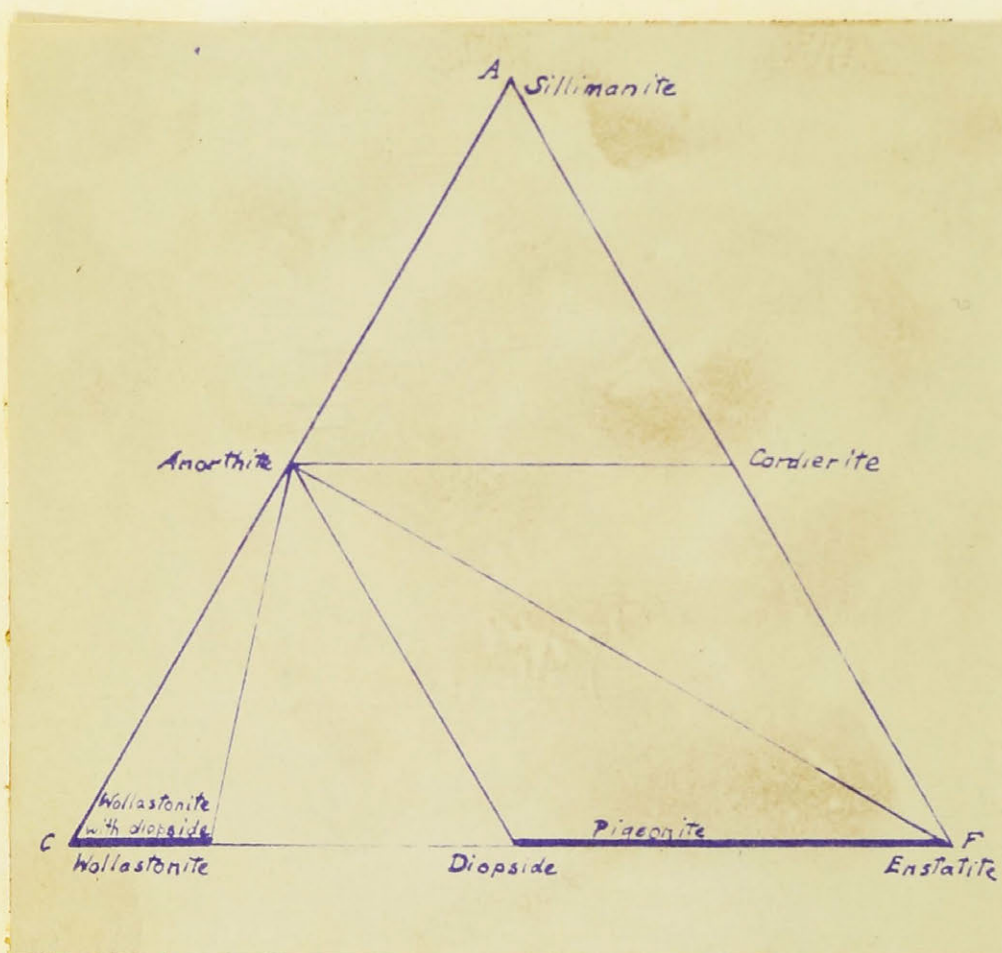


(After Eskola)

Eskola writes on page 159, that "the hornfels facies seems to be restricted to the inner parts of the contact-metamorphic aureoles around laccolithic igneous bodies.... In the contact products of hypabyssal bodies and volcanic products types transitional to the sanidinite facies may be expected." On page 162, he states that "no garnets are stable in the sanidinite facies". Garnets are of common occurrence in sanidine-pigeonite rocks of the Miller Properties; in this respect they show themselves to be transitional between the hornfels facies of Goldschmidt and Eskola's sanidinite facies. Of silica he says, " its stable forms in the sanidinite facies are tridymite and cristobalite. In the hornfels facies only quartz has been met with." It is uncertain whether tridymite occurs, or ever did occur, in the Miller porcellanites; at the present time, quartz, and almost no tridymite, is found. "In the natural occurrences, the sanidinite rocks show poor approximation to true equilibria. Relics from various other facies are almost invariably present." The latter is particularly true of altered igneous rocks or of rocks that have been submitted to a complex metamorphic history, such as the Laacher See rocks, (Brauns, 1912, p.12), in which four different types of metamorphism are recognised. There are no minerals present in a siliceous limestone that can withstand the metamorphic processes, except minerals like quartz, feldspar, and zircon which are, in any case, stable. There is no reason why, in the course of a simple pyrometamorphism of a siliceous limestone, any phase should appear that is not one formed in the normal succession of reactions that proceed progressively in the direction of equilibrium. Those phases

FIGURE 4.

The A, CF - Projection of the Sanidinite
Facies.



The thick lines denote solid solutions.

(After Eskola)

that appear will either be stable as a higher temperature is reached, or will be made over. There are no minerals like, say, tourmaline or the amphiboles, that may be inherited as unstable relics from an earlier epoqe, and that may escape being made over. Therefore, if equilibrium were not reached in the calc-silicate rocks, there was at least a strong tendency toward the establishment of equilibrium. In the present investigation it is impossible to ascertain how nearly equilibrium has been reached, but it is noteworthy that almost no minerals have been found that appear to be metastable. The only ones that probably are metastable are the very rare needles of tremolite, and also those of sillimanite that have survived because the containing clastic quartz grains "armoured" them against the metamorphosing solutions. There was therefore a tendency towards the establishment of chemical equilibrium at the time of most intense metamorphism. Under ideal conditions, the equilibrium point would be determined only by the bulk composition of the original rock, by the concentration of introduced materials, and by the pressure and temperature. In actual practice, the rocks are not a closed system, the temperature does not necessarily stay constant over sufficiently long periods for slow diffusion to take place, and the composition of the rock may change radically in a small volume. Nevertheless, as Eskola has pointed out, it is very helpful to study the ideal associations which would be reached had equilibrium been attained.

Eskola(1920, p.158) further says of the hornfelses:-

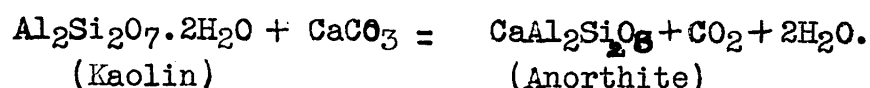
"If only the typical minerals were present, the points

representing the analyses would be located within those fields or within those lines, whose corner points correspond to the composition of the constituent minerals. The hornfelses, however, also contain biotite, a mineral present in most of the hornfelses of classes 1-7. The quantity of ferrous oxide and magnesia in this mineral influences the location of the plotting points, but its existence depends upon the presence of water, which does not appear in the triangle. All the points deviate from their proper positions in a direction toward the biotite field.

" I have therefore also calculated the A, CF values after having subtracted the oxides entering into the biotite, whose percentages were taken from the modes given by Goldschmidt. The values thus corrected have been.....plotted on the triangle,(fig.3), with crosses united to the respective points by dotted lines. It may be seen that the new values, from which the biotite has been eliminated, show perfect agreement with the theory."

A similar correction is necessary for the lime and magnesia constituents due to the presence of scapolite. This mineral owed its existence in part to the presence of chloride and other ions of volatiles. The values of analyses of scapolite rocks plotted uncorrected on the A, CF triangle would not give a true picture of the mineral associations actually present. The CaO and Al₂O₃ that has entered into scapolite formation would have to be subtracted. The corrected values would be removed from the plotted analyses in a direction away from the scapolite field.

The role of Ca CO₃ in highly calcareous rocks of the sanidinite facies seems to be roughly as follows. It forms CaMg(SiO₃) with MgCO₃ and SiO₂. It forms augite with or without scapolite in slightly aluminous rocks. Felspars are not usual in the highly calcareous rocks of the Miller Properties, so that it seems unlikely that anorthite is normally formed in this association. It might possibly be expected from the equation:-



On the other hand, in rocks in which scapolite is lacking, garnet is rather commonly found in highly calcareous rocks. It seems possible, therefore, that grossularite may be stable in the sanidinite facies in rocks not saturated in silica. Alternatively it is possible

that these rocks exemplify the hornfels facies, and not the sanidinite facies, in this respect. Any carbonate left after the formation of these minerals was silicated to give wollastonite. Thus the temperature in the highly calcareous rocks was high and reactions between the original constituents and introduced material were complete, but insufficient silica was introduced to carry silication to completion. The aluminous and magnesian minerals are formed first, and wollastonite is formed only by any further silica that is introduced. The carbonate that still remains plays a passive role, just as does excess silica in the highly **siliceous** rocks. The amphibolite facies is quite unlike the sanidinite facies, in that the metamorphism occurred under autoclave conditions. It differs from both the hornfels and the **sanidinite** facies in that the temperature was lower. K₂O, (FeO+MgO) and Al₂O₃

combine to form mica. "In those rocks in which the quantity of potash is sufficient to form mica with all the $(\text{Mg,Fe})\text{O}$ and Al_2O_3 available, the amount of mica is controlled exclusively by the proportions of the latter oxides. The excess potash then goes to form potash felspar." Wollastonite, grossularite, diopside and anorthite are found in the amphibolite facies, but the ferro-magnesian amphiboles are of importance also, and hornblende, tremolite, anthophyllite and cummingtonite are commonly found in the place of enstatite. Biotite, muscovite, and rarely, cordierite occur as aluminous constituents. Thus the rocks of this facies are quite unlike those of the Miller Properties. The Greenschist facies and the Eclogite facies show even stronger dissimilarities.

In conclusion, then, it is clear that the rocks under consideration are related in properties of mix-crystal formation to the sanidinite facies, and with regard to the presence of garnet, to the hornfels facies. To quote once more from Eskola, "as appears from the previous outline, the divergencies between the two facies are great. They apparently are not so much due to a difference in pressure than in temperature, this having been considerably ~~depressed~~, in the hornfels facies, by the pressure which has prevented the volatile components from escaping." (p.162)

By dividing each facies into classes as Goldschmidt has divided the hornfeldes, a chemical and depth-zone classification like that of Grubermann is no longer necessary. The rocks belong primarily to Hornfels classes 7-10. Class 6 is also represented but the place of diopside and hypersthene is taken by pigeonite.

Classification of the Mineralisation.

The metamorphic rocks had reached a state very near equilibrium before mineralisation began. However, that much of the sulphide mineralisation occurred at a high temperature is indicated by the close association of pigeonite and sanidine with the sulphides, and by the occurrence on Needle Mountain of pyrrhotite, a mineral that formed under conditions of high temperature. This close relationship between the mineralisation and the metamorphism is characteristic of pyrometasomatic deposits.

There are other features that are unusual in deposits of this type, however. They include the extremely fine grain of the porcellanites, the absence of hydroxyl-bearing minerals, the occurrence of sanidine and pigeonite either as rock-forming or as gangue minerals, the open-fissure veins and the crustification. All these features are indicative of a deposit formed at shallow depth and at high temperature. Buddington(1) has called these "xenothermal deposits".

The metamorphic and metallising epoqe was not a simple one. Metamorphism was followed by igneous intrusion, and this in turn by kaolinisation and mineralisation. The mineralising period probably was also prolonged, and sulphides were deposited during a long decline in temperature; nevertheless, on Needle Mountain, at least, where there is such a close association of pyrrhotite and chalcopyrite, it seems most probable that the most extensive mineralisation occurred at a high temperature. The deposit therefore, is a pyrometasomatic one, but shows certain abnormal features that indicate a depth unusually shallow for the formation of such a deposit.

(1) Buddington, A.F. - "High Temperature Mineral Associations at Shallow to moderate depths". Econ. Geol. 30, 1935, p.209.)

Economic Possibilities.

Ore-bodies of considerable size have been outlined. That on Needle Mountain includes about 18,000,000 tons of ore;- equivalent to about half a billion pounds of copper. The Copper Mountain ore-body is believed to be not quite as large. Both however, are very low grade,- about 1% chalcopyrite, or a little less,- and the content^{of gold} is very low. Molybdenite, galena, sphalerite,^{and} kaolin, might be other ores of value.

Mineralisation is quite widespread in the metamorphic area, but the heavy overburden makes prospecting of these showings difficult. A systematic investigation would be extremely costly. It is unknown whether altered rocks underlie the terrain of the younger series on the east, or whether metamorphism is confined to a vertical pipe.

An interesting comparison may be drawn between the Miller Property and the non-porphyry ore-deposits of Bingham, Utah. The latter deposits, according to Hunt, (1924), and Winchell, (1924, 2 references,) show the following characteristics. There is a large porphyry mass that intrudes quartzites and siliceous limestones. The latter form about 10% of the whole sedimentary section. Lime-silicates have been produced in the calcareous members. Ores are found principally in the porphyry, but there are also important replacements of the calc-silicates. The quartzites have very little mineralisation on the whole. However, irregular stockwerks of sulphide ores occur in them in the form of closely spaced fractures in those quartzite beds that are near heavily mineralised, silicated limestones, or near the porphyry contact.

The chalcopyrite and pyrite within 1500 to 2000 feet of the

porphyry contact, are sometimes found massively replacing the limestones in such a way that bedding structures are well preserved. Some of these may be injections of a sulphide magma. No such massive replacements have been seen at the Miller claims. Perhaps at depth, near the contact, heavy replacement beds may be found; at Bingham this replacement is found in the garnet-wollastonite-diopside zone. Tremolite, asbestos, and specularite, minerals foreign to the Miller claims, are also present in this inner zone. The outer zones are a lime-silicate zone, one of non-silicated but decolorized limestone, and finally the unaltered black limestone. The boundary between the discolored and the black, unaltered limestones is generally roughly that between the copper and the lead-producing bodies of ore. A few miles from the Miller deposits, near other porphyry bodies, not in the black unaltered limestone, there is a mesothermal, galena-sphalerite deposit, the Federal Mine, and some galena float has been found near the Miller Properties.

Replacements were usually most extensive along the base of the massive limestone beds. In the massive ores, pyrite is the chief gangue, and non-metallics are of little importance; unlike the Miller ores the gangue is almost non-quartzose. There are useful percentages of gold and silver, - another dissimilarity. Molybdenite, as in Gaspe, is an accompanying ore.

The deposit is believed to be xenothermal and very high temperature, Winchell, (Feb. 1924, p. 895), believes the temperature approached 1200 to 1500°C. The paragenesis was broadly similar to that at the Miller Properties. Thus silication was followed by the introduction, first of the chalco-

-pyrite ores, and later by the silver-lead ores. Carbonate followed after and Winchell believes that it is supergene. Secondary enrichment has been of great economic importance,- another point of divergence from the Miller deposits.

This rather remarkably close parallel is suggestive. The drilling program so far carried out, although extensive, is far from exhaustive. The calcareous Needle Mountain Phase beneath the Copper Mountain ore-body has not been penetrated; it may have been a particularly favourable locus of ore-deposition. Long, diagonal holes might be necessary to cut that vertically-disposed ore-shoot. Other tabular bodies may underlie the Needle Mountain ore-shoot. It is unknown what lies under the Needle Mountain phase. Surface prospecting for galena and sphalerite could be carried out around the decolorized zone, particularly in the more calcareous rocks of the Grande Greve; another deposit like the Federal might be found.

Clearly, apart from surface prospecting for galena in the peripheral zone, any further exploration would be very costly, demanding deep drilling on an extensive scale.

Summary.

The Miller Properties are in central Gaspe Peninsula, about forty miles west of Gaspe village, to which they are connected by a road. The topography is hilly, with a local relief of about 1000 feet; the highest hills are about 3000 feet high. Glaciation was chiefly local, and achieved little beyond widening the valleys.

The Lower Devonian limestones are mostly unmetamorphosed, and regionally strike in an east-north-easterly direction. They are openly folded, but little faulted, and are in places cut by Middle Devonian dykes and sills of diabase and granite porphyry.

The Properties themselves are in this Lower Devonian terrain, but here, there is a high grade of contact metamorphism of the calc-silicate hornfels type. Although granite porphyry apophyses and igneous breccias, are locally more abundant, they are insufficiently developed to have produced the metamorphosed zone. It is believed that there is a subjacent plutonic mass that gave off volatiles and apophyses. The altered zone is about three square miles in area, and is somewhat elongated transverse to the local strike. Cross-folding parallel to north-easterly axes, is locally developed at the Properties. Few dips exceed 30° however, and the pitch is about 15° to the north-east. The traces of the outcrops of beds cross the altered zone from north-west to south-east, and have a gentle "embayment" to the north-east over the plunging anticline in the central portion of the area.

There are two main mineralised areas. The Needle Mountain ore-

body is in the southwest ninth of the metamorphic zone. The anticlinal axis passes through, or just southeast of, this body. The Copper Mountain ore-body lies about 1 mile due north in the northwest and north-central ninth of the zone. The beds in the Needle Mountain area are folded into a gentle north-south dome, and on the east flank of this the ore-body is situated. The rocks of this mountain are calc-silicate rocks,- calcite-wollastonite rocks, with quartz-diopside rocks. Scapolite and grossularite are found apparently in an antipathetic relationship. Pigeonite and sanidine, minerals denoting excessively high temperatures, are also found.

Copper Mountain is capped by a biotite hornfels group of rocks that are themselves overlain to the northeast by fine quartzites and little altered, but decolorized, limestones. This series is grouped together and is locally called the "Younger Series". It is believed to be Lower Devonian. Beneath this series there is the "Copper Mountain Phase",- fine white quartz-diopside porcellanites, with or without garnet. No scapolite or wollastonite are found here, although pigeonite and sanidine are common. Porphyry intrusives were post-metamorphic and pre-mineralisation, and were kaolinised apparently by the mineralising solutions.

The main mineralisation occurred while the rocks were still at a high temperature, although their pyrometamorphism had been completed. Garnet, pigeonite, epidote, quartz and sanidine formed veins approximately in that succession. Chalcopyrite occurs in both ore-bodies in close association with all the above gangues except garnet. Pyrrhotite occurs

in intimate association with chalcopyrite on Needle Mountain, whereas pyrite is the iron-sulphide on Copper Mountain. Replacement is usual in the calcareous Needle Mountain Phase, whereas open fissure veins are more common in the brittle, siliceous rocks of the Copper Mountain body. Besides chalcopyrite and pyrite, molybdenite is a common ore on Copper Mountain, but it is rarely found on Needle Mountain. Galena and sphalerite were later deposited in both ore-bodies, and calcite, fluorite, and anhydrite are found with them in the centre of many crustified veins and lining vugs.

It is believed that considerable silica was introduced during the silication of the calc-silicate rocks. If the silica used in the silication of the carbonate had been that already present in the cherty limestones, there would have been a large volume change,- a change of which there is no evidence. The chloride for the formation of scapolite may be introduced or it may have been present in the connate water. Magnesia was probably introduced and took part in the formation of pigeonite.

The high degree of solid solution that is represented by pigeonite and sanidine suggests an abnormally high temperature. The open fissure veins, crustification, fine granularity, and certain stratigraphic evidence all seem to indicate a low hydrostatic pressure. There is no evidence of stress.

The metamorphic rocks are classified according to the mineral facies classification proposed by Eskola. The facies to which

the rocks of the Miller properties belong is transitional between the hornfels facies and the sanidinite facies. It commonly shows the mineral associations of the hornfels facies, in which grossularite is stable. On the other hand, the presence of sanidine and pigeonite indicates an affinity for the sanidinite facies in which grossularite is not stable.

The mineralisation is closely related to the metamorphism, although it is later. That it is a high temperature mineralisation is indicated by the presence of pyrrhotite, pigeonite, and sanidine in close association with the chalcopyrite in the veins. The deposit is therefore a rather abnormal one of the pyrometasomatic type, which was formed under conditions of high temperature and low pressure, that is, under xenothermal conditions.

The ore-bodies so far revealed by diamond drilling, are large but are too low grade to work at the present time. Precious metals are lacking, and there is no secondary enrichment. In other respects the mineral deposit bears a striking resemblance to the non-porphyry deposits at Bingham, Utah. Deeper drilling, particularly below the Copper Mountain ore-body, might reveal more ore in the underlying calcareous rocks. It is suggested that the bulk of the galena and sphalerite mineralisation is probably outside the decolorised zone of the metamorphic area.

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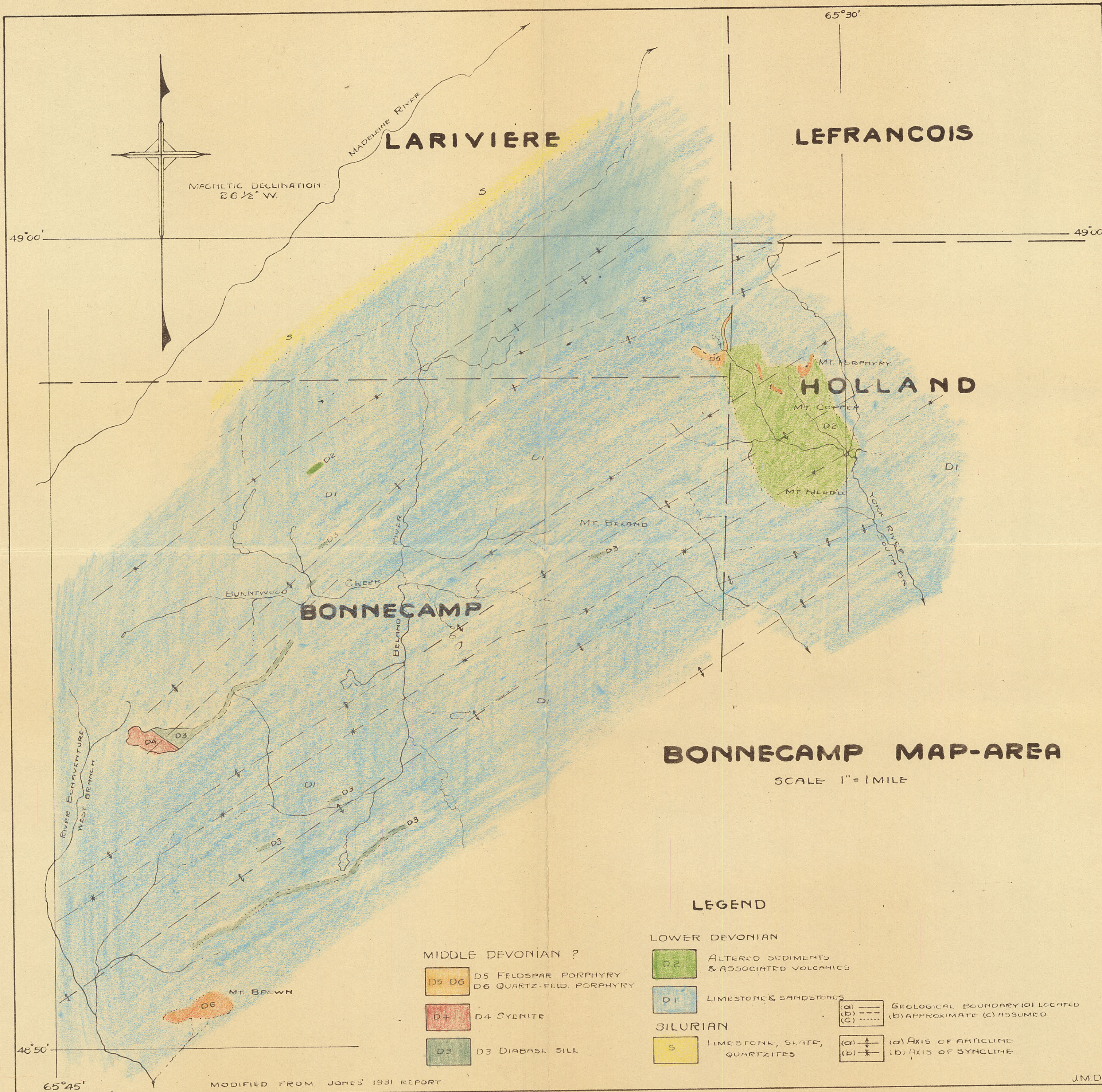
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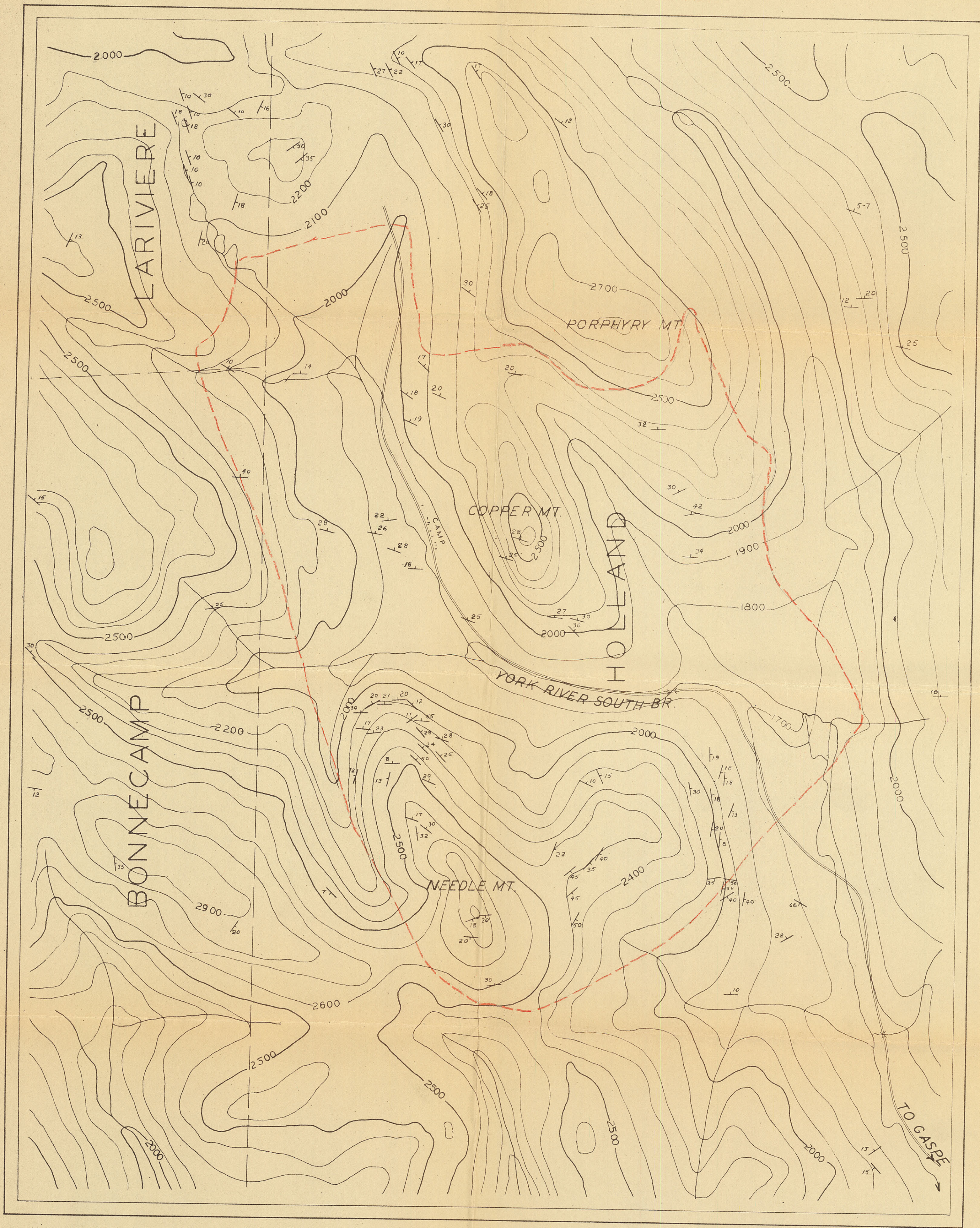
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0 1000 2000 3000 4000
FEET

0 1/2 1
MILES

YORK RIVER COPPER

METAMORPHIC AREA



MILLER COPPER PROSPECT

GASPE NORD
SCALE 1 INCH = 400 FEET

CLAIM POST (JULY 1940)
NORANDA OPTION & STAKINGS OUTLINED

1A 1B 1C 1D 2
COPPER MOUNTAIN PHASE
NEEDLE MOUNTAIN PHASE

