THE OLD NICK PROSPECT

A Nickel Deposit in Southern British Columbia

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Steve Gerhard Enns

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The undersigned certify that they have read, and recommend to

the Faculty of Graduate Studies for acceptance, a thesis entitled

.....A NICKEL DEPOSIT IN SOUTHERN BRITISH COLUMBIA................

....

submitted by ....Steve Gerhard Enns........................

in partial fulfilment of the requirements for the degree of   M.Sc.

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Supervisor

....

....

....

.... Ph.D. P.Eng

External Examiner

Associate Prof. of Geology
Brandon University

Date ..14...april. 1971.   ....

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ABSTRACT

The purpose of the study is a description of the geologic environment containing mineralized dunite and quartzite, and an investigation into what form metallization occurs with a view to explaining the origin of nickel, chromium, and cobalt.

Within the grid area, Permian sedimentary and volcanic rocks form the Anarchist Group which is intruded by a magnesia-rich alpine dunite of Jurassic age. The nearby Cretaceous granodiorite differentiated complex known as the Nelson Pluton has thermally metamorphosed the Anarchist Group and the dunite.

Polished section study shows that disseminated sulphides in the dunite are mainly pentlandite and pyrrhotite occurring interstitial to the olivine-serpentine pseudomorphs. Two generations of pentlandite are found. In the quartzite member of the Anarchist Group, disseminated pentlandite and pyrrhotite are strongly associated with fuchsite bands, whereas more abundant pyrite is associated with the recrystallized quartz mosaic.

Geochemical studies show typically high nickel, chromium and cobalt values for dunite, and anomalously high values of the same metals contained in the

mineralized quartzite. Nickel occurs in pyrrhotite, cobalt appears to be concentrated in pyrite, whereas chromium is tied up in fuchsite. Dunite and quartzite have similar values for the nickel:chromium ratio suggesting a common source of metal mineralization. The relationship between nickel:chromium and nickel:cobalt ratios for quartzite indicates partitioning of these metals during metallization. Nickel, chromium, and cobalt bearing hydrothermal solutions originating from the parent magma to the dunite are believed to be the source of mineralization in quartzite.

ACKNOWLEDGEMENTS

CHAPTER I

OBJECTIVES

The first objective of this study involves a description of the regional geologic setting of the nickel deposit and of the disposition of dunite and quartzite in which mineralization occurs.

Secondly, focus is given to the type of mineralization in order to find out what form nickel and related metals are in.

Thirdly, an attempt is made to explain the occurrence and origin of nickel, chromium and cobalt mineralization on the basis of studies conducted.

CHAPTER II

INTRODUCTION

The Old Nick prospect is located in central southern British Columbia (Fig. 1) just off the Transprovincial Highway No. 3. It is twenty-three miles east of Osoyoos which is situated on the international boundary at the south end of the Okanagan Valley. A point on the grid area (Fig. 3) would be defined by latitude 49°02' and longitude 119°06'.

The area surrounding the Old Nick has seen considerable mining activity since 1859 when British Columbia's earliest gold rush began at Rock Creek.

Most of the past interest has been directed toward gold and silver, but in more recent times copper, chromite, and molybdenum showings have also been reported.

The Old Nick prospect is a low grade large volume deposit with an average estimated grade of approximately 0.25 percent nickel. World Mining (1967) reported mineralization over an area 800 feet by 400 feet. This zone dips into the hill at 38 degrees. Grade is computed equivalent to slightly better than four dollars a ton at 1967 nickel price.

Nickel is the most important economic metal which occurs
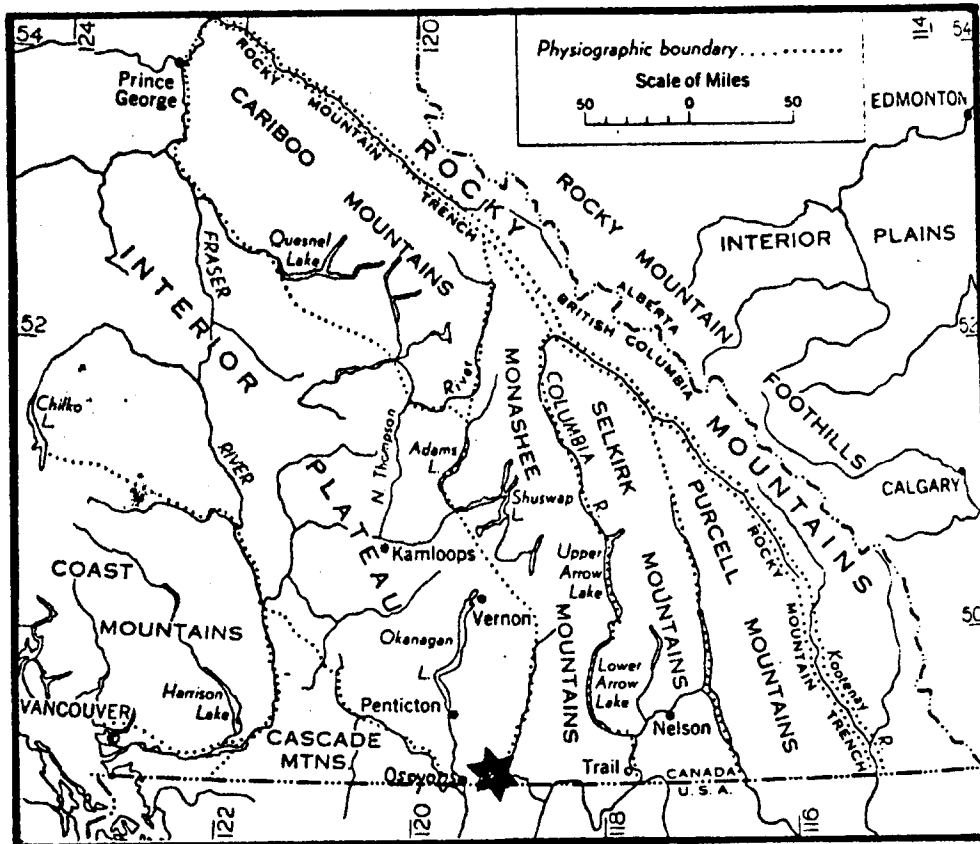
Fig. 1. Physiographic divisions of southern
British Columbia and location of Old
Nick prospect.

in a quartzite host rock along with chromium and cobalt. Ultrabasic rocks also occur on the property, but hold relatively little promise for large volume tonnage of potential economic ore.

After completing an economic feasibility study involving nickel recovery by floatation, a major mining company concluded that the return for every ton of ore processed would be insignificant at present, due to low nickel recovery in a rather complicated process.

Presently, a different approach involving *in situ* microbacterial leaching is under serious consideration by yet another mining firm.

CHAPTER III

GENERAL GEOLOGY

Physiography

The Old Nick claim group lies within the south Interior Plateau region of British Columbia. Forty miles to the east lies the Monashee Mountain Range, while sixty miles west lies the Cascade Mountain chain (Fig. 1).

More specifically, the prospect is bounded on the east by the north-south trending Kettle River Valley. Bounding this region to the west is the north-south trending Okanagan Valley. This valley is made up of a composite northeast and north-northwest oriented fault system.

The country is a maturely eroded highland manifesting itself in typically rounded mountain slopes which are partially covered by a thin veneer of glacial material. Relief ranges from less than 2,000 feet to 3,000 feet in the higher country, and the maximum elevation attained is 7,500 feet.

The major drainages shown in Figure 2 are incised canyon-like streams. Locally these streams may have steep banks up to 300 feet in height. The upper banks of these streams are composed of transported material, the origin of which is fluvial glacial. One exposure examined on the upper south

bank of Rock Creek in trench G (Fig. 3) displays three vertical sets of graded bedding with coarse boulders as large as one foot in diameter. Several sets of terraces are evident at many places on both stream slopes.

Rock Types

The regional geology as shown in Fig. 2 is a compilation of Daly's (1912) map, Little's (1961) work and the writer's own observations in the area.

Anarchist Group

Basement rocks known as the Anarchist Group have been dated as Permian in age (Little, 1961). Included in this group are quartzites, phyllitic slates, meta-argillites, greenstones and marbles in order of abundance. Some of these members have been altered to schists and amphibolites.

All sedimentary units with the exception of marble are very fine-grained. Recrystallization and dynamic metamorphism of the rocks makes identification of bedding difficult so that the only readily discernible structure is schistosity. Color in the quartzite varies from gray to green whereas in phyllite and meta-argillite it is brownish gray, green, and slate gray. The dark coloration is due to the inclusion of small quantities of carbonaceous material.

Greenstones represent volcanic flow rocks occurring as massive and schistose bands commonly interbedded with sedi-

mentary units. Color usually is dark green to gray-green
and rocks are cut by numerous calcite veinlets. Daly (1912)
suggests that both injected and effusive basic rocks are
represented, with effusive types occurring in greater
abundance. He suggests the composition to be that of basalt
or basaltic andesite. Injected basic rocks are also present
within the grid area (Fig. 3). The basic volcanic rocks
have been altered to amphibolite and amphibole-chlorite
schists. Extensive alteration often precludes recognition
of original tuffaceous equivalents, or of primary features
such as amygdales and vesicles.

Marble units, the product of recrystallized low magnesia
limestone, occur as localized pods (Fig. 2). These rocks
have a white to pale bluish gray color and occur in massive
outcrops. Since recrystallization is total, bedding has been
destroyed, as have most fossil fragments. Daly (1912) noted
a few coral fragments, and several crinoid stem fragments
are present in an outcrop one mile east of Rock Creek on
Highway No. 3. Little (1961) also noted a few brachiopod
fragments.of indeterminable age.

Kettle River Formation

The other sedimentary rock group is the Kettle River
Formation believed to be of Mid-Eocene age based on evidence
of plant fossils and radiometric age dating (Monger, 1968).
Minimum thickness has been estimated at approximately
2,000 feet.

Included in this formation are gray to black argillites, fine-to medium-grained light gray sandstones, arkoses and conglomerates with boulders as large as three feet in diameter. These boulders have been derived from the Anarchist Group (quartzite, argillite and greenstone) and the Nelson plutonic suite. The formation lies unconformably on the Anarchist Group basement sequence as well as on the Nelson pluton, but is in turn cut by an intrusive Rhomb Porphyry.

Ultrabasic Plutonic Rocks

The oldest plutonic rocks in the area are altered dunite and serpentinite. They are found within the Anarchist Group but invariably the contact coincides with a strong shear zone. These ultrabasic rocks occur as narrow dike-like bodies and are usually associated with strong faults indicating tectonic activity accompanying intrusion. The dunite near the McKinney Creek-Rock Creek confluence indicates that the ultrabasic rocks in this vicinity definitely pre-date the Nelson plutonic rocks. Inclusions of dunite may be found here within the Nelson diorite. In thin section these dunite inclusions reflect their ultrabasic origin by preservation of recognizable olivine-serpentine-magnetite mesh texture. Further supporting evidence is the observation of small dioritic apophyses into the dunite.

Nelson Plutonic Rocks

The major plutonic event in this vicinity is represented

by the Nelson-Valhalla intermediate plutonic complex.
Although Valhalla plutonic rocks have not been observed
within the map area (Fig. 2), they form a major component
of the large plutonic complex to the north. The Nelson
plutonic suite includes granodiorite, quartz diorite,
diorite, and granite. It also includes quartz monzonite,
syenite, and monzonite whereas Valhalla plutonic rocks
include granite and granodiorite. The complex is believed
to be upper Mesozoic or Cretaceous in age (Little, 1961).

The Nelson pluton within the map area (Fig. 2) occurs
as an elongate northwest-southeast body. Its intrusion
could very likely have been controlled by some underlying
basement structure. It varies from half a mile to almost
two miles in width. Another small pluton outcrops in the
southeastern corner of the map at Myers Lake.

Rhomb Porphyry Intrusive/Extrusive

The youngest intrusive rock in the vicinity is the
rhomb porphyry. Monger (1968) called it a feldspar rhomb
syenite. The largest body of this syenite lies immediately
north of the Transprovincial Highway No. 3 and is referred
to by Daly (1912) as the Rock Creek chonolith. Several
smaller plutons are found in the southeast quadrant of the
map (Fig. 2).

The rock varies in color from gray, gray-green and
pink-gray to dark gray. Commonly displaying a porphyritic
texture, it is made up of subhedral to euhedral rhomb

shaped feldspar crystals 2 mm to 5 mm in length and clino-
pyroxene grains up to 3 mm in length set in a finely crystal-
line mass. The proportion of phenocrysts to matrix varies,
but the composition of the phenocrysts remains similar. In
some cases biotite foils as large as 4 mm in diameter are
the dominant phenocryst. Presence of a few small olivine
crystals is also reported by Daly (1912).

According to LeCheminant (1966) the jackets of the
feldspar phenocrysts show a limited composition, a fairly
constant 2V and are largely orthoclase in composition. In
contrast, the rhomb-shaped triclinic cores vary consider-
ably in their composition, ranging from oligoclase to an-
orthoclase. This is reflected by the variation of 2V falling
into two broad groups. One group varies in 2V from 60° to
75° while another group varies from 80° to almost 100°.
Most of the core material is believed to be made up of a
barium-strontium rich anorthoclase (Daly, 1912).

The extrusive rhomb porphyry lies along the north edge
of the Rock Creek chonolith. Although its relation to the
intrusive phase is obscure, it resembles the chilled contact
phase of the intrusive rhomb porphyry. It is slate gray
to brownish gray with porphyritic feldspars showing the
distinctive rhombic outline. Vesicles and amygdales are
common, with amygdales containing calcite, and more rarely,
opal. They may be found up to 20 mm in length. Generally,
the flows are massive without flow structure of any kind,

flow structure of any kind, and unaccompanied by pyroclastic material.

Structure

This section deals briefly with the structural aspect of the area in order to round out regional geologic description. Since comprehensive structural treatment is beyond the scope of this study, treatment here is restricted only to the most significant structural elements.

First, the basement rocks consisting of the Anarchist Group are fine-grained and often highly contorted into small crenulated similar folds, and complex random folds. Measurable structures in the field consist mainly of foliation attitudes with bedding being a rare occurrence.

Figure 3 shows the interbedded character of the sedimentary and volcanic units, having a general northeast trend and southeast dip. The few bedding attitudes present tend to reinforce this trend.

Eastwood (1969) on noting small calcite filled drag folds within the volcanic sequence along the railway grade, believes that they indicate updip over-riding of the beds. This could be accomplished by development of anticlinal folding. From the repetitious sequence of sedimentary and volcanic units, one can postulate the existence of an anticline, overturned to the northwest with axis plunging gently to the southwest. Its southwest extension is truncated by a

north-northwest trending fault. Southwest of this fault
the pattern becomes considerably more complex.

The Rock Creek canyon tends to follow a zig zag north-
east northwest composite fault system. Associated with some
of these faults are occurrences of altered dunite which
would indicate considerable downward extension of these
faults because ultrabasic rocks are well known for their
association with deep-seated structures. The largest ex-
posure of altered dunite in the vicinity of trenches M, N,
and H appears to trend east with the south contact display-
ing strong shearing. Immediately east another northwest
trending dunite interpreted from magnetometer data was con-
firmed by trenching and powder hole drilling.

Following the last igneous event of the rhomb porphyry
intrusion, there is another major period of structural dis-
turbance. This expresses itself in the form of a parallel
north-northeast trending fault system (Fig. 2). From the
straight traces of these faults across the map one can infer
them as having rather steep dips near the ground surface.
Monger (1968) believes these faults to be largely normal
faults producing tilted blocks such that Tertiary volcanic
and sedimentary remnants are preserved in structural lows.
He further estimates vertical displacements on some faults
of at least 6,000 feet and has found some evidence of strike
slip movement on at least one fault.

CHAPTER IV

DETAILED GEOLOGY

This section deals with rocks encountered within the Old Nick grid area (Fig. 3). Included are metamorphosed varieties of the Anarchist Group and altered dunite. Some attention is also given to the Nelson plutonic rocks, but detailed discussion is limited to the host rocks of nickel mineralization; the mineralized quartzite and dunite. Other rock types are discussed in fuller detail in Appendix I

Within the grid area, extent of natural exposure is limited to a few small outcrops and the canyon walls of Rock Creek. It is estimated that approximately 15 percent of the bedrock is visible for examination if one includes the railway cut and extensive trenching carried out on the property.

The Anarchist Group

The Anarchist Group within the grid area consists of thermally metamorphosed quartzites, argillite, greenstones and impure carbonate rocks. Intrusive basic units believed to be related to the volcanic units are also included. It should be noted (Fig. 3) that volcanic and sedimentary units are interbedded, with sedimentary units being slightly more

abundant than the volcanic units.

Non-mineralized Sedimentary Rocks

Quartzite and argillite are the most abundant sediments.
The argillite rocks have been converted to hornfelses or
meta-argillites by thermal metamorphism from the nearby
Nelson pluton whereas quartzites have been recrystallized.

Quartzite occurs with admixtures of graphite and/or
very fine-grained sericite. The rock grades into a meta-
argillite with increasing amount of fine-grained sericite,
which represents original argillaceous material. All sedi-
ments are fine-grained and recrystallization and deforma-
tion have rendered original structures largely indistinguish-
able. Some banding is frequently present and consists of
quartzo-feldspathic material alternating with brown sericite
the foliation of which is generally parallel to banding.
It is not known whether this type of banding is preserved
bedding or simply recrystallization under stress. A few
reliable bedding attitudes have been noted.

Thin section study of the argillite shows it to be a
very fine-grained rock composed of quartz, feldspar, amphi-
boles, small amounts of biotite and scattered epidote grains.
One section shows development of pyroxene crystals, another
shows cordierite development with secondary chlorite. Garnet
is also present in one case, but no evidence of epidote
breaking down to form garnet was noted. The minerals amphi-
bole, pyroxene, garnet, and cordierite are moderate rank

metamorphic minerals. Grade of metamorphism has been placed in the upper hornblende hornfels facies or perhaps as high as Winkler's (1967) orthoamphibole subfacies of the lower K-feldspar-cordierite hornfels facies. Presence of garnet with cordierite is uncommon and could mean that either; 1) contact metamorphism took place at depth, or 2) the chemical composition of the rock falls within garnet's narrow stability zone allowing for its formation at shallow depth (Winkler, 1967).

Mineralized Quartzite

The mineralized quartzite shows a consistent mineralogy of quartz, fuchsite, sulphide and small amounts of fine grained biotite. Estimated visible sulphide in hand specimen varies from 3 to as high as 15 percent. The mineralized quartzite is usually fine grained, light greenish gray in color and appears to be composed largely of pure quartz and wavy bands of fine grained fuchsite.

Microscopic examination of thin sections reveals irregular patches of pure quartz in mosaic pattern with intergranular boundaries outlined by secondary iron oxides (Plates 1 and 2). The largest individual quartz grains usually attain diameters of not greater than 0.5 mm and these coarser, clean mosaic intergrowths are interpreted as recrystallized quartz veins which have become considerably distorted. Areas of very fine-grained quartz mixed
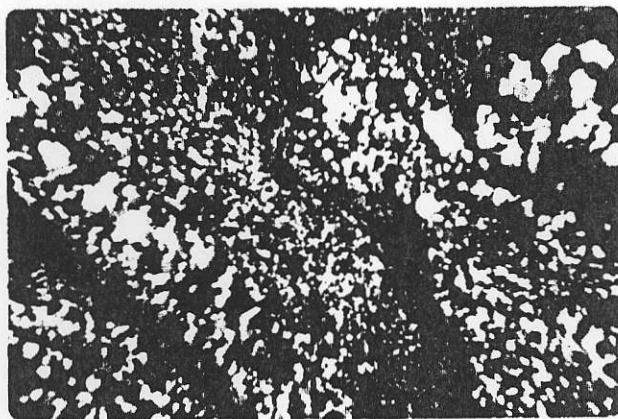
Plate I   Mosaic of clean quartz representing recrystal-
           lized quartz vein, adjacent fine-grained material
           represents original sediment with higher
           argillaceous content.
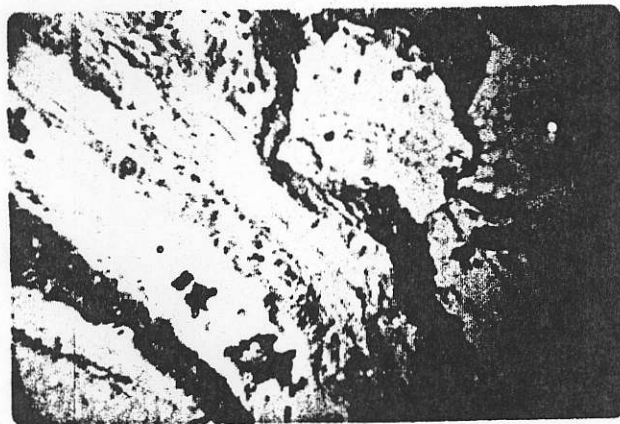
Plate II   Same as Plate I. Note cross-cutting quartz vein-
           lets in fine-grained argillaceous section.
           Crenulated pinched bands of fuchsite.

with sericitic material probably represent the original host rock material before recrystallization.

Interrupting the quartz mosaics are irregularly crumpled bands of fine-grained fuchsite and biotite which pinch and swell discontinuously. These bands contain fine-grained dustings and slightly coarser (0.5 mm) blebs of sulphides, primarily subhedral nickeliferous pyrrhotite. Within the quartz mosaics, subhedral to euhedral sulphide grains are most commonly pyrite.

There is some question about the green mica here referred to as mineral X, which is confined exclusively to wavy bands, and imparts a green color to the quartzite. Eastwood (1968) deduced it to be a chrome phengite, more chrome rich than the type mariposite. However, studies on the basis of careful β measurement and chemical analysis would favour the conclusion that it resembles closely the mineral fuchsite (Table I). An X-ray diffractometer pattern run on mineral X indicates a pattern identical to that of muscovite. This is quite reasonable, since Mg^{+2}, Cr^{+3}, Fe^{+3} and Fe^{+2} will substitute for the octahedral Al^{+3} sites in the muscovite formula $K_4Al_8(AlSi_3)_4O_{40}(OH)_6$. Deer, Howie, and Zussman (1965) report that up to 6 percent Cr_2O_3 has been recorded for some chromium-bearing muscovites and this is believed to be caused by Cr^{+3} substitution for octahedral Al^{+3} sites.

There may be some query regarding the 2V angle of mineral X, the average of which appears to fall closer to

TABLE I

Comparison of Mariposite, Fuchsite and Mineral X

	Mineral X	Mariposite	Fuchsite
Color	pale green	emerald green, apple green to white	green
β	1.594	1.601-1.624	1.593-1.604
Optical Sign	-ve	not given	-ve
Dispersion	r > v	not given	r > v
2V	21°	$0-14^{\circ}$	$30-46^{\circ}$
$Cr_2O_3\%$	4.10% *	0.18-0.78%	0.27-6.08%

* Chemical analyses determined as Cr% and converted to Cr_2O_3 for comparison.

the range reported in literature for mariposite (Table I),
but it should be noted that the procedure used was one out-
lined by Moorehouse (1959). This involves comparison of
isogyre curvatures with his diagram of Wright (Moorehouse,
1959, Fig. 28) on acute bisectrix figures. Eleven deter-
minations were made ranging from 15° to 30°, the average of
which was taken. Furthermore, Whitmore, Berry, and Hawley
(1946) state that

> " .... while an appreciable angle (36°) is diagnostic
> of fuchsite, a smaller optic angle (20°) does not
> necessarily establish a chrome mica as mariposite."

Impure Carbonates

Another type of sediment of minor abundance on the
property is the impure carbonate. Its assemblage is calcite-
quartz-actinolite usually showing medium- to coarse-grained
texture. One thin section shows strained quartz blebs inter-
stitial to calcite and actinolite crystals. Actinolite
forms long prisms 2 to 3 mm in length with typical diamond
shaped cross-section. Only two occurrences are known on
the property (Fig. 3).

Volcanic Rocks

The volcanic rocks are also referred to as greenstones
since they are altered, containing primarily amphibole,
feldspar, epidote and chlorite, and are cut by numerous
calcite veins. They are fine-grained and massive,
but the more altered varieties are somewhat schistose be-

cause of higher chlorite content. Magnetite commonly fills minute fractures in the fresher rock. However, no flows, pillows, or primary structures other than deformed recrystal- lized amygdales can be recognized.

Other volcanic rocks occurring closer to the Nelson intrusion are banded amphibolites. These are made up of fine-grained amphiboles (probably hornblende) with inter- stitial feldspar and some carbonate material. Some small grains of zoisite are disseminated throughout. The bands consist of fine-grained zoisite, epidote and secondary iron oxides, with or without amphibole grains.

Tuffs

Another unit of the volcanic sequence is a mottled and banded rock (Plate III) which consists of a dark green- black matrix with irregular bands and clots of paler green material. These clots appear to be made up largely of pale green amphibole crystals with sheaf form, some as large as 10 mm across.

Microscope study shows that the pale green patches are made up largely of amphibole needles (actinolite) with fray- ed terminations. Interstitial to these are amphibole, cal- cite, small grains of clinopyroxene and small amounts of very fine-grained feldspar material.

The mineralogy, amphibole and clinopyroxene (which appears to be primary) suggests a volcanic origin. The tex- tural appearance is not that of a volcanic flow, but could
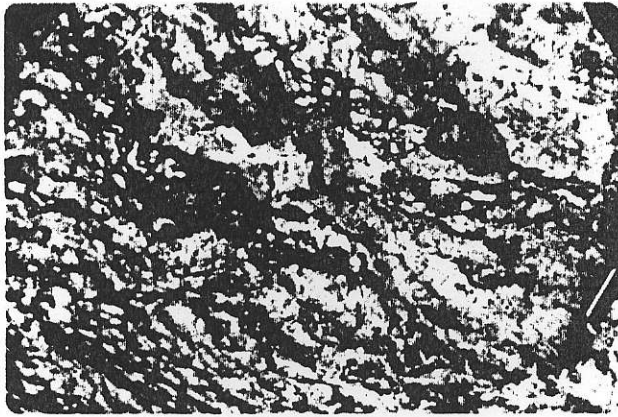
Plate III

Mottled pattern of tuff units. Magnet is 4 inches in length.

Plate IV

Altered dunite displaying rounded inclusion. Note the distinct lineation within the inclusion and flow lineation surrounding the inclusion. Pen is 7 inches in length.
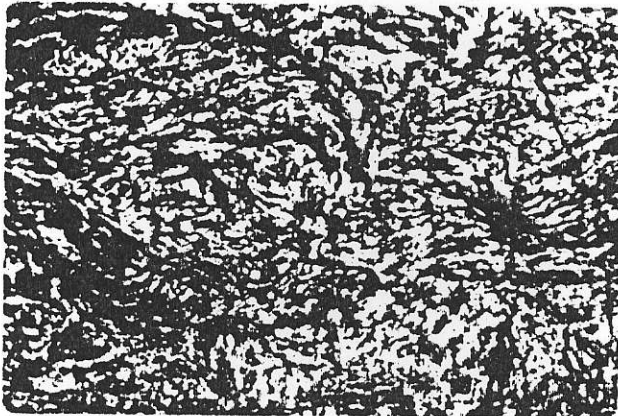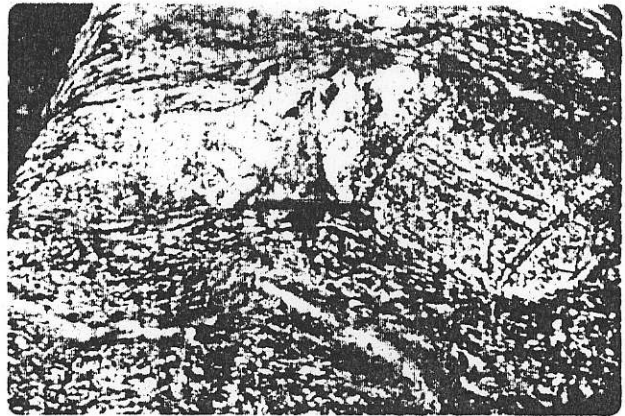
Plate V

Altered dunite showing altered interstitial material (white) and serpentine-olivine pseudomorphs (black). Note lineation of pseudomorphs (x0.5).

conceivably be produced by recrystallization of tuffaceous material, especially if preceded by dynamic metamorphism as suggested by Daly (1912). Recrystallization of the tuffs via thermal metamorphism during intrusion of the Nelson pluton is likely. Further supporting evidence comes from the fact that small amounts of fine-grained quartzo-feldspathic material occur within the mass of secondary amphibole. This quartzo-feldspathic material is interpreted as sedimentary material deposited with the tuff.

Basic Dikes

Several basic hypabyssal dikes likely related to the Anarchist volcanic units occur in the grid area. In hand specimen this rock is recognized by its dark greenish-black color and massive character. It is composed of very fine-grained amphibole and orthopyroxene with green serpentine material occurring along some fractures.

Dunites

The dunitic masses occur in slightly discordant sill-like bodies associated with shear zones and faults (Fig. 3). Contacts with host rocks are invariably sheared and much altered to talc obscuring their relationship with surrounding rock.

Although adjacent host rock shows evidence of thermal metamorphism, intensity does not appear to increase toward the dunite contact. Superimposition of the thermal altera-

tion effect from the Nelson pluton and/or the Rhomb Porphyry intrusion may have obliterated the metamorphic effect of dunite intrusion.

One large waterworn boulder in the creek bed displays fragments of pre-existing medium-grained dunite within a coarser textured dunite matrix (Plate IV). The rounded fragment measuring 16 by 10 inches displays distinct medium-grained lineation. Surrounding this fragment the coarser dunite displays a form of flow structure. Thayer (1960) states that this type of lineation is commonly character-istic of alpine ultramafic intrusions.

In hand specimen the dunite may be a dense, massive, very fine-grained rock, but more commonly it has a coarse mottled black and white massive appearance which is very striking on weathered surface (Plate V). The finer-grained varieties are made up largely of minute amphibole needles and pale green olivine, and have a talcose appearance. The coarse mottled variety contains black dense aphanitic areas made up of serpentine, relict olivine, and magnetite. These constitute a general pattern of lineation (Plate V), espec-ially near the margin of the ultrabasic body. Interstitial to these are white to pale gray ragged patches of talc-carbonate and tremolite. No mineralogical variation is noted across the width of the body which, according to Thayer (1960), is another characteristic of alpine ultrabasic intrusions.

Olivine content varies from 15 to as much as 40 percent,

and occurs as small relict grains (0.01 mm to 0.25) mm in a characteristic mesh pattern with interstitial serpentine and magnetite. Serpentine and magnetite form a pseudomorphous composite after the original olivine crystals, and generally replace 75 to 85 percent of the original grains. Original grains vary in size from 2 mm to 8 mm and are recognizable in thin section by the uniform extinction displayed by remaining relict olivine grains. Less commonly pseudomorphs take on the shape of elongate blades 10 mm to 12 mm in length.

A study on the forsterite content of olivine was carried out by measuring the 2V on a universal stage for relict grains of two serpentine-olivine pseudomorphs per slide. Poldervaart's (1950) graph was used to determine the F_o content. All grains measured were optically positive indicating that forsterite content is greater than F_{o87}. These results are shown in Table 2. Most values lie between F_{o91} and F_{o93}. Section T-140 shows a moderate departure from the others in its higher Mg content of F_{o97-98}. The fact emerging from this study is that the olivines are very Mg-rich, indicating a high MgO/FeO ratio which again is characteristic of alpine ultramafic rocks according to Thayer (1960).

Serpentine occurs as a very fine-grained mass, frequently cross fibre, and most commonly is found in olivine pseudomorphs. The less altered olivine grains commonly

TABLE II

Olivine 2V Determination and Related F_O Content

Section	2V	F_O Content
T-1	87° 88°	{ 93.0 91.0
T-9	88° $87^\circ 30'$	{ 91.0 92.0
T-140	85° $84^\circ 15'$	{ 97.0 98.0
T-121	88° 88°	91.0 91.0

Universal stage measurements performed by J. Macek,
Man. Mines Branch.

show serpentine borders around an olivine core containing minor serpentine along narrow fractures. Serpentine content varies from 10 to 50 percent in the more altered sections. Narrow cross-cutting veinlets represent a later phase of serpentinization.

Abundant talc is found in most sections and varies from less than 5 percent to as much as 40 percent of the rock. It is associated with carbonate and is commonly fine- to medium-grained but occasionally occurs as large coarse flakes up to 1 mm across. Talc occurs in greatest abundance interstitial to olivine-serpentine pseudomorphs (Plate VI) and partially replaces cross-cutting serpentine veinlets. A substantial portion of the carbonate material is magnesite, but the presence of calcite is confirmed by the greater than normal lime content for dunite indicated by major oxide analyses (Table III).

Tremolite varies from less than 5 percent to greater than 50 percent of the total rock and appears to be restricted in its growth mainly to regions of talc-carbonate material interstitial to the olivine-serpentine pseudomorphs (Plate VI). Bladed crystals grow as large as 10 mm long. In sections where tremolite is abundant, talc becomes scarce and interstitial carbonate material has the appearance of a recrystallized mosaic. Very fine dustings of opaque ores (sulphides) occur within tremolite.

Anthophyllite, identified by its high relief, parallel
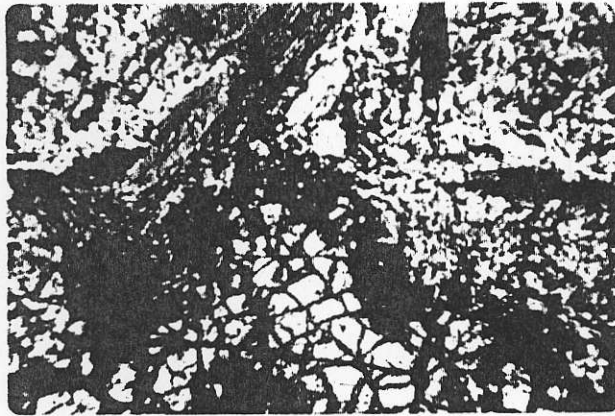
Plate VI   Thin section showing part of olivine-serpentine
           pseudomorph surrounded by serpentine sheath.
           Note interstitial material replaced by Talc-
           carbonate material, and beginning of tremolite
           growth (x80).

extinction and low birefringence is present in two sections. Like tremolite it occurs in patches of talc-carbonate material. Sulphides interstitial to anthophyllite and tremolite seem to have formed later than the amphiboles.

Fresh orthopyroxene is present in rare amounts and is only noted in two sections. In one slide its occurrence is restricted to the thin edge of the section and identification is not conclusive.

The opaque minerals include magnetite, sulphides, and possibly some chromite. These are treated later under the section on mineralization.

Alteration of Dunite

Serpentinization

In sections where talc-carbonate content is less pervasive, microscopic study shows that material interstitial to serpentine-olivine pseudomorphs is usually totally altered to serpentine. Smaller pseudomorphs also are more thoroughly altered than the larger ones. Serpentinization of olivine crystals varies from 35 to 100 percent producing typical mesh structure. Minute dustings of magnetite and secondary iron oxide accompany the serpentine.

No real evidence of volume increase was observed in serpentine replacement, for each pseudomorph displays a uniform extinction across all contained relict olivine grains. This would tend to support Turner and Verhoogen's

(1960) concept that olivine is replaced by an equal volume of serpentine

$$5Mg_2SiO_4 + 4H_2O \rightarrow 2H_4Mg_3Si_2O_9 + 4MgO + SiO_2$$
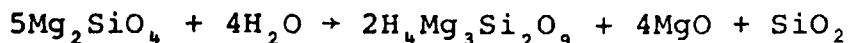
They appeal to removal of magnesia and silica via solution for the difference.

Serpentine also occurs in late fractures and tiny veinlets cutting serpentine-olivine pseudomorphs. Several of these veinlets have the appearance of working inward into the rock a short distance where they rapidly narrow and die out altogether. This type of relationship tends to support the idea of serpentine formation with volume increase.

Two periods of serpentine alteration are suggested. The first one replaced the interstitial material, small olivine grains and progressively worked inward from olivine grain boundaries so that only larger grains survived replacement by serpentine. The later period of serpentinization followed fractures and other planes of weakness cutting across the rock.

Talc-Carbonate Alteration

Talc-carbonate alteration appears to have replaced the serpentine material interstitial to original olivine grains resulting in a mottled black and white pattern (Plate V). This has left serpentine-olivine pseudomorphs as separate entities within a fine grained mass of talc-carbonate material (Plate VI).

Turner and Verhoogen (1960) state that in the presence of aqueous solutions olivine will alter to talc at temperatures between 500°C to 525°C. However, evidence for this type of alteration is lacking in thin section. Whenever olivine is present (usually as relict grains) it is always surrounded by serpentine. Even large original crystals of relatively fresh olivine are invariably separated from talc-carbonate material by a serpentine sheath. Partial replacement of serpentine veinlets by talc-carbonate material further indicates that talc-carbonate alteration is post-serpentinization and selectively replaces serpentine.

Naldrett (1966) outlines three ranks of talc-carbonate alteration. Most of the talc-carbonate alteration of the Old Nick dunite appears to be similar to Naldrett's medium rank where talc-carbonate replaces serpentine interstitial to olivine pseudomorphs. Locally, near one contact, large blocks of sheared dunite are composed entirely of talcose material indicating a high degree of talc-carbonate alteration.

This type of alteration is essentially a dehydration reaction which according to Naldrett is favoured by addition of CO_2, and removal of small amounts of O_2. Little or no exchange of magnesium, iron, silicon, and nickel takes place during the reaction:

$$serpentine + magnetite + CO_2 \rightarrow talc + magnesite + magnetite + H_2O + O_2$$
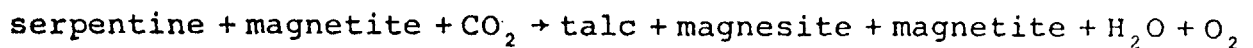
Greenstones adjacent to dunite contain abundant calcite

for a source of CO_2 and the intrusion of the Nelson pluton less than half a mile distant provides a convenient heat supply for dehydration and thermal metamorphism. One could also consider the rhomb porphyry intrusion of Eocene time.

Tremolite Alteration

Tremolite occurrence is notably restricted to the interstitial talc-carbonate material so that its association with talc-carbonate is valid (Plate VI). Microscopic study shows a general inverse relationship between talc and tremolite. Sections with an abundance of talc-carbonate show relatively sparse tremolite crystals, while sections containing large amounts of tremolite display very sparse interstitial talc and recrystallized mosaics of carbonate. This is interpreted as tremolite forming at the expense of talc with progressive dehydration following talc-carbonate alteration. The carbonate remains unaffected except for recrystallization.

Anthophyllite Alteration

The sparse occurrence of anthophyllite bears some resemblance to tremolite in its association with talc. Greenwood (1963) states that anthophyllite can coexist stably with quartz and tremolite, if such rocks were at some time subjected to conditions within the narrow stability range of anthophyllite. He estimates that the range of temperature at which anthophyllite is stable for

any given pressure is of the order of $85^{\circ}C$. Thus, temperature conditions for the depth (given pressure condition) at which metamorphism occurred were probably just on the border of the narrow stability conditions required for wholesale anthophyllite growth resulting in sparse anthophyllite occurrence.

Retrograde Alteration

Retrogressive alteration is present in the dunite, but generally minor in extent. Included is limited alteration of tremolite to talc and some talc-carbonate altering back to serpentine. These types of alteration are not uncommon and would tend to be the result of any hydration reactions accompanying thermal metamorphism.

Nelson Pluton

The occurrence of the Nelson intermediate complex has already been discussed in the section under General Geology. The various phases examined in section are described in some detail in Appendix I.

Field investigation showed that toward the outer margin of the pluton the rock types become distinctly more basic indicating differentiation. A notable increase in mafic minerals occurs, together with an increase in the calcic content of the plagioclase, as one progresses toward the contact. The pluton is primarily granodiorite but contact phases include basic diorite and gabbro. These

basic phases are cut by granodiorite dikes which in turn have been cut by late aplite phases.

The contact between granodiorite and the argillite of the Anarchist Group is typically intrusive at McKinney Creek. Numerous dikes are injected into the argillite which displays severe thermal metamorphic effects such as recrystallization and development of purple brown biotite some distance from the contact. At the contact argillite appears to have been granitized so that the distinction between granodiorite and argillite is obscured.

CHAPTER V

MINERALIZATION

This chapter deals with metallic sulphides and oxides. Included here are pyrite, pyrrhotite, magnetite, hematite, violarite and chalcopyrite which usually occur in that order of abundance.

Important metallization occurs in two ways. These are: as disseminated sulphides, pyrrhotite and pyrite, within an extensive quartzite member of the Anarchist Group, and as disseminated nickel-bearing pyrrhotite within altered dunite. The nickel-bearing quartzite is the more important of the two types since it occurs as large mineralized zones trending roughly parallel to the main structure (Fig. 3).

This study involved an examination of polished sections from selected mineralized rock samples. Microscopic examination included low power examination under 10X magnification of each polished section and estimation of sulphide and oxide content with the use of a 10 mm square transparent grid, and high power examination with the aid of a polarizing reflecting microscope with an effective magnification capability of up to 1350X.

Dunite Mineralization

Selected mineralized dunite samples come from the dunite body exposed in trenches H, M and N. Low power studies show that sulphide comprises between 1 and 6 percent. Oxide concentration varies from nil to 2½ percent. Areas of sulphide may be as large as 3 mm. Large grains display a ragged texture (Plate VII) containing numerous silicate inclusions of fibrous crystals, and commonly having rather frayed contacts with silicates. Most of the larger sulphide areas occur at the edge of or within the talc-carbonate patches, but never within serpentine-olivine pseudomorphs, suggesting that sulphides are primary and interstitial to original olivine crystals (Plate VIII). In contrast, minute quantities of sulphide are found locally in pseudomorphs. Textural evidence as illustrated in Plate VII favours redistribution of sulphides in silicates during serpentinization and further during talc-carbonate alteration in a way similar to that described by Kilburn *et al.* (1969).

Pyrrhotite is the most abundant sulphide, being host to pentlandite, magnetite and silicate inclusions. Locally pyrrhotite is replaced by magnetite, especially in the vicinity of minute fractures containing magnetite, serpentine and some carbonate. Near such fractures no pyrrhotite survives while further away both magnetite and pyrrhotite can be noted. Still further from the fracture magnetite

Plate VII

Ragged texture of sulphides, indicating replacement of sulphides by secondary silicates (x160).

Plate VIII

Serpentine-olivine pseudomorph and interstitial talc-carbonate replacement with contained sulphides (x50).
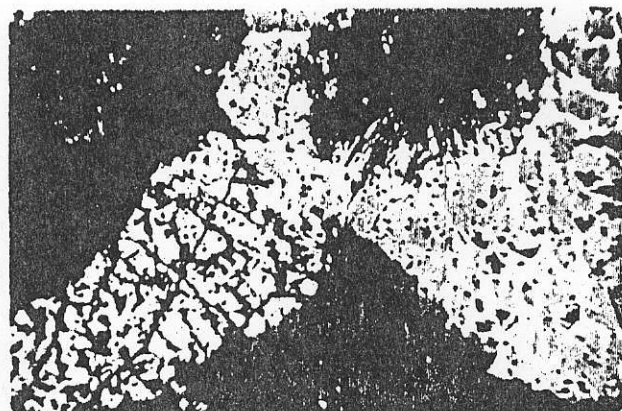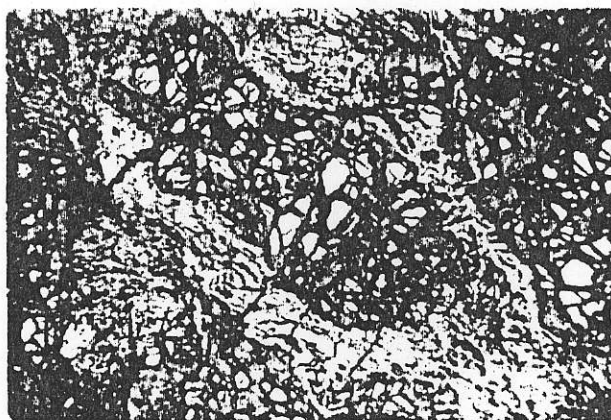
Plate IX

Magnetite-pyrrhotite intergrowth with magnetite replacing pyrrhotite. Vicinity of fracture in lower left hand corner (x100).

is absent (Plate IX). This type of relationship indicates
that in this case sulphide replacement by magnetite is con-
trolled by these fractures. Plate XV illustrates replace-
ment of pyrrhotite by secondary magnetite as a second mode
of sulphide replacement. Pyrrhotite is commonly cut by secon-
dary fibrous silicates which apparently have a larger form
energy than sulphides. Hence, sulphide appears to be inter-
stitial to tremolite as illustrated in Plate X and XI.

Pentlandite is associated with pyrrhotite in all
instances and although it may constitute as much as 80 per-
cent of sulphide grains in some places (Plate XII), it
normally comprises approximately one-third of the sulphides.
There are three modes of occurrence: 1) large grains with-
in pyrrhotite displaying isometric cleavage fracturing
(Plate XII); 2) as fine lamellae; 3) as minute flame
or brush structure (Plates XI and XIII). The pentlandite
grains may vary in size from 0.1 mm to as large as 0.5 mm.
The lamellae and flame structures tend to occur more fre-
quently in small sulphide grains, and are characteristically
very fresh and unfractured unlike the larger pentlandite
grains. This would imply that they formed later than the
pentlandite grains, perhaps by exsolution from a nickeli-
ferous pyrrhotite at a lower temperature. Naldrett and
Kullerud (1967) noting the same phenomena argue that pent-
landite's high coefficient of thermal expansion or contrac-
tion on cooling causes fracturing, whereas exsolution at
lower temperature would leave insufficient thermal con-
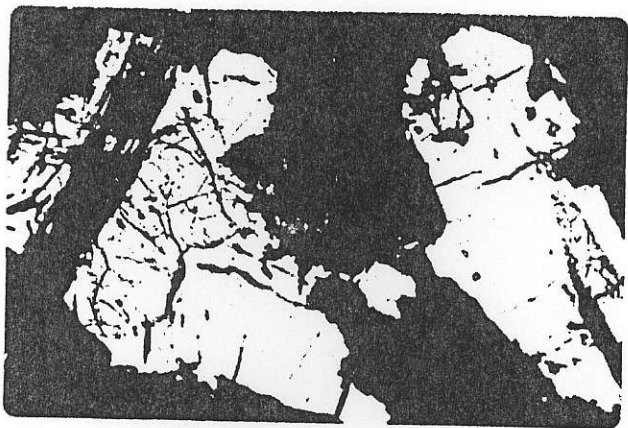
Plate X

Sulphides cut by secondary silicates. Also violarite replacing pentlandite along edges (x100).

Plate XI

Fibrous secondary silicates with interstitial pyrrhotite and pentlandite exsolution lamellae (x100).
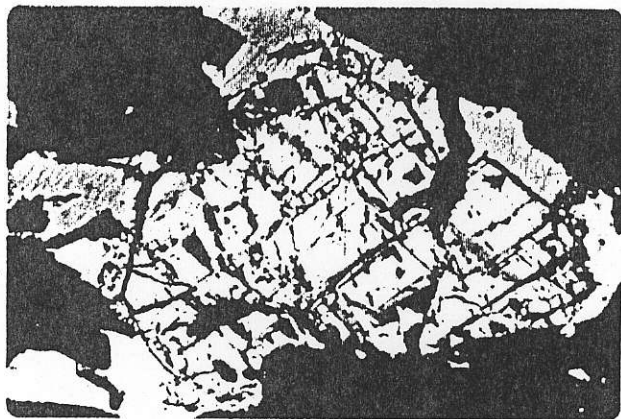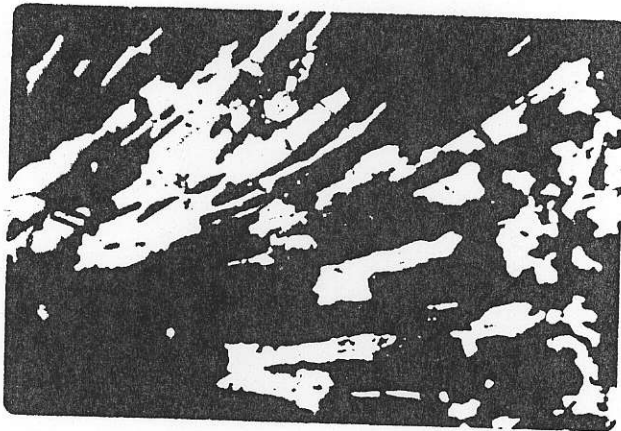
Plate XII

Large pentlandite grain in pyrrhotite showing cleavage fracturing and replacement to violarite (x160).

Plate XIII

    Pentlandite lamellae
and brush or flame structures
in pyrrhotite (x360).

Plate XIV

    Violarite preferen-
tially replacing pentland-
ite (x562).
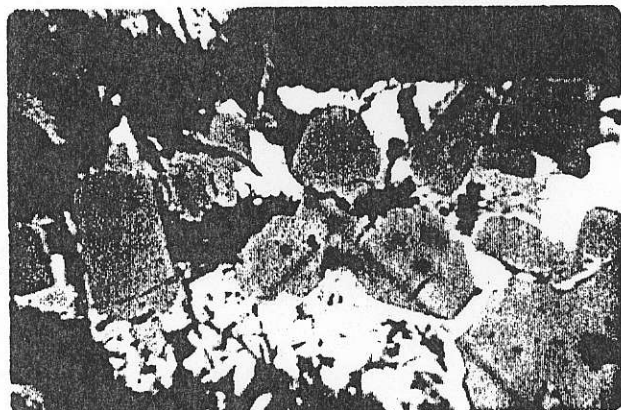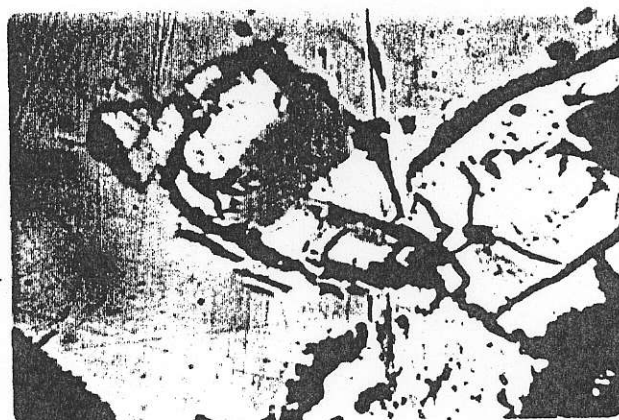
Plate XV

    Secondary growth of
magnetite around original
euhedral grains and replac-
ing sulphide material
(x5 5).

traction on cooling to cause fracturing.

Violarite, $(NiFe)_3S_4$ is identified as such on the basis of its occurrence, violet gray color, isotropic character, and cleavage which is rarely discernable. Plates XII and XIV illustrate the preferential replacement of pentlandite by violarite starting at the borders of pentlandite grains and in cleavage fractures (Plate XII), then progressive replacement of greater amounts of pentlandite with advancing alteration (Plate XIV). An interesting point to note is that only the larger more fractured grains of pentlandite are affected by alteration to violarite. Lamellae, brushes or flame structures remain intact and fresh. It is possible that the larger grains being more fractured, are more susceptible to the supergene process of violarite alteration.

Magnetite usually occurs as subhedral disseminations and tends to be concentrated near fractures which control its occurrence to some degree. Sulphides near these fractures become replaced by magnetite. Other cases of magnetite replacing sulphide are also noted where fractures are absent. Plate XV illustrates the development of secondary magnetite about previously existing magnetite crystals and replacing pyrrhotite. Sparse amounts of very fine magnetite disseminations are noted in the serpentine-olivine pseudomorphs, but low iron content of the magnesian olivine precludes abundant development of magnetite during serpentinization. Some of these grains are actually

chromite. There is the possibility that many of these fine grains could have been dislodged from the soft serpentine host by the grinding and polishing action during preparation of the polished section.

Accessory opaque minerals include hematite and chromite. Hematite is believed to be a secondary alteration mineral after magnetite, and chromite is not abundant.

Paragenesis for the mineralized dunite appears to be as follows. Crystallization of the primary silicate olivine was followed by crystallization of interstitial primary sulphides. This resulted in the irregular patches of pyrrhotite with large fractured pentlandite grains derived from exsolution of nickel sulphides upon cooling. Any chromite present was likely crystallized about the same time as olivine or slightly later. Serpentinization brought on development of magnetite and initiated redistribution of sulphides into the silicates. Talc-carbonate alteration from thermal metamorphism by adjacent intrusive plutons caused recrystallization of sulphides and further redistribution of sulphides in secondary silicates. This was brought to a climax by the development of tremolite. A decrease in the temperature of thermal metamorphism produced further exsolution and development of pentlandite lamellae, brush and flame structures. Lastly, development of violarite and hematite by supergene processes brought the mineral history of the altered dunite to a close.

CONC IN
LATERITIC HORIZON:
Fe, O4, Ni Cr
SULPHIDIZATION ??

Quartzite Mineralization

The ore minerals in the quartzite include pyrite,
pyrrhotite, pentlandite, magnetite, hematite, chalcopyrite
and minor chromite usually in this order of abundance. Of
the two dominant sulphide phases pyrite and pyrrhotite;
pyrite is much more abundant than pyrrhotite. Pyrite appears
to be closely associated with the regions of clean quartz
mosaic whereas pyrrhotite has a strong tendency to associate
with the fuchsite-sericite bands in the quartzite. Total
sulphides may range from 3 percent to 15 percent.

Pyrite generally occurs as euhedral to subhedral
individual grains up to 1 mm in size. It tends to show a
square outline and is characterized in polished section by
its high relief. Some aggregates form semi-massive bands
up to 10 mm in width. One section displaying a pyrite
mosaic is made up of inclusion-free pyrite peripheral to a
mass of pyrite filled with numerous inclusions of silicate
and some sulphide (pyrrhotite). This suggests recrystal-
lixation of the borders of the pyrite mass. Pyrite gener-
ally contains rare amounts of pyrrhotite inclusions, which
in turn contain minute amounts of pentlandite (Plate XVI).
However, it is possible that more pyrrhotite inclusions
within the pyrite are present in rock specimen than show up
in polished section. Because of the minute size of the
inclusions and the differential hardness between the two
sulphides, it is likely that at least some of the inclu-

sions have been lost during preparation of the section.

Pyrrhotite is generally very fine-grained although rare grains may attain sizes measuring more than 1 mm across. In form, pyrrhotite is more anhedral. Its association with many fuchsite-sericite bonds is marked. Little or no pyrite occurs in these wavy bonds. Pyrrhotite has three modes of occurrence; as individual grains, as a mosaic and as rare inclusions with pyrite. Except for pentlandite structures pyrrhotite is generally clean and free of most impurities. High values of nickel are noted for pyrrhotite in a comparison of analyses of pyrite and pyrrhotite concentrations (Table VII).

Pentlandite in the quartzite is strongly associated with pyrrhotite. Unlike the fractured and altered large grains of subhedral pentlandite in dunites, pentlandite in quartzite always looks fresh, and occurs largely as irregular forms in pyrrhotite to maximum width of 0.4 mm. No cleavage traces can be seen in pentlandite. The larger anhedral pentlandite grains maintain a seriate contact with pyrrhotite and in rare cases occupy more than one-half the total sulphide (pentlandite-pyrrhotite) area. Also common are the lamellae of pentlandite measuring 0.01 mm to 0.1 mm in length, and brush or flame structures as illustrated by Plate XVII. One case of intergranular pentlandite within a pyrrhotite mosaic has been observed (Plate XVIII). Hawley (1962) cites pentlandite lamallae, brush structures, and

Plate XVI

Small pyrrhotite-pent-
landite inclusions in pyrite.
Pentlandite is pale yellow
(x1062(.

Plate XVII

Intergrowth of pyrite-
pyrrhotite and exsolved pent-
landite brush structure. Note
euhedral pyrite (x284).
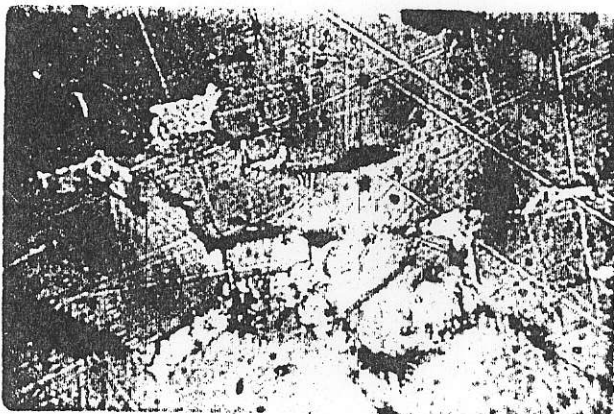
Plate XVIII

Mosaic of pyrrhotite
with intergranular pent-
landite (x450).

seriate contact with pyrrhotite as evidence for exsolution from pyrrhotite. Lack of cleavage fractures in pentlandite, and complete absence of any alteration to violarite, makes this pentlandite similar to the fresh lamellar growths of pentlandite found in dunite. Both are considered to have exsolved from pyrrhotite. The origin of interstitial pentlandite illustrated in Plate XVIII is less certain. Considering its fresh appearance, and the fact that this relatively small amount could conceivably have been derived from pyrrhotite, its origin is postulated as similar to that of the pentlandite lamellae.

Chalcopyrite occurs in rare amounts only. In all cases it occurs with other sulphides, pyrites, and more commonly pyrrhotite. Invariably chalcopyrite occupies the sulphide-silicate grain boundary (Plate XIX).

A few small grains of free magnetite are noted. These attain sizes of up to 0.2 mm in diameter. Its occurrence, however, is uncommon in the mineralized quartzite. Several chromite grains are also present, but generally chromite is very rare.

A possible paragenesis is postulated as follows. Introduction of a hydrothermal solution containing nickel, chromium, and cobalt metals into the relatively porous quartzite occurred during the first stage. The quartzite due to its brittle nature would tend to be the most permeable of Anarchist members. Its neutral chemical nature
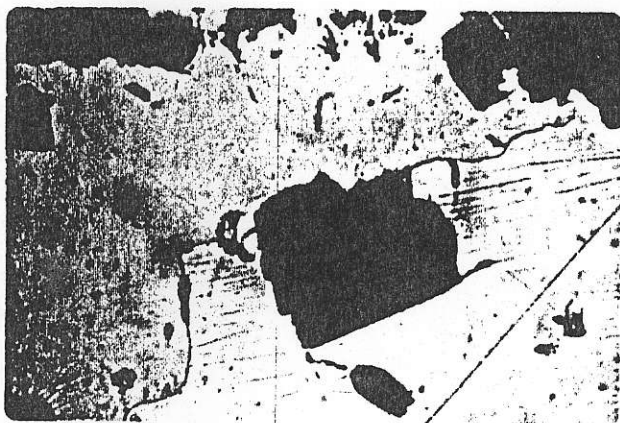
Plate XIX   Rare chalcopyrite occupying corner and edge
of pyrrhotite grain (x360).

would be conducive to solution penetration to a consider-
able distance. Crystallization of fuchsite and minor
amounts of fine-grained biotite was followed by crystalli-
zation of the highest temperature sulphide, pyrite, which
may have trapped minute amounts of pyrrhotite now found as
inclusions in pyrite. It is likely that some of the pyrite
was already present before this period of mineralization
occurred since some of it is associated with pre-existing
recrystallized quartz veins. Following this, the more
sulphur deficient nickel-iron sulphides crystallized in the
form of nickeliferous pyrrhotite, followed by subsequent
pentlandite exsolution. Trace amounts of chalcopyrite may
have formed at this time since it is associated with
pyrrhotite. Thermal metamorphism quite likely triggered
further pentlandite exsolution from nickeliferous pyrrhotite.

CHAPTER VI

GEOCHEMICAL STUDIES

Three suites of rocks were selected for the study.
These include a mineralized suite of dunite rocks, a min-
eralized suite of quartzite rocks and an unmineralized
suite of rocks belonging to the Anarchist Group for a com-
parison of background metal content. The mineralized dunite
is taken mainly from the vicinity of trenches H and M which
show best mineralization (Fig. 3), whereas the mineralized
quartzite specimens have been selected over the entire
mineralized zones and are quite representative. Analytical
procedures are discussed in Appendix II.

Mineralized Dunite

Analyses of the dunite are shown in Tables III and IV,
together with Daly's (1912) single analysis taken from a
dunite on the north side of Rock Creek. Table V illustrates
chemical analyses of comparable serpentinites from locations
in Washington and Oregon together with average fresh dunite
and peridotite analyses taken from literature.

Major Oxides

The SiO_2 content varies from 38.0 to 45.5 percent with

TABLE III

Partial Chemical Analysis of Major oxides of Dunite

	W-140	W-201	W-138	W-261	W-202	W-262	Daly # 282
SiO_2%	41.0	38.0	40.7	45.5	39.0	41.5	40.25
Al_2O_3	0.5	3.8	0.7	1.4	0.5	0.5	1.10
Fe_2O_3	6.0	8.0	7.5	7.5	7.5	7.5	4.61
MgO	27.5	30.0	30.5	31.0	32.5	34.2	37.91
CaO	9.0	6.6	3.2	5.4	7.0	6.8	1.16
Na_2O	0.0	0.0	0.1	0.0	0.0	0.1	0.48
K_2O	0.0	0.0	0.1	0.0	0.1	0.0	0.16
TiO_2							Tr
FeO							3.04
MnO							0.11
H_2O^+							9.08
H_2O^-							0.32
CO_2							1.95
							100.32
Sp Gr	2.73	2.75	2.62	2.89	2.86	2.84	2.868

Partial chemical analyses performed by D. Toy, Amax Geochemical Laboratory, Vancouver, British Columbia

TABLE IV

Metal Content of Dunite

	W-140	W-201	W-138	W-261	W-202	W-262	Average
Cr ppm	1500	2000	2100	1400	3000	2700	
Ni_T	1900	2700	2200	1900	2600	2600	
Ni_S	1400	2400	1700	1600	2200	2300	
Mn	640	700	680	580	880	800	
Co	78	106	98	82	98	110	
Zn	32	44	32	44	36	36	
Pb	24	24	22	18	28	24	
Cu	24	20	16	28	20	12	
Ni/Cu	79	133	137	68	130	216	127
Ni/Co	24.5	25.5	22.5	23.2	26.5	23.6	24.3
Ni/Cr	1.26	1.34	1.04	1.36	0.87	0.97	1.14

Atomic absorption analyses performed by D. Toy, Amax Geo-
chemical Laboratory, Vancouver, British Columbia.

an average of 40.95 percent. The average silica value compares closely to Daly's analysis and also to Coleman's (1967) values for serpentinites. Alumina content varies between 0.5 to 3.8 percent with an average value of 1.2 percent, which corresponds very closely to Daly's single analysis. Both silica and alumina values compare closely to respective average values obtained for fresh dunites (Table V).

Average Fe O content is 7.3 percent, which corresponds closely to Coleman's three analyses of serpentinite.

Magnesia varies considerably with values ranging from 27.5 to 34.2 percent. The average value of 31.0 percent is lower than that reported by Daly (Table III) and Coleman (Table V). The most magnesia-rich sample, however, appears to correspond more closely to the average peridotite than dunite indicated in Table V. High magnesia content of the original olivine grains (Table II) points toward a magnesia-rich dunite. Since the highest MgO value for the Old Nick (Table III) lies well below that of the average dunite (Table V) loss of magnesia by metasomatism is inferred. This metasomatism could have occurred during serpentinization.

Lime content also varies widely between values of 3.2 and 9.0 percent. The average value, 6.3 percent, is greater than the CaO content of Daly's analysis. It can be argued that Daly's analysis represents another dunite body within a different host rock type. Lime content here is much

TABLE V

Chemical Analyses of Comparable Serpentinites

and Average Fresh Ultrabasic Rocks

	Myrtle Creek Ore.*	Ingallis Peak Wash.*	Twin Sisters Wash.*	Average Dunite[†]	Average Peridotite[†]
SiO_2	39.7	40.7	38.6	40.16	43.54
TiO_2	0.04	0.07	0.05	0.20	0.81
Al_2O_3	1.9	2.8	1.1	0.84	3.99
Fe_2O_3	7.4	7.4	9.6	1.88	2.54
FeO	-	-	-	11.87	9.84
MgO	36.7	37.8	34.9	43.16	34.02
MnO	0.14	0.14	0.16	0.21	0.21
CaO	0.26	2.1	3.6	0.75	3.46
Na_2O	0.05	0.08	0.04	0.31	0.56
K_2O	0.01	0.01	0.02	0.41	0.25
H_2O^+	12.5	8.0	11.4	0.44	0.76
H_2O^-	1.1	0.40	1.0	-	-
P_2O_5	-	-	-	0.04	0.05
	99.80	99.70	100.11		
Sp Gr	2.72	2.86	2.73		
Co ppm	100	85	110		
Ni	2000	2000	800		
Cr	2800	3800	1000		
Sc	11	13	17		

* Analyses from Coleman (1967)

† Analyses from Nockolds (1954, Table 9)

higher than that for Coleman's serpentinites, and further-more the lowest value corresponds more closely to that of fresh peridotite (Table V) than to that of dunite. Since petrological evidence shows that the rock is dunite, addition of CaO is interpreted. This could have occurred during talc-carbonate alteration.

Soda and potash analyses are low, which is quite normal for ultrabasic rocks.

Metallic Elements

Nickel

Total nickel content ranges from 1900 to 2700 ppm (Table IV) whereas sulphide nickel values range from 1400 to 2400 ppm indicating that 300 to 500 ppm nickel is held in silicate structure. No definite nickel enrichment is noted toward any contact of the dunite indicating miner-alogical uniformity which is characteristic of alpine ultra-basic intrusions. Goles (1967) in reviewing the literature for trace element concentrations of ultrabasic rocks, states that generally dunites should run from 1000 to 4000 ppm nickel. He arbitrarily chooses an overall average of 1500 ppm. Edel'shstein (1963) in a study of both fresh and altered ultrabasic rocks from the southern Urals concludes that the nickel content of a serpentinite is directly re-lated to the parent rock from which it is derived. His study further confirms that there is a marked dependence of nickel content on mineralogical composition with most

magnesia-rich rocks containing highest nickel values. This
is in agreement with Wilson (1953) who showed that similarity
in ionic radius and valency between Mg^{+2} and Ni^{+2} ions controls
trace element concentration of nickel in magnesia-rich
magmas, and that chalcophile nickel will separate as nickel
sulphide, provided sufficient sulphur is available.

Chromium

Chromium content varies between 1400 and 3000 ppm
(Table IV) in the Old Nick dunite. Goles (1967) considers
2200 ppm as an average estimate for ultramafic rocks. Cr^{+3}
belongs to the lithophile group of metals so that despite
sulphur's presence it will remain in silicate magma (Wilson,
1953). However, oxides first forming from a crystallizing
magma will show chromite enrichment in dunites. This is
contrary to observations made in polished section study
since very little chromite is present. One possible explan-
ation may be that the grains have rolled out of their soft
serpentine host during section preparation. Another possi-
bility is that chromium remained in the silicates during
crystallization of magma due to low P_{O_2} and is now held in
relict olivine grains and serpentine. It is unlikely that
serpentinization would affect chromium content for as
Stueber and Goles (1967) pointed out in their study on fresh
and serpentinized ultramafic rocks, no effect of serpen-
tinization was noted on abundances of Na, Mn, Cr, Sc, and
Co.

Cobalt

Cobalt values vary from 78 to 110 ppm. Goles quotes Stueber's and Goles (1967) overall average of 110 ppm from a study of 113 ultramafic rocks as a reliable estimate for dunite. They found that cobalt generally appears to be insensitive to mineralogy or mode of occurrence. Wilson (1953), however, states that cobalt abundance decreases progressively from ultrabasic to basic magmas, with a behaviour similar to, but less drastic than, nickel. In basic, intermediate, and acid magmas the cobalt distribution is similar to that of copper. Coleman's values shown in Table V closely compare with the cobalt values contained in the Old Nick dunite.

Copper

Copper content in this dunite is low with values between 12 and 28 ppm indicating little more than background content. Goles (1967) quotes 30 ppm as an average abundance for dunite. No chalcopyrite was noted in the polished section study suggesting that copper may be held in silicate minerals.

Manganese

Manganese varies from 580 to 880 ppm. Stueber and Goles (1967) found in their study that manganese abundance in ultramafic rocks is not in any way affected by mineralogic composition or mode of occurrence. Their overall

average of 1040 ppm is somewhat higher than values obtained
for the Old Nick dunite (Table IV).

Base Metals

Base metals values of lead and zinc are low and con-
sidered to be of background importance only.

Metal Ratios

Table IV shows a comparison of metal ratios for analysed
samples of dunite, with arithmatic average for each respec-
tive ratio. The nickel:copper ratio varies widely and has
an average value of 127. This variation reflects erratic
and sparse copper content while the high ratio is indicative
of metal association with a magnesian magma in which nickel
concentration is much greater than copper. Wilson and
Anderson (1959) show that this ratio gradually decreases
with increasing silica content, until in gabbros approx-
imately equal amounts of nickel and copper are found in ores.

Nickel:cobalt ratios are more consistent with an average
value of 24.3. Wilson and Anderson (1959) explain slight
discrepancies in this ratio as the result of cobalt's
ability to enter the high temperature pyrite structure during
pyrite's earlier formation leaving behind nickel in solution.
However, in the Old Nick dunite pyrite is absent, precluding
this type of metal partitioning. Nickel and cobalt are
believed to be largely tied up in pyrrhotite and pentlandite.

Nickel:chromium ratios are also fairly consistent. The

average 1.14 indicates a greater nickel content than
chromium for most samples (Table IV). Again both nickel
and chromium content are enriched in high magnesian magmas.

Summary

Magnesia content of the Old Nick dunite is appreciably
lower than the average fresh dunite due to metasomatism
during serpentinization. Higher lime content is also ex-
plained by metasomatism perhaps during talc-carbonate
alteration. Typically high trace metal contents of nickel,
chromium, and cobalt are found in the dunite. A few samples
contain nickel values above those considered average for
dunite, but under present economic conditions this rock can-
not be considered an ore. Copper and base metals values are
of the order of background only. The high metal ratios
nickel:cobalt, and nickel:copper are typical of mineralized
magnesia-rich ultrabasic rocks, and the nickel:chromiun
ratio shows good consistency with an average value slightly
greater than unity.

Mineralized Quartzite

Major Oxides

A selected suite of eight samples of mineralized
quartzite has been analysed for most of the major oxides
with results shown in Table VI.

The essential minerological constituents of quartzite

TABLE VI

Partial Chemical Analysis of Mineralized Quartzite

	W-16	W-43	W-77	W-83	W-85	W-91	W-220	W-270
SiO_2 %	70.3	82.5	64.0	74.0	78.6	59.0	73.0	70.5
Al_2O_3	8.0	7.4	12.8	10.6	6.4	11.6	9.0	6.4
Fe_2O_3	10.6	5.0	9.0	5.5	5.5	13.5	7.0	11.5
MgO	1.4	0.5	1.7	2.4	3.6	1.0	1.0	1.4
CaO	0.6	0.1	0.6	0.2	0.2	0.4	0.4	0.3
Na_2O	1.1	0.45	1.75	1.0	0.2	1.1	0.45	0.6
K_2O	1.4	2.4	2.3	1.1	0.3	2.9	2.0	1.3
S	8.53	2.20	5.78	3.32	1.96	11.1	4.32	9.21

Partial chemical analysis performed
by D. Toy, Amax Geochemical Laboratory, Vanc. B.C.

include quartz, fuchsite, sulphides and some biotite.

Silica content varies from 59.0 to 82.5 percent. This variation of silica no doubt corresponds with the amount of clean quartz mosaic observed in thin section, which likely reflects recrystallized quartz vein material.

Alumina varies from 6.4 percent to 12.8 percent and is quite likely tied up largely in micas, of which fuchsite is the most abundant. Pure fuchsite is reported by Whitmore, Berry, and Hawley (1946) to contain up to 37.72 percent Al_2O_3. Some alumina is also contained in less abundant biotite.

Fe_2O_3 analyses show values ranging from 5.0 to 13.5 percent. Since total Fe is recorded as Fe_2O_3 one can only say that a small amount of iron is contained as Fe^{+2} and also Fe^{+3} in small amount of biotite. The major contributors of iron are the sulphides pyrite and pyrrhotite, because there is a general correlation between S and Fe_2O_3 content.

The magnesia content generally varies from one to 3.5 percent. One sample contains as low as 0.5 percent MgO. These amounts could conceivably be contained in fuchsite and to a lesser extent in biotite. Whitmore *et al.* (1946, Table III) show that pure fuchsite may contain as much as 3.84 percent MgO.

In sample W-83. estimated to contain 12 percent fuchsite, the 2.4 percent MgO must be contained in fuchsite,

whereas sample W-85 containing no visible fuchsite but 3.6 percent MgO suggests that magnesia is tied up in fine-grained biotite. According to Deer, Howie and Zussman (1966, Table XVIII) naturally occurring biotite may contain up to 12.75 percent MgO whereas metamorphic biotite usually contains nearly 7 percent MgO.

The soda content varies from as little as 0.2 percent to as much as 1.75 percent. Na_2O is contained in fuchsite, small amounts in biotite, and possibly also the very fine-grained admixture of argillaceous material contained in the quartzites. The 0.3 to 2.9 percent K_2O is contained in the same constituents.

The lime content is generally less than 0.5 percent and probably originates from trace amounts of calcium in biotite and fuchsite as no other calcium-bearing minerals are found in the quartzites.

Metallic Elements

Nickel

Study of Table VII shows that total nickel and sulphide nickel values lie close together indicating that little, if any, nickel is contained in silicates. Values from 1300 to 4200 ppm are indicated. Examination of analyses for the pyrite and pyrrhotite fraction demonstrates that nickel is primarily contained in the sulphides, with a strong enrich-ment of nickel in the pyrrhotite. The pyrrhotite fractions are two to ten times higher in nickel than corresponding

TABLE VII

Metal Content of Quartzites and Respective Sulphide Fractions

	Cr %	Ni ppm	Ni %	Mn ppm	Co ppm	Zn ppm	Pb ppm	Cu ppm	Ni/Cu	Ni/Co	Ni/Cr
W-16	0.36	1300	0.12	150	192	52	8	124	10.5	6.8	0.36
Py-16	0.06	-	0.22	25	1150	40	20	100			
Po-16	0.04	-	2.95	100	890	40	20	920			
W-43	0.25	3300	0.31	40	146	20	4	60	55.0	22.6	1.32
Py-43	-	-	-	-	-	-	-	-			
Po-43	0.04	-	2.88	25	1550	60	40	350			
W-77	0.36	2500	0.23	110	146	88	8	240	10.4	17.1	0.70
Py-77	0.80	-	0.63	25	1100	100	20	760			
Po-77	0.03	-	1.92	25	960	40	20	660			
W-83	0.38	2200	0.22	110	136	48	8	148	14.8	16.2	0.58
Py-83	0.54	-	0.62	25	1650	40	40	300			
Po-83	0.16	-	3.60	300	1450	80	20	1160			
W-85	0.26	1400	0.12	400	102	48	12	100	14.0	13.7	0.54
Py-85	1.28	-	0.38	100	1750	20	20	130			
Po-85	0.20	-	3.04	200	1650	140	20	1120			
W-91	0.48	3200	0.32	100	290	40	8	100	32.0	11.0	0.67
Py-91	0.42	-	0.48	50	1050	20	20	150			
Po-91	0.06	-	2.78	100	690	30	20	500			
W-220	0.36	4200	0.39	100	166	100	12	168	25.0	25.4	1.16
Py-220	0.52	-	1.84	100	2250	320	40	400			
Po-220	0.08	-	3.12	50	1000	80	20	630			
W-270	0.25	1500	0.13	50	166	40	8	88	17.1	9.1	0.60
Py-270	0.16	-	0.32	25	790	40	20	110			
Po-270	0.08	-	3.50	200	970	40	20	1180			
Average									21.1	13.7	0.87

Analyses Performed by D. Toy, Amax Geochemical Laboratory, Vancouver, British Columbia.

pyrite fractions for any given sample. This is supported by polished section study; only a few tiny inclusions of pyrrhotite-pentlandite were noted within pyrite grains as shown in Plate XIX, whereas pyrrhotite contains numerous inclusions, lamellae, and brushes or flame structures of pentlandite. The amount of nickel seen in the pyrite analysis may be somewhat high since any pentlandite which breaks free entirely from pyrrhotite would remain behind in the pyrite fraction during the magnetic separation process. This could account for sample Py-220 having a 1.84 percent nickel.

Chromium

Chromium content in whole rock shows contents ranging from 0.25 to 0.48 percent. Examination of the sulphide fractions shows a definite bias of chromium toward the pyrite fraction indicating presence of chromium in pyrite lattice. Pyrrhotite also contains minute quantities of chromium (0.03 to 0.16 percent) but these generally are small enough to be considered trace impurities. Half the samples show no enrichment of chromium in sulphides, whereas three of the remaining four show moderate chromium enrichment in sulphide fractions compared with whole rock analyses.

A plot of whole rock chromium content against alumina is illustrated in Fig. 4. A reasonable trend shows some relationship between chromium content and alumina content. For most quartzite samples made up largely of fuchsite this
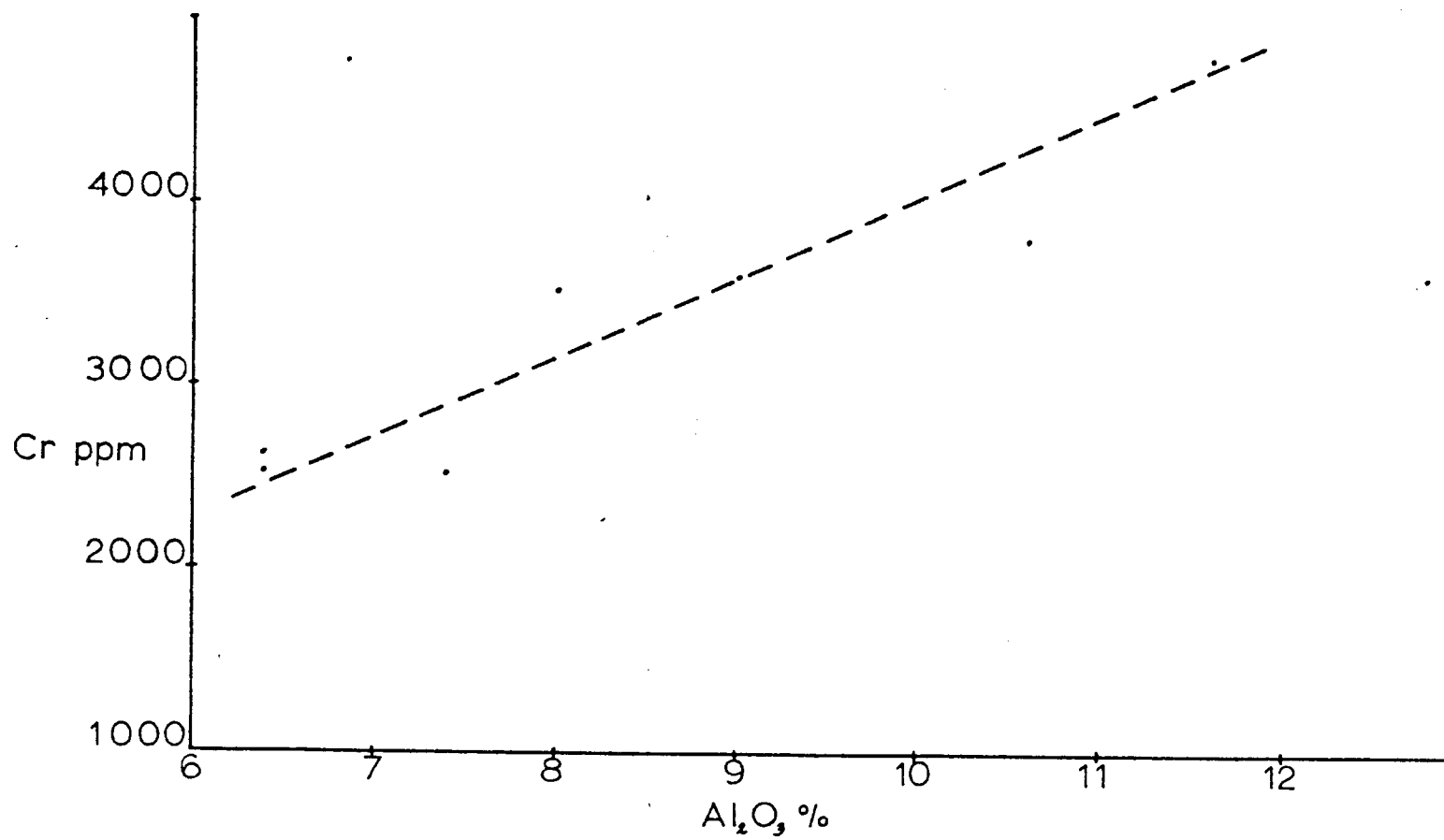
Fig. 4. Plot of chromium against Al_2O_3.

is to be expected, since Cr^{+3} substitutes for the Al^{+3} octahedral sites in the muscovite formula as described in Chapter IV.

Cobalt

Cobalt in whole rock varies from 102 to 290 ppm. Enrichment of cobalt in sulphide fractions as compared with whole rock analyses is marked. Six of the seven comparable analyses indicate cobalt concentration is biased toward pyrite, suggesting that the pyrite structure accommodates considerable trace content of cobalt. Pyrite contains between 790 and 2250 ppm cobalt, whereas pyrrhotite contains between 690 and 1650 ppm cobalt. The average value of cobalt for pyrite concentrates is 1394 ppm whereas for pyrrhotite it is 1145 ppm indicating that the difference in partitioning is not very strong. A possible expanation might be that pyrite forming at slightly higher temperatures from hydro-thermal solutions containing cobalt would tend to accommo-date cobalt in its structure thus depleting the cobalt supply so that less cobalt would be available for incorpor-ation into the pyrrhotite structure.

Figure 5 further confirms the argument that cobalt is associated with the sulphide portion of quartzites. A posi-tive trend is indicated if one uses the sulphur analyses as a rough measure of sulphide content. It must be noted that inasmuch as pyrite contains 25 percent more sulphur by mass than pyrrhotite, a bias toward pyrite exists since pyrite
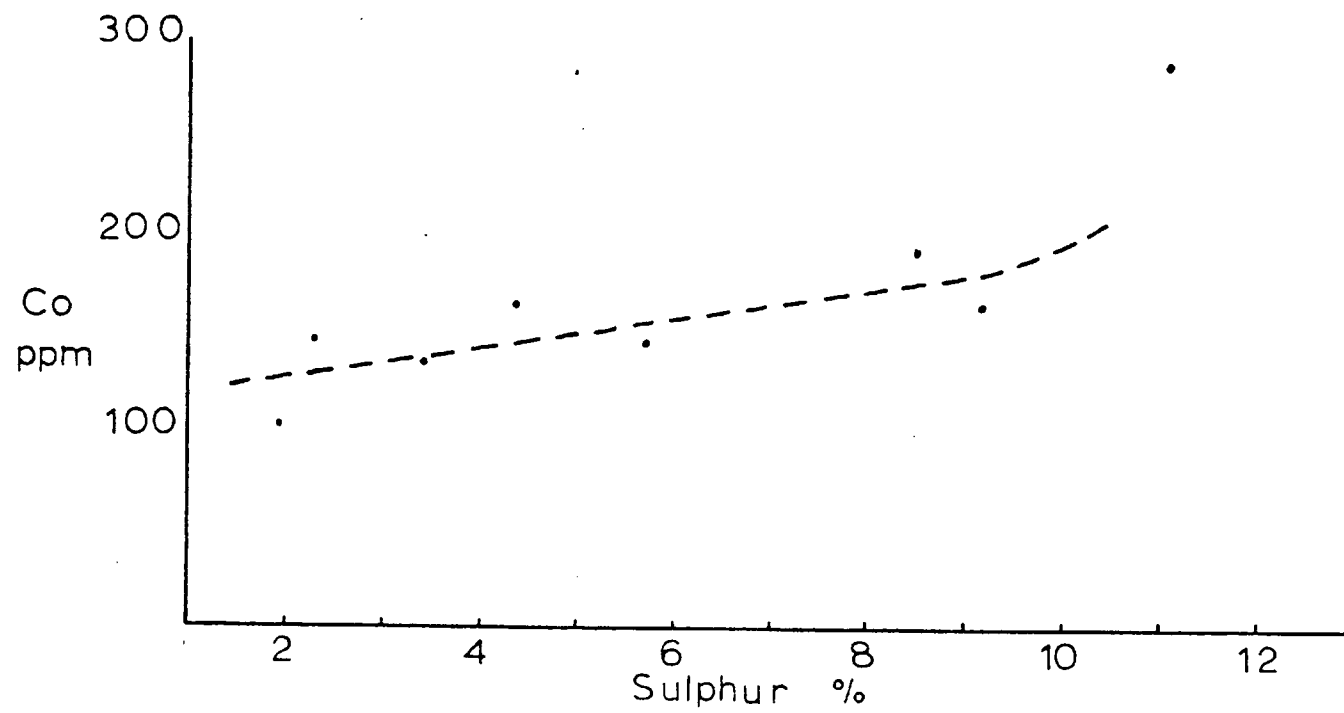
Fig. 5.   Plot of cobalt against sulphur.

occurs in greater abundance than pyrrhotite.

Copper

Whole rock values for copper vary from 60 to 240 ppm. Study of the sulphide analyses shows some presence of copper with pyrite, but a stronger enrichment of copper is noted in the pyrrhotite fraction ranging from 350 to 1180 ppm. The copper association with pyrrhotite is supported by polished section study, which shows that chalcopyrite tends to be associated most frequently with pyrrhotite-silicate borders.

Manganese

Manganese values for whole rock range from 40 to 400 ppm. The mean value is 94 ppm, with only one sample exceeding 150 ppm. It is believed that content of manganese is largely held in secondary manganese oxides commonly associated with secondary iron oxides in weathered fractures.

Base Metals

Base metals zinc and lead show values of background importance only, and are likely held in sulphide form as accessory minerals.

Metal Ratios

Nickel:copper ratios vary from 10.4 to 55 with an average of 21.1 (Table VII). Wide scatter is marked and believed to be a reflection of erratic and sparse copper distribution.

Nickel:cobalt ratios varying between 6.8 and 25.4 show less scatter (Table VII). The average 13.7 is considerably lower for the quartzite than for dunite, indicating a greater enrichment of cobalt in quartzite relative to dunite. Nickel content of the quartzite is also appreciably higher than that of dunite.

Lower and upper limits of the nickel:chromium ratio are 0.36 and 1.32 respectively (Table VII). This again is the most consistent of the three ratios. Its average of 0.87 compares closely to that of the dunite, which is 1.14 (Table IV). The average nickel:chromium ratio of the dunite exceeds that of quartzite by a small amount (0.27) because chromium is relatively more abundant within the quartzite, where it occurs largely in the form fuchsite.

Figure 6 illustrates a plot of nickel:chromium ratio against nickel:cobalt ratio indicating that a trend exists relating these two ratios. This trend reflects the relationship between nickel, chromium and cobalt and is further interpreted as the result of these three elements being controlled by the same metallization period. This inference is further supported by textural evidence mentioned previously; that of the preferential association of nickel-bearing pyrrhotite with the green fuchsite bands.

Summary

The mineralized quartzite consists of a simple mineralogical assemblage, including quartz, fuchsite, and sulphides
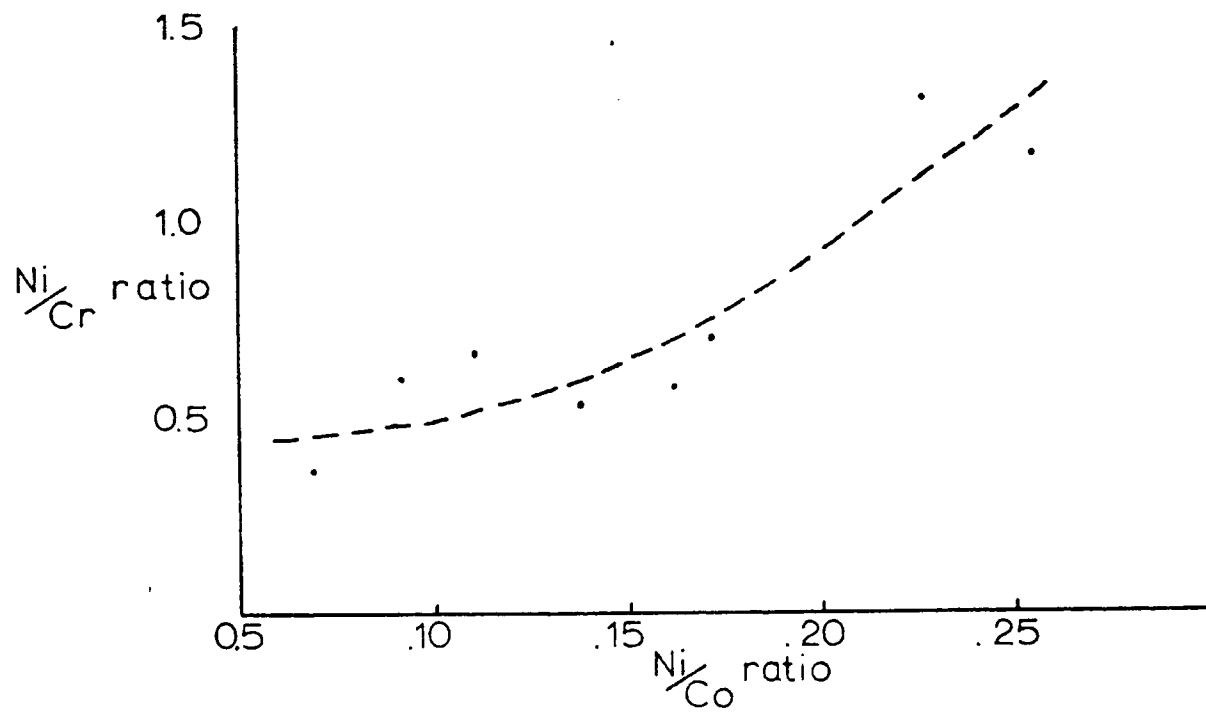
Fig. 6.   Plot of Ni/Cr ratio against Ni/Co ratio.

which is reflected in the whole rock major oxide analyses.

Investigation into the metal content of mineralized quartzite indicates anomalous values in nickel, chromium, and cobalt. Copper is erratic and not present in significant quantity. Lead and zinc are present as background values only, and manganese is believed to be present as the secondary oxide produced by weathering.

Studies of sulphide fractions provide an answer to the question of whether various metals are found in silicate or sulphide form. This question is of importance when considering metallurgical separation. Nickel is held in sulphide form, largely in the pyrrhotite-pentlandite association and to a minor extent within pyrite in the form of pyrrhotite inclusions. Chromium is predominantly in the mineral fuchsite, although there appears to be a small amount of chromium present also in pyrite. Cobalt is contained in the sulphide form, more in pyrite than pyrrhotite.

Metal ratios are of interest, as shown by the relationship of nickel:chromium and nickel:cobalt ratios illustrated by Fig. 6. Nickel, chromium, and cobalt show a relationship by their partitioning during metallization suggesting a common source of mineralization. Furthermore, the close comparison of nickel:chromium ratio of quartzite to the nickel:chromium ratio of dunite favours the concept of a common source of metal mineralization for the quartzite and

the dunite.

Another important fact to consider is the overall metal assemblage for the mineralized quartzite. Anomalous values in nickel, chromium, and cobalt with low copper values and even lower base metal values characterize the mineralized quartzite as well as the dunite.

Whitmore *et al.* (1946) consider fuchsite to be exclusively hydrothermal in origin. Furthermore, they state that in the majority of cases studied by them, the source of chromium for fuchsite formation is contained in intermediate plutons. Although geochemical studies of the intermediate Nelson Pluton nearby are beyond the scope of this study, several copper skarns are known to be associated with its contact as indicated in Fig. 2. These are characterized by chalcopyrite, pyrrhotite, garnet, carbonate, and green amphibole, which is an assemblage entirely different from that of the mineralized quartzite.

The intimate association of nickel-bearing pyrrhotite with fuchsite suggests a hydrothermal origin of nickel, chromium and cobalt. The combination of these three metals classically associated with basic-ultramafic rocks however, precludes the possibility of the intermediate Nelson Pluton being the mineralizing source to the quartzite.

Unmineralized Rock Suite

Partial chemical analyses for major oxides and metal content of a suite of unmineralized rocks from the Anarchist

Group is shown in Table VIII.

Metal content of the meta-argillite includes trace nickel, low cobalt, and absence of chromium. Moderate zinc and manganese is indicated whereas base metals lead and copper are low.

Impure carbonate contains low chromium, nickel, and cobalt content as well as base metal values (Table VIII).

Greenstones show variable lime and Fe_2O_3 content. The varying lime content is attributed to presence of calcite veinlets and recrystallized amygdales containing calcite. Both of these features are common in the rock. Variation of Fe_2O_3 content is attributed to the magnetite veinlets occupying fractures in the rock. The low silica content, high magnesia and low potash-soda content suggest a basaltic magma. Slightly higher values in nickel, chromium, and cobalt are present as would be expected in basic volcanic rocks compared with metasediments.

The tuffs contain significantly higher silica, magnesia, and lime values than the greenstones, whereas alumina and Fe_2O_3 are substantially lower. The higher silica content is attributed to the contemporaneous deposition of siliceous sedimentary material with the tuff. Further studies on the sedimentary environment need to be conducted to shed more light on this possibility. Nickel and chromium values are highest within the unmineralized suite containing greatest magnesia content. Cobalt appears normal whereas base

TABLE VIII

Un-mineralized Suite of the Anarchist Group

	W-11	W-41C	W-15	W-12D	W-115	W-89	W-109	W-181
SiO_2 %	54.50	60.00	51.20	38.50	43.80	51.00	51.50	49.50
Al_2O_3	18.20	14.40	16.00	13.50	12.60	4.00	2.80	3.60
Fe_2O_3	8.50	10.50	14.00	13.50	20.00	8.50	8.00	8.50
MgO	1.40	3.60	3.10	4.50	6.20	11.00	11.00	10.10
CaO	4.60	4.00	7.80	16.20	7.40	20.60	20.40	21.60
Na_2O	6.70	0.55	2.75	1.80	2.35	0.14	0.35	0.40
K_2O	2.30	4.40	2.00	2.40	1.90	0.30	0.20	0.30
Cr	0.00	0.00	0.01	0.00	0.01	0.11	0.12	0.08
Ni	0.01	Tr	0.01	0.01	0.01	0.08	0.04	0.08
Mn ppm	400	560	360	680	340	400	220	400
Co	16	32	48	44	46	34	16	48
Zn	100	116	80	102	80	16	16	40
Pb	16	30	16	24	20	4	4	12
Cu	32	32	152	24	208	28	26	52
	Meta-argillite		Impure Carbonate	Greenstone		Tuff		

Analyses performed by D. Toy, Amax Geochemical Laboratory, Vancouver, B.C.

metals lead and zinc are lowest.

A general pattern of metal distribution emerges from a comparison between the mineralized quartzite suite and the unmineralized suite. Base metal values for both suites are low, although the mineralized quartzite shows a slight enrichment of copper. However, the mineralized quartzite shows distinctly anomalous values of nickel, chromium, and cobalt.

CHAPTER VII

SUMMARY

Most of the Old Nick grid area is composed of the Anarchist Group of rocks. The most important member of this group is the quartzite which contains 5.85 million tons per hundred vertioal feet of 0.25 percent nickel in two gently dipping parallel zones (Fig. 3). The whole sequence of rocks has been thermally metamorphosed to the hornblende-hornfels facies by the nearby Nelson Pluton.

Several small occurrences of altered dunite have intruded the Anarchist sequence. These are alpine intrusions associated with strong shears and faults. Some are mineralized with disseminated sulphides but because of their small volume and low grade the dunite bodies hold little promise of containing ore. Higher lime and lower magnesia found in the sampled dunite as compared with the average fresh dunite is attributed to metasomatism. An alteration sequence for dunite has been established: with hydration, dunite underwent serpentinization, then the increasing dehydration caused by thermal metamorphism the serpentinized dunite underwent talc-carbonate alteration; and finally, development of tremolite and some anthophyllite at the expense of talc

marked the highest rank of alteration.

The nearby Nelson intermediate complex is a large body of granodiorite which is differentiated at the margins. Contact phases include basic diorite and gabbro. Skarn copper showing are also related to the contacts.

The dunite contains typically high values of nickel, chromium, and cobalt with cobalt averaging 95 ppm and chromium averaging 2100 ppm. Most of the nickel is in sulphide form, inasmuch as only 200 to 300 ppm nickel remains in the silicate minerals. Disseminated pyrrhotite and pentlandite may constitute from 1 to 6 percent of the rock and are interstitial to the olivine pseudomorphs. Textural evidence suggests a redistribution of sulphide within secondary silicates. Pentlandite, the main nickel-bearing sulphide, has two modes of occurrence: 1) as large fractured subhedral grains associated with pyrrhotite and partially altered to violarite, and 2) as fresh lamellae and flames which exsolved later at a lower temperature.

Quartzite contains anomalous values of nickel, chromium and cobalt. Disseminated sulphides constitute as much as 15 percent of the rock but average 3 to 4 percent. Of the three sulphides, pyrite, pyrrhotite and pentlandite, pyrite is most abundant. Pentlandite always occurs within pyrrhotite as lamellae, flame structures and intergranular growths. Sparse pyrrhotite-pentlandite growths are found in pyrite. Pyrrhotite and some pyrite is associated with

fuchsite in bands suggesting a hydrothermal origin of the sulphides. Geochemical studies show that nickel is in sulphide form being held in pentlandite and pyrrhotite. Cobalt is also contained in sulphides whereas chromium is held in the silicate fuchsite.

High nickel:copper and nickel:cobalt ratios for the dunite are typical of mineralized magnesia-rich ultrabasic rocks. A relationship between the nickel:chromium ratio and the nickel:cobalt ratio indicates nickel-chromium-cobalt partitioning during metallization of the quartzite. Nickel:chromium ratios for dunite and quartzite are the most individually consistent of all ratios and the average values for each respective suite are sufficiently close to one another in magnitude to suggest a possible common origin.

Several important facts which emerge from the study are: 1) nickel sulphide is associated with fuchsite suggesting a hydrothermal origin of the metals nickel, chromium, and cobalt, 2) similar values for nickel: chromium ratio between dunite and quartzite, and 3) similarity between metal suites of dunite and quartzite. These metal suites include high values of nickel, chromium, cobalt and low copper, lead and zinc. These facts would favour the concept of nickel, chromium, and cobalt-bearing hydrothermal fluids being derived from an ultramafic source selectively mineralizing the quartzite member of the Anarchist Group.

Two possible origins for such mineralizing hydrothermal fluids are the gabbroic phase of the differentiated Nelson complex and the dunite magma. The gabbros, however, are restricted only to the margin of the pluton and are located at a considerable distance from the mineralized zone. Futhermore, the mineralization associated with the Nelson complex is in the form of skarn copper deposits with a different mineralogy, occurring at or near the contact. The dunite which has a similar metal assemblage and nickel:chromium ratio to the quartzite is considered to be related to the origin of the mineralizing hydrothermal fluids. Furthermore, in a few places narrow fine-grained talcose dikes of ultramafic material are encountered in the mineralized quartzite. Thus, the magma source of the dunite is considered to be the origin for the mineralizing fluids which deposited nickel bearing sulphides and fuchsite in the mineralized quartzite zones.

APPENDIX I

DETAIL DESCRIPTION OF ROCK TYPE

Anarchist Group

Non-mineralized Quartzite

The non-mineralized quartzite is found in thin-section
to be composed of wavy bands of very fine-grained sericitic
and graphitic material. These bands pinch and swell in a
crenulated fashion. Contained between them is a pure medium-
grained quartz mosaic which probably represents recrystal-
lized quartz vein material. Zones of very fine-grained
micaceous material and quartz occur locally and may represent
recrystallized very fine clay admixtures. Scattered grains
of epidote occur throughout.

Meta-argillite

The meta-argillites composed primarily of amphibole
and fine-grained quartzo-feldspathic material have a phyl-
litic character distinguished by crenulated discontinuous
bands of fine-grained amphibole mixed with epidote, zoisite,
and iron oxides. Small amounts of plagioclase are present.
Dark coloration of the rock is caused by dissemination of
fine-grained graphite particles.

One specimen studied contains large cordierite crystals

displaying characteristic polysynthetic twinning. Cordierite is pockmarked with retrograde alteration products, fine-grained sericite and chlorite displaying an anomalous "Berlin blue" interference color. Similar alteration is also common around edges of cordierite grains. Pleochroic haloes about zircon are present in cordierite but are more common to biotite which shows slight alteration to chlorite. Other minerals present in small amounts include grains of epidote, zoisite, laths of amphibole, graphite, and secondary iron oxides. A narrow band of garnets is present in section and shows no sign of having formed as a product of the breakdown of epidote during thermal metamorphism. Both minerals are present in small amounts.

Volcanic Rocks

Detailed examination of these rocks in thin section indicates that even the freshest specimens are amphibolites. The rock is fine-grained and has a porphyritic texture. Numerous phenocrysts of strongly pleochroic hornblende display slight alteration to biotite. The groundmass constitutes 45 to 50 percent of the rock and is composed of a very fine-grained mass of amphibole needles and feldspathic material with an abundant fine-grained dissemination of magnetite. In some places elongate patches of very fine-grained quartz-carbonate and feldspar are present. These are considered to be recrystallized amygdales.

The more altered rocks termed greenstones, are composed

of dark brown biotite, secondary chlorite, epidote, zoisite
and iron oxide bands with interstitial fine-grained feldspar
and amphibole material. Scattered between these bands are
fine grains of zoisite, and some grains of clinopyroxene.
One slide also shows development of garnet within the
wavy bands.

Tuffs

These rocks display a unique mottling pattern of pale
green bands and patches within a dark green matrix. Under
the microscope the pale green patches are made up largely of
actinolite needles with frayed terminations indicating
secondary crystal growth. Crystal size may vary from less
than 0.2 mm to as long as 5 mm. Larger crystals are commonly
poikolitic. Interstitial to the amphiboles are calcite,
small grains of clinopyroxene, and small amounts of very
fine-grained quartz-feldspar material.

The dark green matrix of the rock is composed of medium-
grained crystals of clinopyroxene and 10 to 15 percent
zoisite. Large crystals of clinopyroxene show uniform ex-
tinction, are commonly poikolitic, and show evidence of
moderate corrosion. These larger clinopyroxene crystals
are augite whereas the small grains are diopside and appear
to be secondary in origin.

In some localities fine grained dark brown wavy bands
accompany the pale green patches of this unit. Microscopic
study indicates these bands to be composed of epidote,

zoisite, and secondary iron oxides. Biotite with secondary
chlorite commonly accompanies epidote in these bands.

Nelson Plutonic Rocks

Gabbro

A sample of medium-grained gabbro from the junction of
McKinney Creek and Rock Creek contains 40 to 45 percent
plagioclase laths which display oscillatory zoning and range
in composition from An_{55} to An_{63}. Clinopyroxene occurs in
moderate amounts from 7 to 10 percent as remnant grains of
augite within secondary hornblende. Amphibole makes up
35 to 50 percent of the rock in two sections studied.
Amphibole is characteristically poikolitic, with inclusions
of plagioclase, pyroxene, biotite, and some magnetite. The
5 to 6 percent biotite is of the red-brown Ti-rich variety
containing zircon inclusions surrounded by pleochroic
haloes. Other minerals present include chlorite, magnetite,
small amounts of oalcite associated with amphibole, and trace
amounts of quartz and K-feldspar.

Plagioclases are remarkably fresh having suffered only
slight sericitization along microfractures and cleavage
cracks, and a mild degree of saussuritization. The clino-
pyroxene is severely altered to poikolitic hornblende. The
amphibole has in turn been considerably altered to poiko-
litic red-brown biotite and magnetite. Chlorite has further
replaced small amounts of biotite.

Another type of gabbro located in the railway cut south

of Rock Creek and west of the Old Nick grid (Fig. 2) contains a slightly different mineralogy. The main difference is the presence of 20 to 25 percent pleochroic orthopyroxene occurring as subhedral stubby prisms up to 2 mm in length. Some crystals display oscillatory zoning. The absorption formula X = pink, Z = pale green is diagnostic of hypersthene. Poikolitic amphibole contains remnants of corroded hypersthene grains. Presence of apatite is noted in this sample, but otherwise the mineralogical content and alteration is similar to that of the previously described gabbro sample. Even the plagioclase composition corresponds closely (An_{55} to An_{65}) to that of the previously studied sample.

Basic Diorite

Another rock type which is less basic and located further from the contact of the pluton is the basic diorite. It contains 60 to 65 percent plagioclase laths (An_{40} to An_{58}) which display oscillatory zoning, fresh borders and heavily altered cores. Alteration products include sericite and saussurite. Amphibole is poikolitic and shows strong pleochroism, green to brown. Biotite is also poikolitic and of the dark red-brown Ti-rich variety. As an alteration product of amphibole, biotite is in turn altered to chlorite which displays an anomalous "Berlin blue" interference color. Other minerals include small amounts of hypersthene, quartz, some K-feldspar, zircon, and magnetite associated with biotite.

Granodiorite

The granodiorite sample was taken from a dike near the junction of Baker Creek and Rock Creek. It is composed of 50 to 55 percent subhedral plagioclase (An_{30} to An_{40}), 15 to 20 percent orthoclase, and 10 to 15 percent quartz. Both quartz and orthoclase are interstitial to plagioclase which displays some oscillatory zoning and is moderately altered to sericite and saussurite. Alteration is more intense in plagioclase cores. Myrmekitic intergrowth occurs locally between fresh plagioclase borders and adjacent K-feldspar.

Mafic minerals include 5 percent amphibole, 10 to 15 percent strongly pleochroic biotite, 5 to 7 percent chlorite and 1 to 2 percent remnant hypersthene. Amphibole is an alteration product of hypersthene and in turn is altered to chlorite. Biotite appears to be primary and contains accessory zircon inclusions. Other accessory minerals include magnetite and calcite.

Granite

The specimen of granite was taken from a dike located on the west·side of Rock Creek, north of its junction with McKinney Creek (Fig. 2). This granite intrudes all of the basic phases and thus represents the latest phase of the Nelson intrusive complex.

Minerals include 30 percent quartz, 30 percent orthoclase, 15 percent plagioclase (mostly albite), 5 percent microcline, 5 to 7 percent micas (mostly sericite) and

minor amounts of epidote, chlorite, zircon, and sphene.

Orthoclase and quartz display typically anhedral form in

contrast to plagioclase laths. Sericitization is most

severe along cleavage fractures or in cores of albite-

twinned plagioclase laths. Orthoclase is only slightly

affected by sericitic alteration. Small amounts of fine-

grained epidote associated with plagioclase indicates slight

saussuritization.

APPENDIX II

ANALYTICAL PROCEDURE FOR GEOCHEMICAL STUDIES

All samples were crushed and ground to minus 60 mesh for separation and analysis. The dunite suite and non-mineralized suite were treated as whole rock samples. The mineralized quartzite suite was further subdivided into three sample types which include whole rock, pyrite fraction and pyrrhotite fraction. Sulphide separation in quartzite was accomplished with the use of super-panner. Further purification of the sulphide samples by means of heavy liquid separation proved successful in eliminating all the silicate material. Methylene iodide with a specific gravity of 3.10 was used as the heavy liquid. Following an acetone rinse the sulphide samples were further split into magnetic and non-magnetic portions corresponding to respective pyrrhotite and pyrite fractions with the use of a powerful permanent magnet.

Whole rock procedure used by the laboratory consists of analysis for SiO_2, Al_2O_3, total Fe as Fe_2O_3, MgO, CaO, Na_2O, and K_2O. This is only considered to be a partial analysis, since samples were not run for H_2O, CO_2, and several other oxides. Preparation involved fusing 0.100 gram portions of sample with one gram lithium metaborate,

100 millilitres of 5 percent HNO_3. Samples were then run using internal standards and U.S. Geological Survey standards. The sulphide fractions received the same preparation except that only 0.500 gram portions of the material were used.

Determination of total nickel content involves an assay procedure. Here 0.500 gram portions of whole rock, or 0.250 gram portions of sulphide material were dissolved in HCl, HNO_3, $HClO_4$, and HF, then diluted to 100 millilitres. Sulphide nickel content was determined using the H_2O_2 and ammonium citrate leach method.

For other metallic elements Mn, Co, Zn, Pb and Cu, determination involved the usual geochemical procedure of digesting a 0.500 gram sample with HNO_3 and $HClO_4$ diluted to 10 millilitres. All metals were determined using the atomic absorption model PE 290.

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FIGURE 3

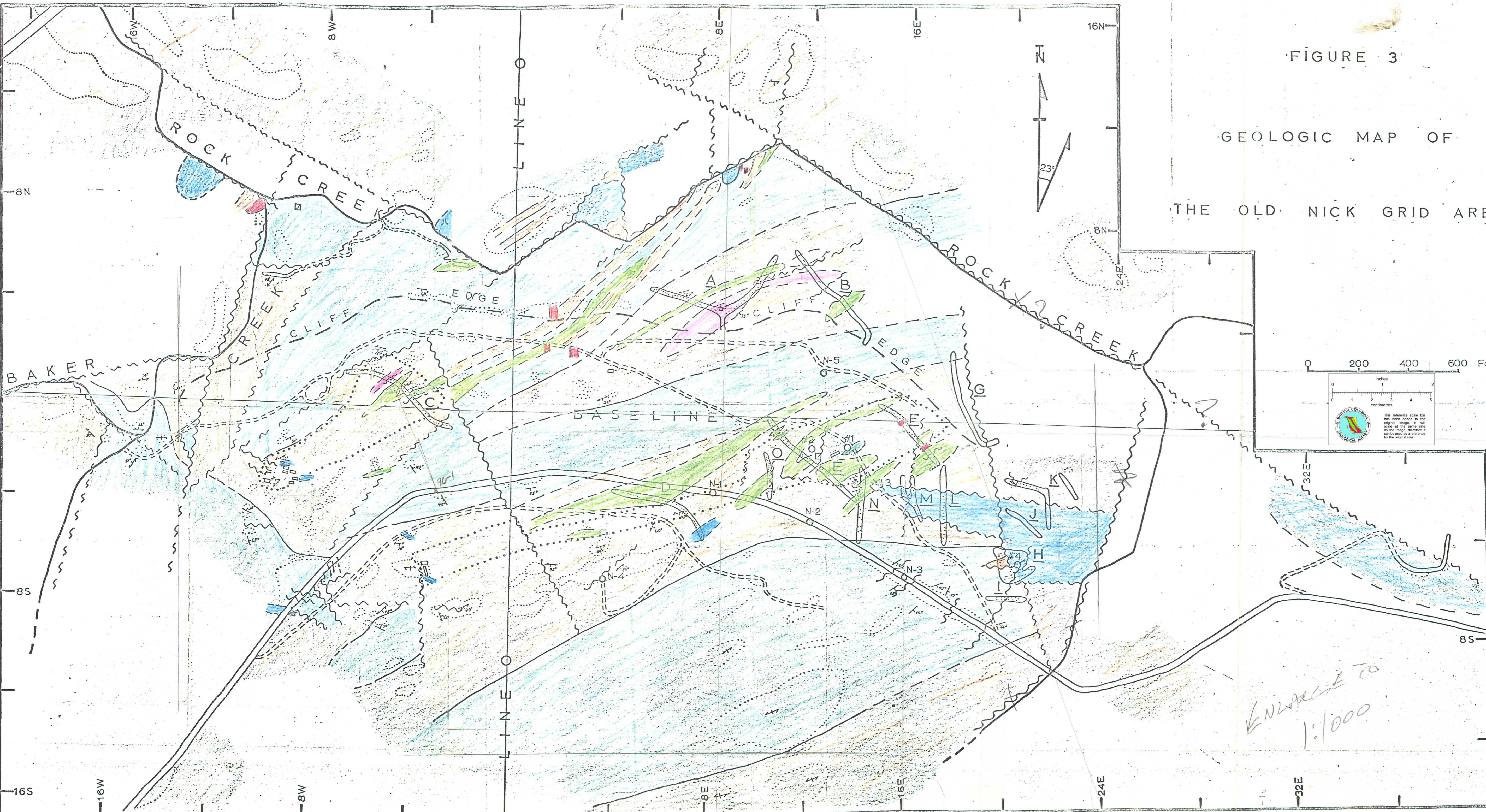GEOLOGIC MAP OF

THE OLD NICK GRID AREA

CRETACEOUS
NELSON PLUTONIC ROCKS
Granodiorite dikes

JURASSIC
ALTERED DUNITE

PERMIAN ANARCHIST GROUP
HYPABYSSAL BASIC DIKES

TUFFS

SEDIMENTARY ROCKS
Graphitic quartzite, sericitic quartzite,
fuchsite quartzite, and meta-argillite

VOLCANIC ROCKS
Greenstone and amphibolite

IMPURE CARBONATE

0   200   400   600 Feet

Abandoned adit
Abandoned shaft
Abandoned prospector pit
Diamond drill hole collar
Trench
Bridge of Transprovincial Highway No. 3
Abandoned Great Northern Railway grade
Logging access road
Stream
Extent of rock exposure
Zone of mineralization
Geological contact defined, inferred
Fault or strong shear defined, inferred
Foliation inclined, vertical
Bedding, banding in case of volcanic rocks,
or contact attitude
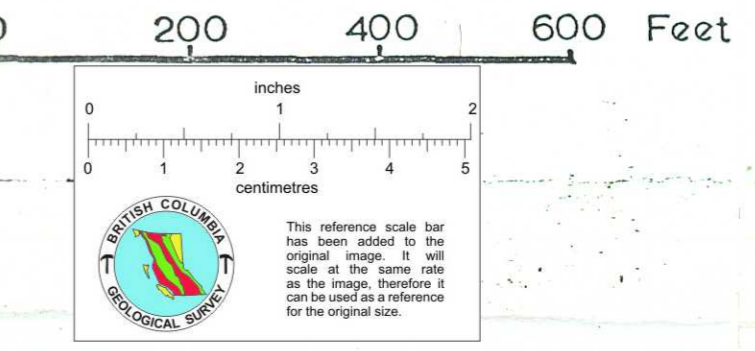
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