MONTANA STATE UNIVERSITY

Geology of the Kelsey copper-molybdenum property, Okanogan County, Washington
by Michael William Roper

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Earth Science (Geology)
Montana State University
© Copyright by Michael William Roper (1973)

Abstract:
The Kelsey Property is a copper-molybdenum prospect in Okanogan County, Washington. The property is located 4 miles northwest of Oro-ville, Washington, and 2.5 miles southwest of Osoyoos, British Columbia, on the western side of the Okanogan River Valley.

The Okanogan Valley region has recently become an exploration target for porphyry ore deposits. The north-south trending Quesnel Trough may be a major control for these orebodies. The Kelsey Property is in line with the southerly projection of this structure, and possess the same general geology as typical British Columbia porphyry orebodies, including similar lithology, structure, and alteration types.

The property area is underlain by greenschist facies metamorphic rocks of Permian to Triassic age. The sill-like Silver Nail pluton was emplaced in Triassic to Jurassic time, partly controlled by metamorphic foliation. The multi-phase pluton possesses a central core of coarse grained quartz diorite, and an upper and lower layer of fine grained mafic diorite.

Hydrothermal alteration of the Silver Nail pluton has produced an asymmetric surficial zoning pattern measuring one mile east-west by 2.5 miles north-south. Initial potassic alteration was followed by propy-litic alteration depositing iron and copper sulfides in fine, closely-spaced joint fracture filling veinlets, and in sporadic high-grade quartz veins. Minor molybdenite with quartz was deposited late in this phase, associated with slight shearing. A final explosive hydrothermal alteration phase formed the breccia of the Silver Nail pluton, and the associated tactite and massive sulfide alteration zones.

Tertiary volcanic and sedimentary rocks occur in fault contact with older, altered rocks on the west and southeast margins of the property. Faulting is dominated by two trends of post-mineral normal faults. North-south faults are parallel and subsequent to a major normal fault separating Paleozoic-Mesozoic rocks from the Tertiary intrusive volcanic plug along the western margin of the property. Northeast-southwest faults appear to be en echelon dip-slip fault traces reactivated by tensional crustal readjustments, resulting in minor normal fault movement.

In presenting this thesis in partial fulfillment of the require-
ments for an advanced degree at Montana State University, I agree that
the Library shall make it freely available for inspection. I further
agree that permission for extensive copying of this thesis for schol-
arly purposes may be granted by my major professor, or, in his absence,
by the Director of Libraries. It is understood that any copying or
publication of this thesis for financial gain shall not be allowed
without my written permission.

Signature *Michael W. Roper*

Date *April 21, 1973*

GEOLOGY OF THE KELSEY COPPER-MOLYBDENUM PROPERTY

OKANOGAN COUNTY, WASHINGTON

by

MICHAEL WILLIAM ROPER

A thesis submitted to the Graduate Faculty in partial
fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Earth Science (Geology)

Approved:

Milton J. Edie

Head, Major Department

Robert A. Chadwick

Chairman, Examining Committee

K Goering

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1973

TABLE OF CONTENTS

List of Figures

viii

List of Photomicrographs

List of Plates Included
in Rear Pocket

x

Abstract

The Kelsey Property is a copper-molybdenum prospect in Okanogan
County, Washington. The property is located 4 miles northwest of Oro-
ville, Washington, and 2.5 miles southwest of Osoyoos, British Columbia,
on the western side of the Okanogan River Valley.

The Okanogan Valley region has recently become an exploration target
for porphyry ore deposits. The north-south trending Quesnel Trough may
be a major control for these orebodies. The Kelsey Property is in line
with the southerly projection of this structure, and possesses the same
general geology as typical British Columbia porphyry orebodies, includ-
ing similar lithology, structure, and alteration types.

The property area is underlain by greenschist facies metamorphic
rocks of Permian to Triassic age. The sill-like Silver Nail pluton was
emplaced in Triassic to Jurassic time, partly controlled by metamorphic
foliation. The multi-phase pluton possesses a central core of coarse
grained quartz diorite, and an upper and lower layer of fine grained
mafic diorite.

Hydrothermal alteration of the Silver Nail pluton has produced an
asymmetric surficial zoning pattern measuring one mile east-west by 2.5
miles north-south. Initial potassic alteration was followed by propy-
litic alteration depositing iron and copper sulfides in fine, closely-
spaced joint fracture filling veinlets, and in sporadic high-grade
quartz veins. Minor molybdenite with quartz was deposited late in this
phase, associated with slight shearing. A final explosive hydrothermal
alteration phase formed the breccia of the Silver Nail pluton, and the
associated tactite and massive sulfide alteration zones.

Tertiary volcanic and sedimentary rocks occur in fault contact with
older, altered rocks on the west and southeast margins of the property.
Faulting is dominated by two trends of post-mineral normal faults.
North-south faults are parallel and subsequent to a major normal fault
separating Paleozoic-Mesozoic rocks from the Tertiary intrusive volcanic
plug along the western margin of the property. Northeast-southwest
faults appear to be en echelon dip-slip fault traces reactivated by
tensional crustal readjustments, resulting in minor normal fault move-
ment.

GENERAL REGIONAL DESCRIPTION

The Kelsey Property is a copper-molybdenum prospect located approximately four miles northwest of Oroville, Washington, and three miles southwest of Osoyoos, British Columbia. The property has the form of an elongate, north-south trending rectangle including roughly ten square miles. The study area is centered at approximately 119 degrees 30 minutes west longitude, 49 degrees north latitude, and includes land both north and south of the United States-Canada Border (Figure 1).

The writer has concentrated his efforts on that portion of the property on the American side of the border, though a geologic map and some information concerning the Canadian side of the property will be presented. The area discussed in detail in this paper includes secs. 1 and 12, R. 26 E., T. 40 N., and secs. 5, 6, 7, and 8, R. 27 E., T. 40 N., Okanogan County, Washington.

Physiographically the area is situated on the eastern margin of the Northern Rocky Mountain Province, northeast of the Okanogan Range, easternmost of the north-south trending multiple ranges that form the Northern Cascade Mountain Section (Fenneman, 1931). This corresponds to the assignment of the area to the boundary between the Plains of the Interior System to the east and the Coastal System to the west, using the Canadian Cordilleran physiographic divisions (Bostock, 1948).

The Northern Rocky Mountain Physiographic Province is composed of irregular mountain ranges of roughly similar character. These mountain

2

Figure 1. Index map of Washington showing position of study area.

units are divided by relatively continuous north-south trending val-
leys. The continuity of these so-called 'trenches' is in part struc-
tural, but has been made more distinct by glacial erosion. These
linear depressions, from east to west, include the Rocky Mountain
Trench, Purcell Trench, Selkirk Valley, and the Okanogan Valley (Figure
2). The Kelsey Property is situated in the Okanogan Valley, approxi-
mately one mile west of Osoyoos Lake, a glacially widened portion of
the Okanogan River.

Topography in the property area is moderately rugged, with eleva-
tions ranging from 1000 to 3000 feet. Mountains in the general area
possess summit altitudes of 5000 to 7000 feet. The Okanogan River
enters the United States on the eastern margin of the study area and
flows south through a broad, alluviated valley to join the Columbia
River approximately 60 miles to the south. Perhaps the major geo-
morphic agent that has acted upon the topography in this locality has
been the Okanogan Lobe of the Cordilleran Ice Sheet (Flint, 1935).
This piedmont glacier advanced to the southeast from source areas in
the mountains of South Central British Columbia, ultimately reaching
the vicinity of the confluence of the Okanogan and Columbia Rivers.
The most recent geomorphic agent shaping the local topography appears
to have been the periglacial Okanogan River, which produced the present
bench-like configuration of the surface of the Kelsey Property by the
scouring of its channel margin.

Figure 2. Regional map indicating major physiographic units. (After Fenneman, 1931; and Bostock, 1948)

The climate in the area is semiarid, locally described as a 'pocket desert', receiving from 5 to 10 inches of precipitation per year. The summers are hot and dry, and the winters relatively mild. The soil varies from a brown soil occurring on glacial or river terraces and alluvial fans in the Okanogan River Valley, to thin, discontinuous, mountainous soil types poorly developed on bedrock or glacial drift (British Columbia Natural Resource Conference, 1956). Natural vegetation is roughly zoned according to altitude. Sage brush and scrub grasses dominate the lower elevations, giving way to sparse coniferous forests above the 2500 foot elevations.

Population in the region is relatively sparse, generally concentrated along the Okanogan Valley. Tourism is a major industry in the area. The main agricultural enterprise is fruit growing in orchards located on low, flat, alluvium covered river terraces. The orchards must rely entirely on irrigation for their water supply. Land not being actively irrigated at the lower elevations is commonly fenced off and used for cattle grazing. The Kelsey Property is located entirely on such grazing land, but is contiguous with irrigated orchard land to the east.

The general area is serviced by a relatively close network of secondary roads which provide good access to the back country. The property itself is well situated with regard to transportation. There is a Burlington Northern railroad depot at Oroville, Washington, with a line

south toward Wenatchee, Washington, and a line northwest into British Columbia. There is a north-south trunk highway (U.S. 97) within a half-mile of the Kelsey Property. In Osoyoos, British Columbia, this highway intersects a major east-west Canadian route (Highway 3). With regard to power, the Chief Joseph Dam and hydroelectric generation system is located approximately 70 miles south of the property.

REGIONAL GEOLOGY

Introduction

The writer became acquainted with the Kelsey Property as a field geologist for the American Exploration and Mining Company (Amex), San Francisco, California, in the summer of 1971. At this time Amex was conducting a regional exploration program in the vicinity of the Okanogan River Valley in search of disseminated sulfide deposits in an area coincident with the southerly projection of a broad zone of pseudo-disseminated copper-molybdenum deposits of a type termed 'British Columbia porphyry deposits'.

The general region of the Okanogan Valley and the area to the north has become an interesting target for mineral exploration quite recently as a result of the discovery of several copper and molybdenum orebodies in British Columbia. These sulfide orebodies represent a class that is becoming increasingly well defined.

Geology of the British Columbia Porphyry Deposits

The ore deposits of this type tend to be disseminated rather than massive sulfide bodies, and may be only indirectly related to major intrusive masses, though they may be related to cupolas above deep-seated granitic batholiths. They correspond in part to Lindgren's pyrometasomatic deposits (high temperature replacement bodies near the border zones of igneous intrusives), but are similar to the porphyry copper deposits of the American Southwest in their disseminated nature,

sulfide mineralization, and alteration mineral assemblages (Titley and Hicks, 1966; Park and MacDiarmid, 1970).

The British Columbia porphyry deposits possess many characteristics in common, as described by Fahrni (1966). The deposits generally occur in clastic, calcareous sedimentary or volcanic rocks of late Triassic to Jurassic age deposited under shallow marine conditions. The ore-bodies are found where the variable character of beds provides contrasts of strength and permeability localizing fracturing, alteration, and the deposition of sulfide minerals.

There are normally indications of regional intrusion on a batho-lithic scale with Jurassic to Cretaceous age granodioritic rocks, though major intrusive contacts need not be closer than two or three miles from an orebody. Stock-like bodies of granodiorite, syenite or gabbro, and related feldspar dikes are commonly intimately associated with the ore, and may themselves be mineralized.

Folding is generally not significant and may be limited or absent, but block faulting, both before and after ore deposition, is a well defined feature. A closely spaced joint-fracture system is necessary to provide access for fluids from fault channel-ways to the area of sulfide precipitation. Low rank regional metamorphism of the green-schist facies (typical of low temperature-moderate pressure conditions) is generally present, which may indicate considerable amounts of ero-sion since formation.

Sulfide mineral occurrences include: Chalcopyrite, bornite, molybdenite, pyrite, and pyrrhotite. Gangue minerals commonly associated with the deposits include: magnetite, hematite, garnet, calcite, epidote, actinolite, diopside, secondary potassium feldspar, potassium-silicate alteration in general, and various combinations of hydrothermal clays. Of economic importance, bornite and chalcopyrite with minor gold and silver values, and to a lesser extent molybdenite, occur as pore and fine fracture fillings in the metamorphic country rock and smaller intrusive rock units in the orebodies. Tertiary sediments in the vicinity are further evidence of an erosional cycle, and Tertiary volcanic flows indicate continued geologic activity.

A major structural control suggested by Campbell and Tipper (1970) for the bulk of the British Columbia porphyry deposits is the Quesnel Trough. The Quesnel Trough is a narrow, north-northwest trending eugeosynclinal belt of dominantly lower Mesozoic volcanic clastic and sedimentary rocks that lies between the highly deformed Precambrian and Paleozoic rocks of the Pinchi Geanticline to the west and Omineca Geanticline to the east (Figure 3). The trough extends from near the 49th parallel into northern British Columbia. Geologic maps and interpretation by R.B. Campbell and H.W. Tipper of the Geological Survey of Canada are the major sources of information concerning the geology of the Quesnel Trough (Campbell, 1961, 1963; Campbell and Tipper, 1966; Tipper, 1959, 1960).

Figure 3.   Regional map showing the Quesnel Trough and associated structural features.   Gray pattern indicates occurrences of 200 m.y. intrusives.   (After Campbell and Tipper, 1970)

The Quesnel Trough is a partly fault-bounded structure, but is clearly a trough in that it contains younger rocks flanked by older rocks in the adjoining geanticlines. In contrast to the moderately to weakly deformed rocks of the Quesnel Trough, the older rocks of the geanticlines are commonly much deformed and metamorphosed. Broad areas of the trough are covered with Tertiary volcanics.

Various granitic plutons were emplaced in the region near the close of the Triassic. These plutons lie in a broad zone that trends north-westerly, slightly oblique to the north-northwest trend of the Quesnel Trough. These plutons are grouped as the 200 million year old (m.y.) intrusives, typified by the Guichon batholith, on which the Highland Valley and Craigmont copper-molybdenum orebodies are located (White, et al, 1967). A second roughly linear array of porphyritic granodioritic plutons of approximately mid-Cretaceous age, grouped as the 100 m.y. intrusives, parallels the 200 m.y. intrusives along their northeast margin.

A plot of pyrometasomatic and pseudo-disseminated sulfide mineral deposits in British Columbia and Washington (Figure 4) compared to the configuration of the Quesnel Trough and the 200 m.y. intrusives (Figure 3) suggests that copper has an affinity for broad areas near the contact between the 200 m.y. granitic intrusives and the Triassic-Jurassic volcanic and sedimentary rocks of the trough (Ney, 1966; Woodcock, et al, 1966; Campbell and Tipper, 1970). This further implies that copper

Figure 4.   Regional map showing major occurrences of pyrometasomatic
and disseminated copper sulfide (X symbol) and molybdenum
sulfide (O symbol) mineralization. (After Ney, 1966;
Campbell and Tipper, 1970; and Woodcock, et al, 1966)

has a wide potential distribution over broad areas of intersection between the 200 m.y. plutons and the Quesnel Trough. Molybdenum shows a more subdued relationship to the intersection of the margin of the 200 m.y. intrusives and the trough.

For these reasons exploration for copper and molybdenum sulfide mineralization has been concentrated in the areas of projected intersection between the Quesnel Trough and the Triassic to Cretaceous age intrusives. Various broad theories on metallogeny and metallogenic provinces have been put forth by Sullivan (1948), Bilibin (1955), Turneaure (1955), Wisser (1960), Petroscheck (1965), and Smirnov (1968). Theories dealing with metallogenesis in British Columbia specifically have been put forth in papers by Ney (1966), and White (1966). No theories thus far fully explain the processes responsible for the concentration of copper and molybdenum in British Columbia.

Geology of the Okanogan Valley Region

Tectonically the general region surrounding the Okanogan Valley has been considered as part of the southern margin of the Northern Cordillera (King, 1969). The Northern Cordilleran mountain belt trends northwesterly with a width of about 500 miles, from below the 49th parallel in Washington, Idaho, and Montana, up into Alaska. The Okanogan Valley is located roughly at the boundary between the miogeosynclinal portion of the Cordillera forming the Northern Rocky Mountains to the

east, and the eugeosynclinal to the west evidenced by supracrustal vol-
canics and sediments covering the Coast Ranges of British Columbia.

Precambrian crystalline rocks do not normally crop out within the
ranges of the Northern Cordillera. However, younger Precambrian meta-
sediments are extensively exposed in the higher uplifts in the miogeo-
synclinal belt and adjoining eugeosynclinal belt.

Late Paleozoic and early Mesozoic eugeosynclinal deposits extend
over the length of the Northern Cordillera, and many sequences attain
thicknesses of more than 25,000 feet. Deposition was widely inter-
rupted during the early Triassic, mostly by epeirogenic movements
accompanied by moderate deformation.

During the Mesozoic, granitic rocks were emplaced in the eugeosyn-
clinal area on a vast scale along the entire length of the Northern
Cordillera and beyond. Various dating methods indicate a prolonged
period of emplacement, from 250 to 70 m.y., through all of the Meso-
zoic and into the Tertiary. Radiometric dating has further suggested a
pulse-like emplacement of granitic plutons at approximately 30 m.y.
intervals during the Mesozoic (Gabrielse and Reesor, 1964).

Perhaps the dominant faults in the Northern Cordillera are the
lengthy, north-south trending longitudinal fault zones commonly ex-
pressed as topographic trenches or valleys separated by roughly linear
mountain ranges (Figure 5). The Okanogan River Valley may be an exam-
ple of this type of structure. The straight or gently curved courses

Figure 5. Regional map indicating major faults in the Northern
Cordillera. Thrusts with barb on upper plate. (After
Campbell, 1966; Wheeler, 1966; and Yates, et al, 1966)

of this type of fault zone, the interchange of apparent up-thrown and down-thrown sides, and the frequent lithologic differences between rocks on opposite sides have suggested to King (1969) that these faults are major strike-slip faults. Strike-slip movement has been proved in a few segments, but the actual sense and amount of displacement in the majority of structures remains unclear. Further detailed information on the tectonic history of the Western United States has been put forth by Gilluly (1963, 1965).

In the Okanogan Valley area, bedrock consists chiefly of metamorphosed sedimentary and volcanic rocks of Permian, Triassic, and Jurassic or Cretaceous age that have been intruded by numerous Mesozoic age plutons. The metamorphic rocks consist of a folded succession of weakly to moderately metamorphosed eugeosynclinal deposits, mainly siltstone, fine clastic conglomerate, limestone, chert, and volcanics. The sequence probably aggregates more than 30,000 feet in thickness (Fox and Rinehart, 1971).

The metamorphic rocks have been intruded by a great number of plutonic rocks. The intrusions in the area of the Okanogan Valley vary in age from Triassic or Jurassic to early Tertiary, and range in size from small masses less than a mile in diameter to batholiths (Krauskopf, 1941). The majority of these plutons possess an elongate northwest to north-northwest trend. Their compositions are dominantly granodioritic, but range to gabbro and malignite.

Visible cross-cutting of one intrusive through another is quite uncommon, and the genetic relationships as well as the time relationships between plutons remain in doubt. The problem of correlation is made more difficult because of the internal variation in composition and structure in many of the intrusives (Waters and Krauskopf, 1941; Snook, 1965).

The region of the Okanogan Valley at the 49th parallel approximately coincides with the quartz diorite boundary line described by Moore (1959). The quartz diorite line is a roughly north-northwest trending, statistically determined boundary which separates an area of common quartz diorite intrusives to the west from the area of less common occurrences of quartz diorite to the east.

Metamorphic and plutonic rocks in the area are locally cut by small plugs of Tertiary dacite or andesite, and are commonly overlain by lava of similar composition interstratified with clastic sedimentary rocks.

Summary

The regional geology of the Okanogan Valley seems to correspond in approximate age and general rock type to those rocks associated with typical British Columbia porphyry deposits. The structural and tectonic relationships are relatively continuous from areas of known copper-molybdenum sulfide mineralization in British Columbia to the Okanogan Valley. The entire region has been intruded by numerous dominantly

granodioritic Mesozoic age plutons. Finally, the area is situated in line with a reasonable southerly projection of the Quesnel Trough. For these reasons it seems reasonable to attempt to correlate copper-molybdenum sulfide mineralization occurring on the Kelsey Property in the Okanogan Valley to the broad class of British Columbia porphyry deposits.

GEOLOGY OF THE KELSEY PROPERTY

Introduction

The Kelsey Property is a known mineralized area that has been intermittently prospected over the past half century. The property area contains hundreds of prospect pits, short adits, and less common extensive underground workings. The prospecting in concentrated on quartz veins and the more rare massive sulfide occurrences. Exploration in the property area undoubtedly gained impetus from the success of the Dividend Mine on the Canadian side of the border on the Kelsey Property. This mine reportedly yielded approximately $2,500,000 in gold during the early 1900's from a gently dipping quartz vein associated with massive sulfides in metasedimentary rocks.

Unfortunately the Dividend deposit appears to be unique in the Kelsey Property area. The dominant minerals in all other observed quartz veins in the area include sulfides, but only traces of gold and silver. However, numerous quartz veins do contain large concentrations of chalcopyrite along with pyrite. Though some prospectors attempted to mine the copper, the sporadic, discontinuous high-grade accumulations were not large enough to warrant production.

With the advent of production from large volume-low grade disseminated copper deposits in the American Southwest and British Columbia, interest developed in the altered, commonly chalcopyrite-mineralized rock between the high-grade quartz veins. It was at this point, in the

early 1960's, that various promoters and mineral exploration concerns became interested in the Kelsey Property as a possible porphyry copper deposit.

Various geophysical tests were conducted and numerous drill holes were completed in the property area. However, no detailed geologic map, alteration map, or petrographic examinations were made of the Kelsey Property until Amex began work on the property during the field season of 1971.

The geology of the Kelsey Property was mapped by the writer for Amex at a scale of one inch equals 400 feet over approximately 40 days of field work in the summers of 1971 and 1972. During the field work and preliminary preparation of this paper the writer had access to the various drill logs, geophysical data, and incomplete geologic reports compiled over the past decade by various mineral exploration companies.

During the field season of 1972, Amex also completed a number of drill holes on the property. The writer was present during most of this drilling program, and logged a number of the drill holes. Access to the collection of drill logs and assay data was essential to the structural interpretation and construction of geologic cross sections of the Kelsey Property.

The purpose of this large scale mapping of the property area was to ascertain the surface extent, configuration, type, intensity, and possible source of alteration and sulfide mineralization. The writer,

therefore, concentrated his efforts on the altered, sulfide-bearing igneous intrusive rocks in the property area and spent less time on the relatively barren metamorphic rocks, post-mineralization Tertiary volcanic and sedimentary rocks, and Quaternary alluvium.

The results of field mapping and structural interpretation are displayed in the five plates included in the rear pocket of this paper. Plates I, II, and III portray the geology of the Kelsey Property on the American side of the border, as mapped and interpreted by the writer. Plate IV is a geologic map of the Canadian side of the Kelsey Property by D.P. Simpson, Osoyoos Mines, 1940, which has been partly field checked, revised, and enlarged upon by the writer. Plate V is an alteration map of the American portion of the Kelsey Property by the writer which will be discussed in the Alteration-Mineralization section of this paper.

Lithologic Descriptions

Paleozoic-Mesozoic Metamorphic Rocks:

Several different sequences of lithologically similar, regionally metamorphosed, greenschist facies metamorphic rock units crop out in the property area, but were not differentiated in the writer's field mapping. The metamorphic rock units in the area, from oldest to youngest, include the Anarchist Group, the Kobau Formation, and the Ellemeham Formation, as described by Fox and Rinehart (1971). These meta-

sediments were generally deposited under eugeosynclinal marine conditions.

The Anarchist Group consists of complexly folded, low-grade metamorphic rocks of the greenschist facies including: slate, phyllite, fine grained impure marble, greenstone, fine clastic metaconglomerate, and metawacke. Only the fine grained metaclastics are well foliated, and where bedding can be detected, it is generally parallel to the foliation. Individual beds possess little lateral continuity, either intergrading or intertonguing with other beds. In total, the Anarchist Group probably aggregates more than 20,000 feet in thickness. Fossils found at several localities have confirmed a Permian age.

The Kobau Formation is composed of interlayered green phyllite, greenstone, and metachert, of the greenschist facies. This unit overlies the Anarchist Group along a gently dipping plane of angular unconformity. The thickness has been estimated to be greater than 12,000 feet. The Kobau Formation is thought to be Permian or Triassic in age since it is known to be intruded by late Triassic plutons and overlies the Permian Anarchist Group.

The Ellemeham Formation consists of scattered remnants of a once continuous deposit which includes a basal layer of greenstone or metadiabase, overlain by a dominantly intraformational breccia, with local greenstone clasts originating in the Anarchist Group and Kobau Formation. The unit is only weakly metamorphosed. The Ellemeham Formation

was deposited on a surface beveled on Anarchist and Kobau terrain, and
is thought to be Jurassic or Cretaceous in age (Rinehart and Fox, in
press).

Significant field relationships noted with regard to the metamor-
phic rocks on the Kelsey Property are:

1) Inclusion of sporadic Kobau Formation (?) greenstone
wedges or slivers in the Mesozoic age Silver Nail pluton;

2) Transitional and intertonguing contacts between the
metamorphic rock units and the intrusive Silver Nail plu-
ton;

3) Inclusion of Kobau Formation (?) metachert or quartz-
ite fragments in the Silver Nail pluton breccia unit;

4) Local massive sulfide flooding of phyllitic rocks
adjacent to impermeable impure marble of the Anarchist
Group; and

5) Absence of a well defined contact metamorphosed zone
or aureole in the greenschist facies metamorphic rocks in
contact with the Silver Nail pluton.

Several conclusions can be drawn from these relationships. Includ-
ed greenstone wedges, rather than forcefully stoped angular blocks, im-
ply relatively passive intrusion of the Silver Nail pluton, perhaps
along foliation planes in the metamorphic country rock. Apparent tran-

sitional contacts between the metamorphic greenstone and fine grained mafic diorite phase of the Silver Nail pluton imply that some assimilation of greenstone into the intrusive has taken place. Angular quartzite fragments in the breccia unit of the Silver Nail pluton indicate at least one phase of active, forceful emplacement. Massive sulfide occurrences perhaps demonstrate the control of percolating hydrothermal fluids by metamorphic foliation, and their consequent entrapment against impervious beds. Finally, the absence of a high-rank, contact metamorphosed zone in the greenschist facies metamorphic rocks at their contact with the pluton may indicate that conditions of temperature and pressure were not radically different between the intrusive and the country rock.

Mesozoic Intrusive Rocks:

The Mesozoic intrusive rock types occurring on the Kelsey Property represent multiple phases of the Triassic to Jurassic age Silver Nail pluton (Fox and Rinehart, 1971). This tabular intrusive body varies from a coarse grained, rarely porphyritic quartz diorite, to a fine grained mafic diorite, and includes all variations between these two rock types. A discontinuous, roughly oval breccia phase of the pluton crops out on the southern margin of the intrusive. Sporadic wedges or slivers of metamorphic greenstone are included in all phases of the intrusive.

Petrographic examination of the various phases of the Silver Nail pluton and associated alteration and mineralization was conducted on approximately 60 thin sections cut from surface samples collected on the Kelsey Property. Plate V indicates the position of the thin section samples on the property, and the Appendix to this paper gives a rough grouping of the samples according to rock type. References used during petrographic examination and interpretation of thin section samples include: Bastin (1950), Cameron (1961), Kerr (1959), Moorhouse (1959), and Park and MacDiarmid (1970).

The mafic diorite and quartz diorite map units were differentiated in the field according to grain size, proportion of quartz to plagioclase, and relative amounts of mafic minerals. In hand specimen, the quartz diorite map unit consists of medium to coarse grained, quartz flooded, felsic diorite. This rock type exhibits a porphyritic texture locally, and also may show a gross, gneissic lineation of mineral grains. Quartz generally occurs as coarse, gray, translucent, anhedral grains sandwiched between pale green, sericitized-sausseritized plagioclase crystals. Mafic minerals generally appear completely chloritized. This rock type is strongly jointed, and commonly carries sulfide bearing quartz-calcite-epidote veinlets as fine joint-fracture fillings. Where sheared, the quartz diorite resembles a pale, pearly gray-green, sericite schist.

Petrographic examination reveals that the quartz diorite consists

of roughly 60 percent plagioclase, 15 percent quartz, 5 to 10 percent potassium feldspar (K-spar), 5 percent amphibole (actinolite ?) after pyroxene, 5 percent chlorite replacing all mafic minerals, rare sphene, possible biotite, and sporadic quartz-calcite-epidote veinlets carrying pyrite, chalcopyrite, and magnetite, locally oxidized to hematite.

Plagioclase occurs as moderately to heavily altered, locally strained and sheared, blocky crystals. The crystals are generally so thoroughly altered to sericite, and to a lesser extent sausserite, that accurate An determination is not possible. Plagioclase crystals are not zoned, but locally possess clear albite alteration rims. Sericite alteration generally appears as highly birefringent studs along twin planes down the length of the plagioclase crystals.

Quartz and K-spar appear as strained, anhedral, intersutured mineral grains which have apparently crystallized from a potassium-rich silicate solution secondary to the crystallization of the plagioclase. Rare, euhedral, hexagonal quartz crystals occur in this mixture of generally anhedral quartz and K-spar grains. The K-spar commonly possesses a faint, irregular gridiron structure, and apparently is a potassium feldspar mineral species between orthoclase and microcline in composition (Photomicrograph 1). The permeation or flooding of quartz and K-spar into an at least partially solidified dioritic unit is evidenced by the following:

1) The relatively fresh, unaltered look of the quartz

Photomicrograph 1. Quartz diorite, thin section K-23-A. Sericitized
     plagioclase flooded by partly strained quartz and K-spar. Note
     faint gridiron structure on K-spar (microcline ?), upper right
     center of field. Approximate field of view, 1.5 x 2.0 mm.,
     cross nicols.

                                        Photo by Jerry Nelson

and K-spar compared to the plagioclase;

2) The association of quartz and K-spar as intersutured anhedral grains surrounding euhedral, altered plagioclase crystals;

3) Local shearing, dislocation, and partial crushing of plagioclase crystals; and

4) Local occurrences of quartz dissolving and replacing plagioclase and amphibole crystals (Photomicrograph 2).

Mafic minerals in the rock include twinned amphibole (actinolite ?) apparently formed by replacement of pyroxene. Small remnants of pyroxene rarely occur in the amphibole crystals. Perhaps the dominant mafic mineral in the rock is chlorite, which occurs as fine grained, scale-like, green crystalline aggregates, and as apparent pseudomorphs after amphibole and pyroxene minerals. Chlorite also replaces rare, foliate, phyllite rock fragments included in the quartz diorite. Primary biotite occurs very rarely.

Where sheared, the coarse quartz diorite exhibits a marked lineation of mineral grains parallel the plane of shear. Sericite and chlorite alteration are more intense, and quartz is generally more coarse grained, probably resulting from remobilization.

Secondary features which cross-cut the quartz diorite include sulfide bearing quartz-calcite-epidote veinlets, and quartzo-feldspathic

Photomicrograph 2. Quartz diorite, thin section K-23-A. Quartz
    flooding of sericitized-sausseritized plagioclase. Note
    secondary nature of quartz, apparently dissolving-replacing
    clear albite rims of plagioclase crystals. Approximate field
    of view, 1.5 x 2.0 mm., cross nicols.

Photo by Jerry Nelson

dikes. These features will be discussed in the Alteration–Mineraliza-tion section of this paper.

In hand specimen, the mafic diorite map unit consists of medium to very fine grained, dirty green, locally sheared diorite, with chlor-itized mafic minerals and yellowish-green sausseritized plagioclase. Quartz is rare or absent, except as secondary veinlets. This rock type is locally strongly fractured and sporadically veined by varying com-binations of quartz, calcite, and epidote, carrying pyrite and chalco-pyrite. The mafic diorite resembles a dark green chlorite schist in areas of strong shearing.

Petrographic examination of the fine grained mafic diorite phase of the Silver Nail pluton reveals that the rock consists of approximately 75 percent plagioclase, 15 percent mafic minerals moderately to thor-oughly altered to chlorite, 5 percent quartz, 2 percent K-spar, and 3 percent disseminated magnetite. Sporadic quartz-calcite-epidote vein-lets carrying pyrite, chalcopyrite, and magnetite cross-cut the rock.

Plagioclase occurs as blocky crystals, generally thoroughly coated with very fine, opaque sausserite alteration, to identifiable epidote. The crystals are not zoned, nor is the sericitic alteration as intense as is generally found in the quartz diorite (Photomicrographs 3 and 4). Quartz occurs relatively rarely, associated with K-spar as a flooding agent, and in medium to coarse grained quartzo-feldspathic dikes.

Photomicrograph 3. Quartz diorite to diorite, thin section K-112-B.
   Slightly fractured and warped, sericitized-sausseritized
   plagioclase. Note secondary epidote veining along with
   quartz flooding. Approximate field of view, 1.5 x 2.0 mm.,
   cross nicols.

                                        Photo by Jerry Nelson

Photomicrograph 4. Mafic diorite, thin section K-11. Intensely
    sausseritized-epidotized plagioclase remnants. Approximate
    field of view, 1.5 x 2.0 mm., cross nicols.
                                        Photo by Jerry Nelson

Mafic minerals observed in thin section examination include twinned amphibole (actinolite ?), possible rare hornblende and biotite, and remnant pyroxene. Mafic minerals generally appear to be undergoing replacement by chlorite, which is the most common ferro-magnesian mineral. Magnetite is generally intimately associated with mafic minerals as fine grained euhedral crystals which appear disseminated through the mafic crystals, often surrounded and cross-cut by chlorite.

Secondary mineralization in the mafic diorite is dominated by sulfide bearing calcite-epidote veinlets, rather than quartz-K-spar flooding and quartzo-feldspathic dikes. Sulfide minerals consist of pyrite and chalcopyrite, locally intermixed with magnetite, and commonly oxidized to hematite.

The major petrographic differences noted between the fine grained mafic diorite and the coarse grained quartz diorite phases of the Silver Nail pluton are:

1) Grain size;

2) Relative amounts of mafic minerals;

3) Relative proportion of quartz and K-spar to plagioclase; and

4) Dominant alteration mineral assemblages, quartz-K-spar-sericite in the quartz diorite versus chlorite-calcite-epidote associated with the mafic diorite.

The breccia map unit is complex in lithologic composition, mineralogy, and contact relations with metamorphic rocks and with other phases of the Silver Nail pluton. In hand sample, the matrix varies from a very fine grained, mafic, magnetite bearing diorite, to a coarse grained tactite mineral assemblage including: calcite, garnet, magnetite, actinolite, and local massive sulfide accumulations. Fragments included in the breccia vary from angular, one inch fragments of metachert or quartzite on the southeast margin of the breccia zone, to irregular, rotated blocks of felsic diorite up to 10 feet in diameter on the northwest margin of the breccia zone. The breccia unit has undergone local shearing, as have the other Mesozoic intrusive rocks on the Kelsey Property, and also includes sporadic, sulfide bearing quartz-calcite-epidote veins.

Petrographic examination of the breccia-tactite unit reveals the variety of included fragments in the breccia, and the intensity of associated metasomatic or hydrothermal alteration. Fragments included in the breccia consist of:

1) Fine grained metamorphic quartzite (possibly Kobau Formation) composed of intricately intersutured quartz grains;

2) Heavily chloritized, sausseritized, hornfels-like metamorphic greenstone; and

3) All varieties of thoroughly altered diorite, from

coarse grained quartz diorite to fine grained mafic diorite.

The matrix varies from complex, altered, coarse grained, mafic minerals (dominantly actinolite) commonly carrying fine grained, disseminated, euhedral magnetite crystals, to a complex skarn of intermixed garnet, calcite, magnetite, quartz, wollastonite, actinolite, and other mafic minerals (Photomicrograph 5). Associated with the skarn or tactite alteration are sporadic occurrences of massive sulfides (Plate V). Massive sulfides consist of dominantly pyrite, with chalcopyrite, associated magnetite, and possible pyrrhotite. The breccia unit appears to be the source or at least the conduit of the tactite-massive sulfide mineralization on the southern margin of the Kelsey Property. Though the breccia unit is genetically related to the Silver Nail pluton, it has been intensely metasomatically or hydrothermally altered, and therefore will be discussed more thoroughly in the Alteration-Mineralization section of this paper.

Tertiary Sedimentary and Volcanic Rocks:

Tertiary volcanic and sedimentary rocks occur on the margins of the Kelsey Property, apparently in fault contact with the older metamorphic and intrusive rocks. The Tertiary rock units were examined in the field only so far as to determine the configuration and style of their contact with the sulfide bearing Paleozoic and Mesozoic rocks.

Photomicrograph 5. Tactite alteration, thin section K-16-B. Shattered
garnet crystals in calcite matrix, associated magnetite. Left
view: plain light; Right view: cross nicols. Each field of
view approximately 1.0 x 1.5 mm.

Photo by Jerry Nelson

Fox and Rinehart (1971) describe the sedimentary units which crop out on the southeast margin of the property area as consisting of a boulder conglomerate derived chiefly from granitic rocks, a second conglomerate derived from dominantly granitoid alkalic rocks, and minor arkose and graywacke. Any number of plutons in the general area of the Okanogan Valley could have served as the source of the granitic material composing these sedimentary units. The age relationship between the Tertiary volcanic and sedimentary rock units is unclear, though structural interpretation by the writer suggests that the volcanics are younger (Plate III).

The Tertiary volcanic rocks on the western margin of the Kelsey Property consist of hornblende dacite porphyry, identified as an intrusive plug by Fox and Rinehart (1971). The age of this plug, determined through the potassium-argon dating of hornblende, is 51.4 ± 2.6 m.y. (Fox and Rinehart, 1971). The age plus the geographic position implies that the rocks are a southern continuation of the Eocene volcanic province of South Central British Columbia (Mathews, 1964).

The hornblende dacite porphyry, in thin section petrographic examination, consists of approximately 50 percent plagioclase, 15 percent hornblende, 5 percent magnetite, and 30 percent fine grained matrix. The plagioclase is commonly zoned, with slightly sausseritized albite rims. Plagioclase phenocrysts also contain sporadic micro-veinlets of sericite in fine fractures in the crystals.

The hornblende occurs commonly as twinned phenocrysts with slightly altered rims. The crystals exhibit olive-green pleochroism under plain light. Magnetite is fine grained compared to the hornblende and plagioclase, but more coarse than the matrix. Magnetite crystals are generally euhedral, randomly disseminated through the matrix of the rock. The matrix is composed of slightly crushed and brecciated, very fine plagioclase crystals and microlites. The entire matrix is irregularly coated with very fine sericite-sausserite altered patches.

Quaternary Alluvium:

Several areas on the Kelsey Property are covered by thin, discontinuous patches of Pleistocene alluvial and glacial deposits consisting of coarse gravel, sand, and silt. This cover is probably less than 10 feet thick in the property area, but may be hundreds of feet thick in the Okanogan River Valley and Osoyoos Lake to the east of the property. The writer did not map Quaternary alluvium where the underlying bedrock could be reasonable deduced by structural projection or from drill hole data. Bedrock float is generally not reliable as a field mapping guide in the alluvium covered areas.

Various topographic and surficial features of the Pleistocene glacial and periglacial activity are apparent in the property area. These features include:

    1) Disrupted drainage features such as Hot Lake;

2) Several kettle-like depressions occupied by swamps;

3) Coarse glacial striations on bedrock;

4) Rare glacial erratics; and

5) Sporadic silt and gravel blankets.

Structure

Major Structural Features:

Perhaps the dominant structural feature of the region is the north-south trending Okanogan Valley. This linear feature probably results from movement on some major north-south trending fault, the sense of which is unknown. The emplacement of numerous intrusive, plutonic masses in the area also may have strongly affected shearing and faulting on the Kelsey Property.

The presence of the Tertiary hornblende dacite porphyry plug on the Kelsey Property, and the occurrence of two Tertiary calc-alkalic diatremes south of the property, near Oroville, Washington, (Fox and Rinehart, 1971) indicates local deep-seated igneous activity which may have previously influenced the emplacement of the Mesozoic Silver Nail pluton.

The gross form of the Silver Nail pluton, as indicated by surface mapping and drill hole interpretation, appears to be roughly sill-like (Plates I, II, and III). The inner tabular core is composed of coarse grained quartz diorite. Layers of fine grained mafic diorite lie above

and below the central quartz diorite core. The entire tabular, sill-like mass dips gently to the north. A thin, discontinuous breccia zone of the pluton lies parallel to and beneath the core, and possesses a similar trend.

Foliation in the metamorphic rocks on the northwest margin of the Kelsey Property displays a dominantly north-south strike with a moderate westerly dip. On the southern margin of the property the metamorphic foliation possesses a roughly northeast-southwest strike, but the rocks are tightly folded, making the magnitude and direction of dip quite variable.

Faults:

There are two dominant fault trends in the property area, north-south and northeast-southwest trending. Faults were mapped mainly on the basis of abrupt lithologic changes and topographic expression, as observed in the field and from air photo interpretation. Determination of sense and distance of movement was made difficult by the similarity and intertonguing relationships of the lithologic units, and by the profusion of slickensides at almost random orientations. The sense and distance of movement indicated is conjecture based upon topographic features, surface mapping, structural projection from drill hole information, and structural interpretation from regional tectonic patterns.

The linear north-south faults on the property have been interpreted

by the writer as high-angle normal faults. The major fault of this type is the fault separating the Tertiary volcanics from the Paleozoic and Mesozoic rocks on the western margin of the Kelsey Property. This fault probably results from forces associated with the emplacement of the volcanic plug. The roughly parallel fault traces to the east of this major fault on the Kelsey Property appear to be stair-step normal faults subsequent to the major fault. Movement on these normal faults seems to be relatively slight, probably from 25 to 300 feet.

The northeast-southwest trending faults in the property area are considered by the writer to a series of en echelon, right lateral strike-slip faults which have been reactivated with normal fault movement. These faults may have undergone initial activation before the emplacement of the Tertiary volcanic plug, but show definite evidence of movement after solidification of the Tertiary volcanics. This post-Tertiary fault movement is evidenced by strong linear topographic features traceable from the Paleozoic-Mesozoic rocks on the Kelsey Property onto the Tertiary volcanics.

Though topographic expression of the northeast-southwest fault trend is strong, there does not appear to have been significant strike-slip displacement. Faults of this trend on which major movement has been interpreted possess only near vertical, normal fault displacement. This en echelon appearance and limited strike-slip movement is reasonable considering the gross structure of the Okanogan Valley. The

Okanogan Valley consists of a north-south trending fault structure off-set along its length by several large-scale, northeast-southwest trend-ing, right-lateral strike-slip faults (Figure 5, p. 15).

An example of this type of fault exhibiting substantial movement has been interpreted by the writer as occurring on the northern margin of the Kelsey Property, in Canada. This fault is traceable for at least three miles to the northeast of the property, where the fault appears to offset Osoyoos Lake. Therefore, it seems likely that the northeast-southwest trending faults are en echelon, joint-like features exhibiting limited movement, related to the major right-lateral, strike-slip faults in the area.

Various tensional crustal adjustments have since reactivated these planes of weakness, causing generally minor, secondary normal fault movement. This movement is commonly on the order of 50 to 100 feet, though the fault separating the Tertiary conglomerate from the Paleo-zoic metasediments on the southeast margin of the Kelsey Property may possess as much as 1000 feet of displacement.

Shear Zones:

Shearing is common throughout the Kelsey Property, but most evident in the Silver Nail pluton, commonly associated with alteration miner-als. Two major trends of shear dominate in the property area. The most common trend is an east-west to northeast-southwest striking shear

plane, dipping moderately to the north to northwest. This trend occurs in secs. 5, 8, and the eastern margin of sec. 6, R. 27 E., T. 40 N. (Plate I), and on the southeast portion of the Canadian side of the Kelsey Property (Plate IV). A north-south to north-northwest - south-southeast striking shear trend, dipping moderately to the west to west-southwest dominates through secs. 6 and 7, R. 27 E., T. 40 N.

The different shear trends apparently result from separate compressive force couples. The source of the force couples is unknown, but is very likely associated with regional and local emplacement of numerous plutonic rock masses. Individual shear planes are commonly one to four feet thick, strongly foliate, locally schistose, slickensided, heavily altered, partly mylonitized zones. Though shears are profuse throughout the property area, they are not continuous features, and cannot be traced for any distance on the surface.

The common association of secondary alteration minerals with the shear zones implies that hydrothermal fluids preferentially traveled along these more permeable zones. This further suggests that shearing took place contemporaneous with or previous to the alteration and mineralization processes which have acted on the Kelsey Property.

Summary:

The Kelsey Property has been subject to two major trends and styles of high-angle faulting, and to at least two force couples producing

low-angle, discontinuous shear planes of different orientations. The probable structural sequence in the property area is as follows:

1) Movement (strike-slip ?) along the north-south trending Okanogan Valley fault;

2) Emplacement of the tabular, multi-phase, Triassic to Jurassic age Silver Nail pluton, possibly partly controlled by the Okanogan Valley fault;

3) Shearing of the Silver Nail pluton, shortly followed by alteration and mineralization of the intrusive rocks;

4) Regional, right-lateral, northeast-southwest trending strike-slip faulting offsetting the Okanogan Valley fault at various places along its length;

5) Subsequent formation of en echelon, joint-like fault traces exhibiting minor movement parallel to the major, offsetting strike-slip faults;

6) Upward emplacement of the Kruger Mountain Tertiary hornblende dacite porphyry plug along the major north-south trending normal fault on the western margin of the Kelsey Property;

7) Formation of subsequent, north-south trending, stair-step normal faults across the Kelsey Property, east of the major normal fault bounding the volcanic plug; and

8) Minor tensional crustal adjustment producing the

present somewhat graben-like form to the Kelsey Property, and reemphasizing the joint-like, en echelon, northeast-southwest fault traces with slight normal fault movement along the planes of weakness.

Alteration-Mineralization

Alteration Types, Extent, and Zoning:

The altered, mineralized area on the Kelsey Property is roughly rectangular in form, extending at least one and one-half miles east-west by approximately three miles north-south. The altered area is bounded (or covered) by Tertiary volcanic and sedimentary rocks and Quaternary alluvium on the east and west margins of the property, and by relatively unaltered metamorphic rocks on the southern margin (Plate V). The altered area to the north, on the Canadian side of the property, though obscured by alluvium, appears to be terminated by a strong northeast-southwest trending fault (Plate IV).

The configuration of the altered area is used as an aid in determining the extent of the copper-molybdenum sulfide mineralization, which appears to be intimately related to the overall alteration process on the Kelsey Property. Alteration minerals observed in the field, in approximate order of abundance, include: chlorite, quartz, calcite, epidote, sericite, K-spar, pyrite, pyrrhotite (?), actinolite, garnet, chalcopyrite, magnetite, hematite, and molybdenite.

The most common alteration mineral assemblages noted during field

mapping of the Kelsey Property include:

1) Intense, pervasive chloritization of the metamorphic

rocks and of the fine grained phase of the Silver Nail

pluton;

2) Quartz and secondary K-spar flooding, and associated

sericitization, generally confined to the coarse grained

phase of the Silver Nail pluton;

3) Sporadic, medium to coarse grained quartzo-feldspathic

dikes, generally occurring in the coarse grained phase of

the Silver Nail pluton;

4) Skarn-tactite mineralization with local massive sul-

fides associated with the breccia phase of the Silver Nail

pluton; and

5) Sulfide bearing (pyrite and chalcopyrite) quartz-

calcite-epidote veins, veinlets, and fine joint-fracture

fillings occurring in all phases of the pluton, but con-

centrated in the coarse grained quartz diorite.

There is an apparent gross zoning of the alteration mineral assem-

blages on the Kelsey Property. The different alteration types form a

rough asymmetric pattern north and south of the outcrop of the breccia

phase of the Silver Nail pluton (Plate V). Figure 6 portrays the gross

Figure 6. Segment of geologic cross section D-D' (Plate III) showing alteration zones. Approximate scale, one inch equals 1000 feet.

alteration zoning in cross section, as interpreted by the writer.

The southern-most alteration zone of massive sulfides forms a tongue-like surficial pattern, roughly 500 feet wide by three-fourths mile long, trending southwest from the breccia phase of the pluton. This zone is characterized by sporadic, discontinuous, tabular to pod-like sulfide bodies replacing metamorphic rocks. The sulfides consist dominantly of pyrite and pyrrhotite (?), with chalcopyrite and associated magnetite. The configuration of the massive sulfides is controlled by bedding features in the metasediments they replace.

The tactite alteration zone, which includes and surrounds the breccia unit, consists of a complex, irregular intermixed garnet, calcite, actinolite, and magnetite mineral assemblage, and is associated with sporadic, irregular blebs and aggregates of sulfide minerals disseminated through the matrix of the breccia. The presence of disseminated sulfides in the breccia matrix, and the position of the massive sulfide alteration zone on the margin of the breccia, apparently controlled or channelled by bedding features in the metasediments, suggests that the breccia is the source or at least the conduit of the sulfide-rich mineralizing fluids.

Processes associated with hydrothermal brecciation and alteration have been described in considerable detail by Bryner (1961), Perry (1961), and Kents (1964). Breccias such as that occurring on the Kelsey Property have been classified as 'co-hydrothermal' by Bryner

(1961). This signifies a hydrothermal rather than volcanic origin. Co-hydrothermal breccias generally show a higher incidence of alteration and metallization than do other breccia types. Kents (1964) further emphasizes the association of breccias with hydrothermal processes, and attributes the formation of hydrothermal breccias to a process of magmatic pulsations which provide the force necessary for a hydraulic ramming of the altering fluids into overlying rocks.

The silicified-sericitized alteration zone occurs as an irregular, roughly one-half mile wide, east-west trending band cropping out across the northern margin of the tactite alteration zone. The zone follows approximately the outline of the outcrop of the coarse grained quartz diorite, and is characterized by quartz-K-spar flooding, strong sericitic alteration, and sporadic quartzo-feldspathic dikes. This zone carries the strongest copper and molybdenum sulfide mineralization, in high-grade quartz veins and as thin joint-fracture-slickenside fillings.

The intensely chloritized alteration zone exhibits an irregular, discontinuous pattern surrounding the other alteration features, and is characterized by almost complete chloritization of mafic minerals. The most intense expression of this zone occurs in the fine grained mafic diorite phase of the Silver Nail pluton. The intense chloritization continues north of the American-Canadian Border. The major portion of this zone occurs along the northern margin of the silicified-seric-

itized alteration zone, and the chloritized zone includes local silici-fied-sericitized patches. This zone carries minor chalcopyrite in fine quartz-calcite-epidote veinlets and joint-fracture fillings.

Economic Sulfide Mineralization:

Copper and molybdenum occur in sulfide minerals in appreciable quantities on the Kelsey Property. Copper is found dominantly in chal-copyrite ($CuFeS_2$). Very rarely, bornite (Cu_5FeS_4) and chalcocite (Cu_2S) have been identified in percussion drill hole cuttings, assoc-iated with chalcopyrite. Sporadic surficial encrustations of malachite-azurite (Cu_2CO_3x OH) have also been noted on the property, resulting from the weathering of copper sulfide minerals. However, there is no supergene enriched blanket of secondary chalcocite.

Molybdenum occurs in the mineral molybdenite (MoS_2), and is much less abundant than is copper. Molybdenite is generally found with quartz as very fine joint-fracture filling veinlets, or as thin films (paint) on slickenside planes. Molybdenite occurs very rarely as fine rosette-like crystalline clusters in coarse grained quartz veins. Without exception, molybdenite appears as the latest sulfide mineral deposited.

Chalcopyrite mineralization occurs in three modes, which appear to be related to alteration zoning:

    1) Sporadic, discontinuous, high-grade chalcopyrite

stringers in coarse grained quartz veins are generally
located on the periphery of the quartz-sericite alteration
zone. The percent copper assay value for these high-grade
accumulations may range up to 15 percent.

2) Very fine (hairline to 1/16 inch) chalcopyrite vein-
lets associated with a quartz-calcite-epidote mineral
assemblage occur most consistantly in the thoroughly
jointed, sericite-quartz altered, coarse grained quartz
diorite, often intermixed with pyrite and less commonly
magnetite (Photomicrograph 6). The percent copper assay
value for this type of mineralization ranges from approx-
imately 0.1 to 0.5 percent.

3) Chalcopyrite is also found intricately intermixed with
pyrite and magnetite (with possible pyrrhotite) as fine
blebs in the breccia matrix in the tactite alteration zone,
and in massive sulfide accumulations on the southern mar-
gin of the property. These occurrences of chalcopyrite
are very limited and discontinuous, and may range from 0.1
to 0.7 percent copper locally.

Petrographic examination of polished thin sections from the massive
sulfide and tactite alteration zones apparently indicates two stages of
sulfide mineralization. Metallic minerals observed include relatively

Photomicrograph 6. Pyrite-magnetite veinlet, thin section K-18-B.
    Intermixed pyrite and magnetite in fine veinlet through mafic
    diorite. Note hematite alteration rim around pyrite.
    Approximate field of view, 1.5 x 2.0 mm., plain reflected
    light.

                                        Photo by Jerry Nelson

fresh, clean-looking primary pyrite, irregular large blebs and micro-fracture fillings of chalcopyrite cross-cutting the primary pyrite (Photomicrograph 7), and secondary pyrite carrying fine inclusions of chalcopyrite and magnetite intermixed in the pyrite matrix (Photomicrograph 8). The texture observed resembles the exsolution textures produced by the solid solution unmixing of immiscible copper-iron sulfide and iron oxide fractions during crystallization (Bastin, 1950; Park and MacDiarmid, 1970). Mineral assemblages of this sort are not uncommon, as reported by McKinstry (1959) in his compilation and conclusions on the phase relationships in the sulfide ore minerals, with respect to the copper-iron-sulfer-oxygen ternary system.

Copper sulfide mineralization appears to have occurred as a late stage in the alteration processes acting on the Silver Nail pluton in the area of the Kelsey Property. Alteration appears to have been controlled in a gross sense by the structure of the tabular, gently dipping pluton. Hydrothermal fluids appear to have percolated up the dip of, and parallel to, the core of the intrusive. The probable sequence of alteration and sulfide mineralization, as determined by field relationships, thin section petrographic examination, and interpreted paragenetic sequence is as follows:

1) Emplacement of the Silver Nail pluton, with late-stage shearing of the at least partly crystallized intrusive;

2) Hydrothermal alteration resulting from fluids emanat-

Photomicrograph 7. Chalcopyrite cross-cutting and filling micro-
     fractures in primary pyrite, polished section K-16-A.
     Magnification x 200, plain reflected light.
                                        Photo by Jerry Nelson

Photomicrograph 8. Primary pyrite (left), chalcopyrite bleb (top-
     center), and secondary pyrite with fine included chalcopyrite
     and magnetite exhibiting exsolution-like texture (right);
     polished section K-16-A. Magnification x 200, plain reflected
     light.

                                        Photo by M.W. Roper

ing from below the pluton, controlled by the structure of

the intrusive, and probably channelled along shear planes;

3) Potassium-rich, silicate hydrothermal alteration of

the core of the Silver Nail pluton, resulting in quartz-

K-spar flooding, sericitic alteration of plagioclase, and

sporadic, coarse grained quartzo-feldspathic dikes;

4) Cooling of the quartz flooded core of the pluton,

resulting in intense, closely spaced jointing and slight

fracturing;

5) Copper and iron-rich sulfide mineralization and hydro-

thermal alteration controlled by the structure of the Sil-

ver Nail pluton, resulting in fine chalcopyrite and pyrite

bearing quartz-calcite-epidote veinlets throughout the

quartz-sericite alteration zone, and forming sporadic high-

grade chalcopyrite accumulations in thick quartz veins on

the periphery of this zone;

6) Addition of molybdenum-rich sulfide fluids, probably

associated with slight shearing of the pluton, resulting in

very fine molybdenite-quartz veinlets, joint-fracture fil-

lings, and molybdenite 'paint' coated slickensides; and

7) Late hydrothermal ramming of fluids into the Silver

Nail pluton resulting in partial brecciation of the in-

trusive body, and producing the tactite and associated

massive sulfide alteration zones by the addition of iron
and copper-rich sulfide fluids.

The most consistent and continuous copper and molybdenum sulfide
mineralization occurs as closely spaced, joint-fracture-slickenside
filling veinlets, controlled by the gently dipping, tabular structure
of the Silver Nail pluton. This structural control over chalcopyrite
mineralization is demonstrated in Figures 7 and 8. These cross sec-
tions (which are roughly at right angles to one another, and intersect
at drill hole P-23) portray the tabular, layer-like nature of copper
metallization, parallel the core of the pluton. The most pervasive
chalcopyrite mineralization occurs in the coarse grained quartz dio-
rite, which also roughly corresponds to the quartz-sericite alteration
zone.

This relationship is further demonstrated in Figures 9 through 12.
Figure 9 is a geologic map of the Kelsey Property which shows the gen-
eral coincidence of surface copper mineralization with the coarse
grained quartz diorite. Figures 10 through 12 are maps of the property
on which composite percent copper has been contoured from drill hole
assay values. Figure 10 portrays the contour pattern of percent copper
composited from 0 to 100 feet below the surface. Figures 11 and 12
indicate contour patterns obtained from composite percent copper values
from 100 to 200, and 200 to 300 feet below the surface respectively.

Figure 7. Segment of geologic cross section B-B' (Plate II) connecting drill hole
assay values for copper in coarse grained quartz diorite. Approximate
scale, one inch equals 200 feet. White pattern 0-0.19% Cu, light gray
0.20-0.29% Cu, dark gray 0.30-0.50% Cu.

Looking Southwest

Figure 8. Segment of geologic cross section D-D' (Plate III) connecting drill hole assay values for copper in coarse grained quartz diorite. Approximate scale, one inch equals 200 feet. White pattern 0-0.19% Cu, light gray 0.20-0.29% Cu, dark gray 0.30-0.50% Cu.

Figure 9. Geologic map of the Kelsey Property, with pattern
indicating areas of most impressive surface copper
mineralization. Scale indicated by 1000 foot grid.

61

Figure 10. Map of the Kelsey Property contouring percent copper
from drill holes, composite assay values 0-100 feet
below surface. Scale indicated by 1000 foot grid.

Figure 11. Map of the Kelsey Property contouring percent copper
            from drill holes, composite assay values 100-200 feet
            below surface. Scale indicated by 1000 foot grid.

Figure 12.   Map of the Kelsey Property contouring percent copper
            from drill holes, composite assay values 200-300 feet
            below surface.   Scale indicated by 1000 foot grid.

Contour maps thus produced again demonstrate the coincidence of copper mineralization with the quartz diorite phase of the Silver Nail pluton. It should be noted, however, that the contour pattern observed may partly result from the non-random, biased drill hole array on the Kelsey Property. Certainly a more equidistant drill hole array would give a more statistically correct contour pattern.

Figures 13 through 15 are maps of the Kelsey Property contouring composite percent molybdenite (MoS_2) from drill hole assay data, again from 0 to 100, 100 to 200, and 200 to 300 feet below the surface respectively. To produce the contour patterns for molybdenite, the writer assumed that all assay data for molybdenum (Mo), as recorded on earlier drill logs, was for molybdenite (MoS_2), as recorded on Amex drill logs. The writer also somewhat arbitrarily set trace values, as recorded on earlier drill logs, as 0.005 percent molybdenite in order to obtain number values to contour.

Contour patterns thus produced further verify the previously observed coincidence of sulfide metallization with the quartz diorite phase of the Silver Nail pluton (and the quartz-sericite alteration zone), though as suggested above, the molybdenite contour patterns are highly interpretive.

Figure 13. Map of the Kelsey Property contouring percent molybdenite
from drill holes, composite assay values 0-100 feet below
surface. Scale indicated by 1000 foot grid.

Figure 14.   Map of the Kelsey Property contouring percent molybdenite
             from drill holes, composite assay values 100-200 feet
             below surface.   Scale indicated by 1000 foot grid.

Figure 15.   Map of the Kelsey Property contouring percent molybdenite
from drill holes, composite assay values 200-300 feet
below surface.   Scale indicated by 1000 foot grid.

Environment of Alteration-Mineralization:

Various conclusions pertaining to the chemistry of hydrothermal solutions and the conditions of temperature and pressure present during alteration and sulfide mineralization can be drawn from observed secondary mineral assemblages, paragenesis, and depositional textures. Comparison of alteration and sulfide mineral assemblages between numerous porphyry deposits has produced a pattern suggesting similar physical and chemical conditions associated with the hydrothermal processes (Creasy, 1966; Lowell and Guilbert, 1970; see Appendix).
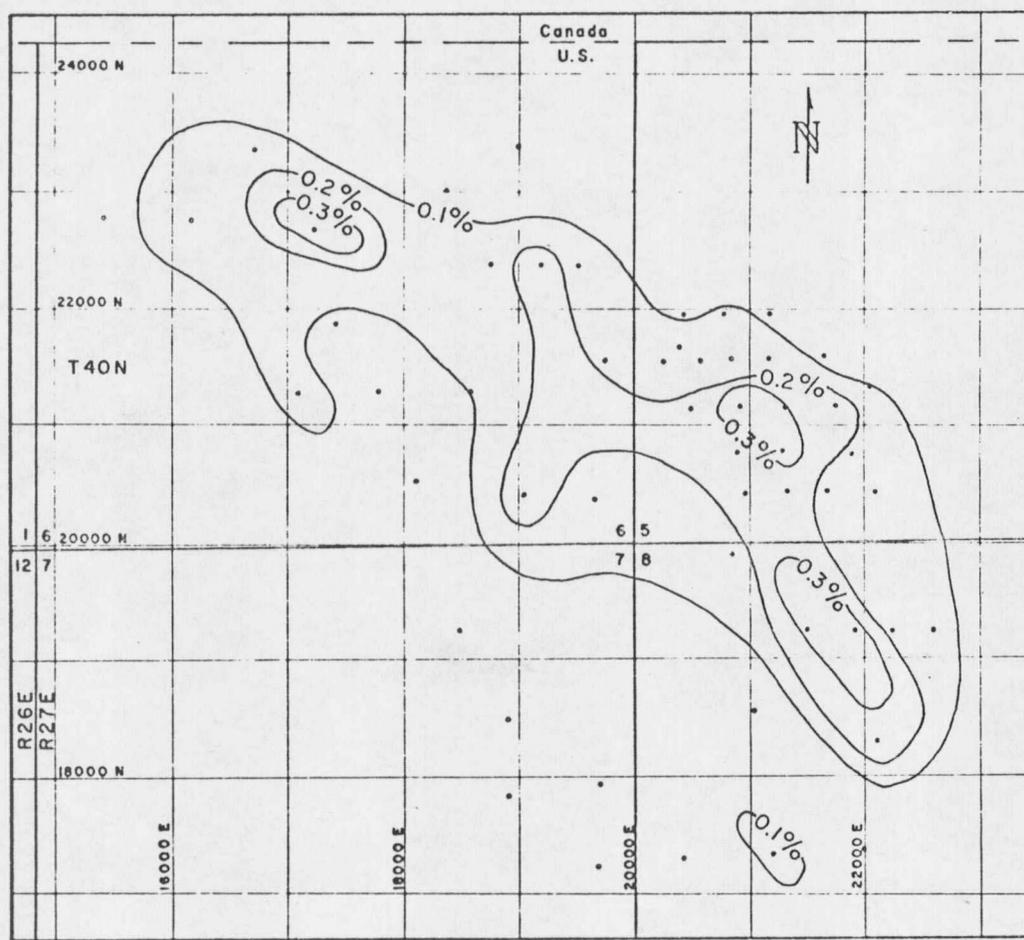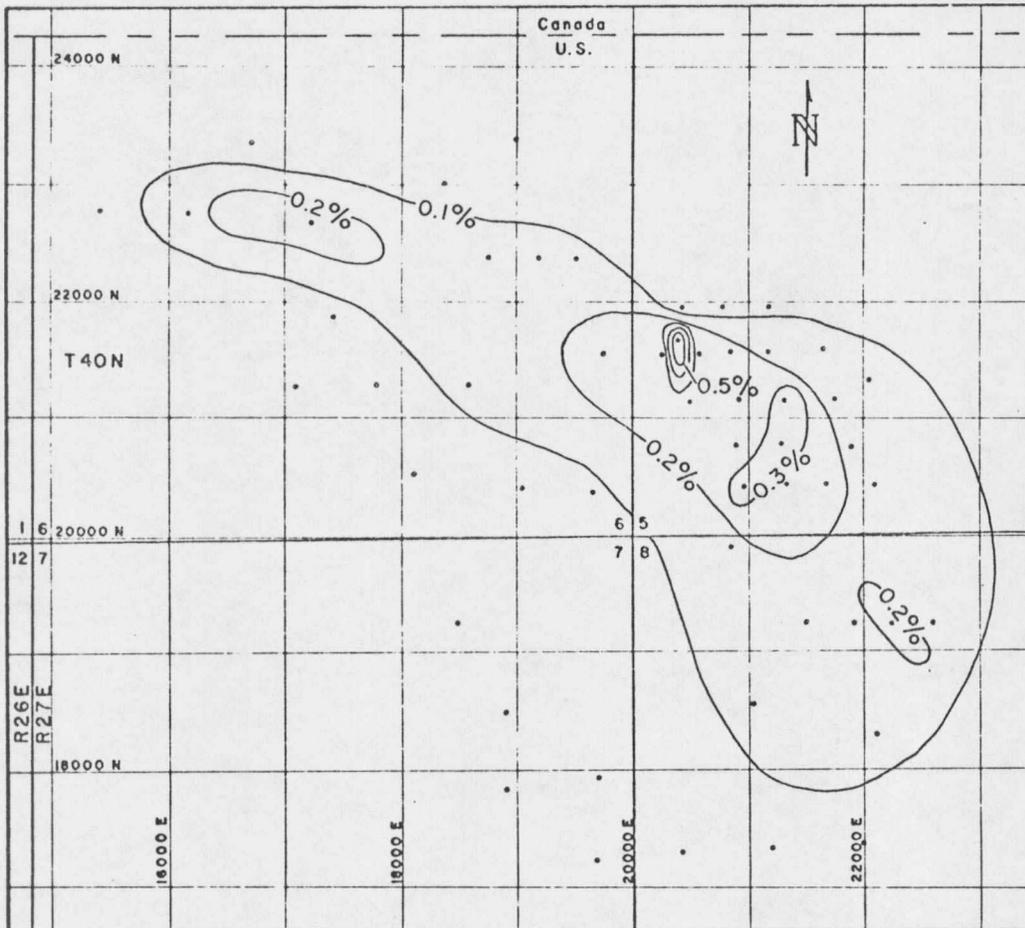
Interpretation of the physical conditions producing the observed hydrothermal mineralization associated with the porphyry deposits has yielded somewhat ambiguous results. Physical conditions determined by various investigators (Creasy, 1966) range in depth from 3000 to 12,000 feet, and vary in temperature from 175 to 650 degrees C. This range in conditions results from the variables which must be taken into account in the study of hydrothermal systems. These variables include:

1) Composition and structure of the host rock;

2) Temperature and pressure of hydrothermal solutions;

3) Constantly changing composition and concentration of hydrothermal solutions; and

4) Reaction time.

Chemical solutions producing hydrothermal alteration and sulfide

mineral deposition are thought to consist of two major types: aqueous saline solutions, and hydrous silicate melts (Smith, 1954). Aqueous saline solutions are divisible into two sub-types, one high in salts, the other high in carbon dioxide (CO_2). Hydrous silicate melt solutions are thought to be much less common, and are believed to represent the late silicate fraction of magmatic crystallization. Independent studies by Smith (1954) and Krauskopf (1957) have demonstrated that solutions are liquid rather than gas, as vapor transport alone cannot satisfactorily account for the origin of ore deposits. Helgeson (1964) and White (1968) further emphasize the importance of chemical complexing in the transport of dissolved metals in ore fluids.

The principal primary hydrothermal sulfide minerals occurring in the porphyry deposits include: pyrite, chalcopyrite, and molybdenite. The hydrothermal silicates generally observed include: clay minerals, muscovite (sericite), biotite, quartz, and K-spar (orthoclase and microcline). Other common alteration minerals are: magnetite, hematite, chlorite, the epidote group, and carbonate minerals.

Three major types of alteration are generally used to categorize the hydrothermal mineral assemblages associated with porphyry deposits. These are the propylitic, argillic, and potassic alteration types, summerized as follows from Creasy (1966) and Meyer and Hemley (1967):

1) Propylitic alteration is characterized by the minerals chlorite, calcite, epidote, and may include talc, kaolinite,

and sericite. This alteration assemblage is thought to
originate from CO_2-rich fluids, and has an upper temper-
ature limit of formation from 400 to 480 degrees C.

2) Argillic alteration is distinguished by the presence
of clay minerals of the kaolinite and montmorillonite
(smectite) groups, along with chlorite and sericite.
Indications of strong leaching of lime during the forma-
tion of this alteration type is evidenced by the absence
of the carbonate and epidote mineral groups. K-spar is
not considered stable under argillic alteration conditions.
The difference between propylitic and argillic alteration
is thought to be due to the chemistry of altering solutions
rather than temperature and pressure differences.

3) Potassic alteration is distinguished by the assemblage
sericite, secondary biotite, and secondary K-spar. Potas-
sic alteration originates from potassium-rich silicate
solutions in the temperature range of 400 to 585 degrees
C., though favorable concentrations of K^+ and H^+ ions can
result in potassic alteration at lower temperatures.

All hydrothermal fluids carry excess water and silica. Quartz,
therefore, can and generally does occur in all alteration phases.
Iron, copper, and molybdenum sulfide mineral assemblages, along with

iron oxides, may also occur in any alteration type, producing pyrite, chalcopyrite, bornite, molybdenite, hematite, and magnetite. It should also be emphasized that all minerals listed for a given alteration type need not be present. Alteration type is determined by the minerals observed, and there is considerable overlap between the propylitic, argillic, and potassic alteration mineral assemblages.

Hydrothermal alteration of the Kelsey Property appears to include two phases commonly observed in porphyry deposits: potassic and propylitic alteration. Depth of cover at the time of alteration and mineralization is estimated to be on the order of one mile. Field and petrographic examination suggest an initial potassic alteration phase (400 to 585 degrees C.), depositing quartz, K-spar, and sericite through the central core of the Silver Nail pluton, upon which a lower temperature (400 to 480 degrees C.) iron and copper-rich sulfide bearing propylitic alteration phase has been superimposed. This is evidenced by intense chloritization on the outer margins of the Silver Nail pluton, and chalcopyrite bearing quartz-calcite-epidote veinlets which cross-cut the potassic altered zone. Molybdenum-rich sulfide fluids were added late in the propylitic alteration phase. Late stage hydrothermal activity then formed the breccia phase of the pluton, and produced the tactite alteration zone and associated massive sulfides on the southern margin of the property.

Summary:

The Kelsey Property is a hydrothermally altered, copper-iron-molybdenum sulfide mineralized area. The most thoroughly altered rock unit is the Silver Nail pluton, a tabular, sill-like intrusive of dioritic composition. The hydrothermal fluids which altered and metalized the intrusive were apparently channelled and controlled by the structure of the pluton.

A gross, asymmetric alteration zoning pattern was observed on the Kelsey Property, as illustrated in Plate V and Figure 6 (p. 47) of this paper. Two alteration mineral groups dominate on the property area: quartz-calcite-epidote-chlorite, and quartz-K-spar-sericite. These alteration types correspond to the propylitic and potassic types respectively, as described and defined by Creasy (1966), Meyer and Hemley (1967), and others. These alteration types, along with argillic alteration, are commonly associated with porphyry deposits.

The chemical composition of solutions which may have produced the observed mineral assemblages has been discussed by Smith (1954), Schwartz (1959), Creasy (1966), and Meyer and Hemley (1967). Solutions producing propylitic and potassic alteration types are thought to consist of lower temperature CO_2-rich saline fluids, and higher temperature K-silicate acid solutions, respectively.

Metallic sulfide minerals may be deposited by either alteration phase. On the Kelsey Property, copper, iron, and molybdenum sulfides

were apparently precipitated and deposited with the propylitic phase as fine veinlets in the strongly fractured, previously potassic altered core of the Silver Nail pluton, and in sporadic quartz veins throughout the property area. Common minerals in the fine veinlets include pyrite, chalcopyrite, and associated magnetite enclosed in a quartz-calcite-epidote mineral assemblage.

The breccia phase of the pluton and the associated tactite and massive sulfide alteration zones apparently result from late stage hydrothermal brecciation, coincident with the addition of copper and iron sulfides. Petrographic examination of polished sections from the tactite and massive sulfide alteration zones demonstrates two phases of sulfide mineraliatoon, an initial phase depositing pyrite, and a secondary phase depositing chalcopyrite as coarse, irregular blebs, and as fine inclusions with magnetite in the secondary pyrite phase.

Of economic interest, the potassic altered quartz diorite core of the Silver Nail pluton carries the most consistent copper and molybdenum mineralization as closely spaced joint-fracture-slickenside filling veinlets. This relationship is indicated in Figures 7 through 15. The entire property area, and the quartz diorite core of the pluton in particular, has been explored and evaluated with percussion, rotary, and diamond drilling. The copper-molybdenum metallized area appears to have been delineated and surrounded, though possible extensions may exist to the east, beneath the alluvium-filled Okanogan River Valley.

CONCLUSION

Regional Interpretation

The general region of the Okanogan River Valley contains numerous
intrusive bodies, normally of acidic to intermediate composition, that
is monzonite to diorite. The intrusives vary in age from Triassic to
early Tertiary, and range in size from small masses less than one mile
in diameter to batholiths. The plutons are relatively unaltered, and
generally barren of pervasive hydrothermal sulfide mineralization.
Secondary mineralization, where observed in the region, is most common-
ly in the form of locally sulfide bearing quartz veins. The Silver
Nail pluton on the Kelsey Property is somewhat unique in the region,
having been moderately to intensely hydrothermally altered and metal-
lized with iron, copper, and molybdenum sulfide minerals.

The writer has attempted in this paper to determine whether the
mineralization observed on the Kelsey Property can be correlated with
the broad class of porphyry deposits in general, and British Columbia
porphyry deposits in particular. In order to successfully demonstrate
such a relationship, at least three types of similarity should be dem-
shown:

1) Regional setting;

2) Local geology; and

3) Type of alteration-mineralization.

Campbell and Tipper (1970) have convincingly argued that the struc-

ture of the Quesnel Trough partly controls the distribution of porphyry deposits in British Columbia. The Kelsey Property is situated in line with a reasonable southerly projection of the trough, and structural and tectonic relationships are relatively continuous from areas of known copper-molybdenum sulfide mineralization in British Columbia to the property. Regional intrusives are on the same scale, of similar rock type, and of the same general character in the Okanogan River Valley as those associated with the orebodies in British Columbia. Finally, the roughly linear distribution of porphyry deposits in British Columbia trending toward the Kelsey Property suggests a relationship.

The description of the geology of the Kelsey Property in this paper has shown the general similarity between its geology and that observed in typical British Columbia deposits, as described by Fahrni (1966). Similar features include: country rock type, general structure, intrusive relationships, lithologic ages, alteration mineral assemblages, and sulfide mineralization. Intruded rocks are roughly similar, Triassic to Jurassic age, eugeosynclinal sedimentary and volcanic rocks, metamorphosed to the greenschist facies. Regional scale intrusives of a similar character are present. Folding is not significant, but block faulting is common. Finally, a closely-spaced joint-fracture system is present to allow mineralization and alteration of the host rock.

Fine joint-fracture filling sulfide mineralization and the pervasive hydrothermal alteration observed on the Kelsey Property are simi-

lar to assemblages noted on various porphyry orebodies (Creasy, 1966; Fahrni, 1966). Sulfide minerals commonly include: pyrite, chalcopyrite, and molybdenite. Associated hydrothermal alteration (gangue) minerals include: magnetite, hematite, garnet, calcite, epidote, actinolite, clay minerals, and K-spar.

Similarities between alteration and mineralization of the Kelsey Property and typical British Columbia type porphyry deposits are far more common than differences. It seems reasonable to conclude that the property may indeed be a variety of the British Columbia porphyry type mineralization, the major difference being one of scale, that is volume of metallized rock.

The most recent theory on the source and control of the British Columbia porphyry deposits, put forth by Campbell and Tipper (1970), has previously been discussed in this paper. However, quite recently the theory of lithosphere plate tectonics, embodying the concepts of sea floor spreading, transform faulting, and underthrusting at continental margins and island arcs, has been employed as a speculative model for the origin and distribution in space and time of porphyry copper-molybdenum deposits on a world-wide scale.

Sillitoe (1972) suggests that porphyry ore deposits constitute a normal facet of calc-alkaline magmatism, and cites chemical and isotopic data consistent with the generation of calc-alkaline igneous rocks on underlying subduction zones at the elongate compressive junc-

tures between lithospheric plates in the Western Americas, Southwest Pacific, and Mideast orogenic belts (Figure 16).

It has further been proposed (Sillitoe, 1972) that the metals contained in porphyry deposits were derived from the mantle at divergent plate junctures (ocean rises) as associates of basic magmatism, and transported laterally to subduction zones as components of basaltic or gabbroic oceanic crust (Figure 17).

Sillitoe (1972) believes that the temporal and spatial distribution of porphyry ore deposits is dependent on three principal factors:

1) The availability of metals on the underlying subduction zones;

2) The time and location of magma generation; and

3) The erosion level of an intrusive-volcanic chain.

The possible relationship between the occurrence of porphyry ore deposits and lithospheric plate tectonics suggests the importance of analyzing orogenic belts in terms of plate tectonics with regard to copper-molybdenum exploration.

Summary of Geologic History

The purpose of this summary is to present in chronological order the major events which have affected the geologic evolution of the Kelsey Property. Partial sequences of geologic events have previously

Figure 16. Porphyry belts of the world in relation to Mesozoic-Cenozoic orogenic belts and accreting and consuming plate boundaries. (From Sillitoe, 1972)

Figure 17. Schematic representation of the genesis of porphyry copper deposits
produced by the mechanisms associated with plate tectonics. (From
Sillitoe, 1972)

been given in this paper. This summary will attempt to tie together all occurrences affecting the property in the regional setting of the Okanogan Valley, with the approximate age of events bracketed or dated as closely as possible (Figure 18).

The earliest recorded geologic activity on the property is the deposition of the oldest lithologic units in the area. The Anarchist Group and Kobau Formation were deposited in Permian-Triassic time (270-180 m.y.) as eugeosynclinal marine sediments. These units consist of siltstone, fine conglomerate, limestone, chert, and volcanics.

Beginning in mid-Permian time and continuing through the beginning of the Tertiary (250-70 m.y.), granitic plutonic rocks were emplaced in the eugeosynclinal sediments on a vast scale along the entire length of the Northern Cordillera. This large scale igneous activity in the buried sediments folded and regionally metamorphosed the rocks to the greenschist facies, producing slate, phyllite, marble, and greenstone.

Coincident with this large-scale intrusive activity were various structural-tectonic movements producing the present fault framework of the Northern Cordillera. Triassic to Jurassic (225-135 m.y.) movement along the linear, morth-south trending Okanogan Valley lineament may have in some way controlled the emplacement of the Silver Nail pluton.

The dioritic pluton was apparently emplaced as a tabular, sill-like body, possible partly controlled by foliation in the pre-existing Anarchist Group and Kobau Formation metasediments. Possible pulse-like

Figure 18. Age relationships of geologic events affecting the Kelsey Property.

emplacement is suggested by slight crushing and straining of plagio-
clase crystals, and by shearing generally parallel to the core of the
pluton.

Hydrothermal alteration, mineralization, and brecciation of the
Silver Nail pluton took place at some time between the Triassic-Juras-
ic crystallization of the intrusive, and the Tertiary emplacement of
the hornblende dacite porphyry plug on the western margin of the prop-
erty. However, if hydrothermal alteration originates from the same
magma chamber that produced the intrusive pluton, as is suggested by
many authors, it seems likely that the secondary mineralization process
must rather closely follow the emplacement of the pluton in order to
take advantage of the same fluid channel-ways. The writer, therefore,
considers the alteration-mineralization process to have taken place at
some time between late Triassic and late Jurassic time, closely fol-
lowing the emplacement of the Silver Nail pluton.

The probable sequence of alteration and sulfide mineralization on
the Kelsey Property is as follows:

1) Emplacement of the Silver Nail pluton, with late stage
shearing of the at least partly crystallized intrusive;

2) Hydrothermal alteration resulting from fluids emanat-
ing from the same magma chamber emplacing the pluton, con-
trolled by the structure of the intrusive, and probably
channeled along shear planes;

3) Potassium-rich, silicate (potassic) hydrothermal alteration of the core of the Silver Nail pluton, resulting in quartz-K-spar flooding, sericitic alteration of plagioclase, and sporadic coarse grained quartzo-feldspathic dikes;

4) Cooling of the silicate flooded core of the pluton, resulting in intense, closely spaced jointing and slight fracturing;

5) Copper and iron-rich sulfide mineralization and propylitic hydrothermal alteration controlled by the structure of the pluton, resulting in fine, chalcopyrite and pyrite bearing quartz-calcite-epidote veinlets throughout the fractured potassic altered zone, and forming sporadic high-grade chalcopyrite accumulations in quartz veins on the periphery of this zone;

6) Addition of molybdenum-rich sulfide fluids, probably associated with slight shearing of the pluton, resulting in very fine molybdenite-quartz veinlets, joint-fracture fillings, and molybdenite 'paint' coated slickensides; and

7) Late stage hydrothermal ramming of fluids into the Silver Nail pluton, resulting in partial brecciation of the intrusive body, and producing the tactite and associated massive sulfide alteration zones by the addition of iron and copper-rich sulfide hydrothermal fluids.

Structural and tectonic forces have acted upon the Kelsey Property contemporaneous with other geologic events. The probable structural sequence in the property is as follows:

1) Movement (strike-slip ?) along the north-south trending Okanogan Valley fault;

2) Emplacement of the tabular, multi-phase Silver Nail pluton, perhaps partly controlled by the Okanogan Valley fault;

3) Shearing of the Silver Nail pluton parallel its core, shortly followed by hydrothermal alteration and mineralization of the intrusive;

4) Regional, right-lateral, northeast-southwest trending, strike-slip faulting offsetting the Okanogan Valley fault at various places along its length, on the northern margin of the Kelsey Property in particular;

5) Subsequent formation of en echelon, joint-like fault traces exhibiting minor strike-slip movement parallel to the major offsetting, strike-slip faults;

6) Upward emplacement of the Kruger Mountain Tertiary hornblende dacite porphyry plug, along the major north-south trending normal fault on the western margin of the property;

7) Formation of subsequent, north-south trending, stair-

step normal faults across the Kelsey Property, east of the

major normal fault bounding the volcanic plug; and

8) Minor tensional crustal adjustments producing the

present, somewhat graben-like form of the Kelsey Prop-

erty, reemphasizing the joint-like, en echelon, northeast-

southwest fault traces, with slight normal fault movement

along the planes of weakness.

The final, major geologic event recorded in the Okanogan Valley and

the Kelsey Property is Quaternary (Pleistocene) glaciation, and assoc-

iated Recent periglacial activity. Glaciation was effected by the

Okanogan Lobe of the Cordilleran Ice Sheet, as described by Flint

(1935). Various Recent erosional and depositional actions have been

superimposed upon the Pleistocene glacial topography to produce the

present bench-like topographic configuration of the Kelsey Property.

Various Aspects of Mineral Exploitation

In any mineral exploitation enterprise, various economic, legal,

and environmental aspects must be considered (Flawn, 1966). Should the

Kelsey Property be brought into production, it would very likely be as

a low grade-high volume open-pit operation. The property would, there-

fore, possess all the problems associated with open-pit mineral extrac-

tion, plus several rather unique problems because of the position of

the property on the United States-Canada Border.

The geographic position of the property necessitates a working knowledge of international law, assuming mineralization both north and south of the border was exploited. The differences between Canadian and American mining law have been summarized by Ely (1961) and Macdonell (1965). Mineral law, of course, is a constantly changing factor as various legislatures make statutory changes from year to year. The major problems encountered with an international mining property would most likely be economic, associated with different tax structures, depletion allowences, and possible multiple taxation.

Environmental protection is an important consideration in any mining operation (Landau and Rheingold, 1971). Natural wildlife in the property area is limited to a few deer, numerous rodents, and a large snake population. It is doubtful that mining activities would harm or displace a significant animal population from the Kelsey Property.

Pollution of the air and water would perhaps be the most critical problem associated with any development of the Kelsey Property. The Okanogan Valley has two main industries, tourism concentrated on Osoyoos Lake, and fruit orchards on the alluvial margins of Osoyoos Lake and the Okanogan River. Therefore, particulate matter or noxious gases which would harm the fruit orchards or offend people would have to be controlled.

Prevention of water pollution would be a critical factor because of the proximity of Osoyoos Lake. Osoyoos Lake, which extends into Canada,

is a relatively unpolluted recreation area and source of much of the irrigation water for agriculture in the area. Precautions would have to be taken to prevent the addition of deleterious substances to the ground water and surface drainages on the property.

Certainly, if economic considerations can be met and the Kelsey Property is put into production, adequate environmental protection of the surrounding area can be designed and maintained in the mineral exploitation scheme to prevent any decrease in regional air or water quality. While the mining industry in general should not initiate mineral extraction schemes which are against the best interests of the public, a viable, competitive mining industry is a vital necessity for the maintainance of a stable technological nation. Therefore, mineral-ized areas must be open to exploration and exploitation where adequate environmental safeguards can be employed.

APPENDIX

Thin Sections Grouped According to Rock Type

(Position on Kelsey Property indicated on Plate V)

Coarse Grained Quartz Flooded Diorite:

sheared	unsheared	
10	21	108-A
20	23-A	112-B
23-B	38-A	157
38-B	41-A	160-A
43-C	43-A	179
45-A	45-B	283-A
53	51	285

Quartzo-Feldspathic Dikes:

18-D
41-C
50 ($\frac{1}{2}$)
108-B
198

Medium to Fine Grained Mafic Diorite:

11	72 ($\frac{1}{2}$)	94-B
18-A	73	192
18-B	75-A	198
36	75-B	199
49	75-C	
50 ($\frac{1}{2}$)	83	

Metamorphic Rocks:

27	94-A
41-B	112-A
41-D	155
43-B	160-B
44	234
72 ($\frac{1}{2}$)	274

Tactite Alteration
Associated with Breccia:

14	16-B	220
*15-A	18-C	222-A
15-B	*57	222-B
*16-A	*65	283

Explanation:

($\frac{1}{2}$)   Thin sections containing more than one rock type

*   Polished thin sections of massive sulfides

Definition of Porphyry Ore Deposits

The broad non-technical usage of the term 'porphyry deposit' has made it somewhat difficult to define. Parsons (1933) noted that a concise definition applicable to all such deposits was impractical, but cited several characteristics thought to be common to all of the orebodies:

1) The deposit is of such magnitude and shape that it can be mined advantageously by large-scale, low-per-ton cost methods, either by underground block-caving or in open pits;
2) The copper minerals are distributed so uniformly through large sections or blocks of the deposit that it is more profitable to mine by bulk methods than by the selective methods of the so-called vein or bed mines;
3) An intrusion of porphyry, or closely related igneous rock, has played a vital part in the genesis of the ore, though the porphyry itself may not constitute the major part of the deposit;
4) The geologic process known as secondary enrichment has operated to concentrate the copper, resulting in a zone of leached capping overlying the main body of ore, which typically is enriched with chalcocite; and
5) The zone of secondary enrichment is typically underlain by a zone of primary and unenriched material called 'protore'.

Bateman (1950) listed similar characteristics for the porphyry copper deposits of the American Southwest in his treatment of economic mineral deposits, summarized as follows:

1) Low grade;
2) Large-scale, low-cost methods of mining;
3) Associated with stock-like intrusions of monzonitic porphyries;
4) Disseminated replacements in porphyry or intruded schist;
5) Blanket shape, greater horizontal than vertical dimensions;

6) Similar primary mineralogy (pyrite, chalcopyrite,
bornite ?, and possible molybdenite);
7) Intense sericitization and local silicification;
8) Overlain by leached cappings (limonite gossan);
9) More or less supergene enrichment (secondary chal-
cocite); and
10) Similar modes of origin.

The probable origin of a typical porphyry copper deposit has been

described by Emmons (1940), as follows:

1) Intrusion of an acidic or intermediate stock;
2) Cooling of the upper part of the stock;
3) Fracturing and shattering of a part of the stock.
The fractured part may be an upright cylinder, generally
with the orebody elongated parallel to the long axis of
the stock or to a finger of it. In several deposits, the
invaded marginal rocks as well as the intrusive are shat-
tered, mineralized, and ore-bearing;
4) Fluids rise into the fractured body, hydrothermally
altering it greatly by deposition of quartz, sericite, and
local orthoclase. Pyrite, chalcopyrite, and other sul-
fides are deposited. The minerals fill closely spaced
cracks and replace parts of the wall rocks;
5) Erosion and oxidation follow. At the surface and in
the vadose zone, pyrite, chalcopyrite, and other minerals
are dissolved, and copper is carried downward to be re-
deposited near and below the water table, chiefly as chal-
cocite. Silicates are altered to kaolin, and gypsum forms
from calcite. The supergene sulfide ore forms a blanket
between the leached zone and the hypogene ore, and grades
into the latter by decrease of chalcocite;
6) The surface outcrop, leached, and supergene ore zones
move downward as erosion proceeds. Some chalcocite is
oxidized, but copper becomes more and more concentrated
below the leached zone, enriching and extending the zone
of sulfide ore.

The most recent description and definition of porphyry deposits,

which includes both geologic and economic considerations, has been

given by Lowell and Guilbert (1970), quoted as follows:

> A porphyry deposit is here defined as a copper and/or
> molybdenum sulfide deposit consisting of disseminated and
> stockwork veinlet sulfide mineralization emplaced in var-
> ious host rocks that have been altered by hydrothermal
> solutions into roughly concentric zonal patterns. The
> deposit is generally large, on the scale of several thou-
> sands of feet, although smaller occurrences are recog-
> nized. The relatively homogeneous and commonly roughly
> equidimensional deposit is associated with a complex,
> passively emplaced stock of intermediate composition in-
> cluding porphyry units. It contains significant amounts
> of pyrite, chalcopyrite, molybdenite, quartz, and sericite
> associated with other alteration, gangue, and ore minerals
> and metals including minor lead, zinc, gold, and silver.
> Mineralization and alteration suggest a late magmatic to
> mesothermal temperature range. The deposit is generally
> associated with breccia pipes, usually with a large crack-
> le brecciation zone, and is surrounded by peripheral min-
> eral deposits suggestive of lower temperature mineraliza-
> tion.
>
> The grade of primary mineralization in typical porphyry
> copper deposits ranges up to 0.8% Cu and 0.02% Mo, and por-
> phyry deposits in which molybdenite is the chief economic
> mineral have grades ranging up to 0.6% Mo and 0.05% Cu.
> All porphyry copper deposits contain at least traces of
> molybdenite, and all porphyry molybdenum deposits contain
> some chalcopyrite. Many deposits contain recoverable
> quantities of both minerals, either in separate orebodies
> or in ore with approximately equal copper and molybdenum
> dollar values. Although typical porphyry copper deposits
> differ from typical molybdenum deposits in some respects,
> the existence of gradational characteristics in metalliz-
> ation suggests a common origin.

Literature of particular application to porphyry ore deposits which
further provide encyclopedic reference lists include: Titley and Hicks
(1966), Lowell and Guilbert (1970), Clark (1972), and Kessler (1973).

REFERENCES CITED

Bastin, E.S. (1950) Interpretation of ore textures: Geol. Soc. Amer., Mem. 45.

Bateman, A.M. (1950) Economic mineral deposits: John Wiley & Sons, New York, p. 486.

Bilibin, G.A. (1955) Metallogenic provinces and eras, transl.: Geol. Surv. Can. Library.

Bostock, H.S. (1948) Physiography of the Canadian Cordillera: Geol. Surv. Can., Mem. 247.

British Columbia Natural Resource Conference (1956) British Columbia atlas of resources: Smith Lithograph Co., Ltd., Vancouver, 92 p.

Bryner, L. (1961) Breccia and pebble columns associated with epigenetic ore deposits: Econ. Geol., v. 56, p. 488-508.

Cameron, E.N. (1961) Ore microscopy: John Wiley & Sons, New York, 243 p.

Campbell, R.B. (1961) Quesnel Lake, west half, British Columbia: Geol. Surv. Can., Map 3-1961.

——————————— (1963) Quesnel Lake, east half, British Columbia: Geol. Surv. Can., Map 1-1963.

——————————— (1966) Tectonics of the south central cordillera of British Columbia in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, Map.

——————————— and Tipper, H.W. (1966) Bonaparte River, British Columbia: Geol. Surv. Can., Map 3-1966.

——————————— and Tipper, H.W. (1970) Geology and mineral exploration potential of the Quesnel Trough, British Columbia: Can. Inst. Min. Met., Transactions, v. 73, p. 785-790.

Clark, K.F. (1972) Stockwork molybdenum deposits in the western cordillera of North America: Econ. Geol., v. 67, p. 731-758.

Creasy, S.C. (1966) Hydrothermal alteration in Geology of the porphyry copper deposits: Univ. Ariz. Press, Tucson, p. 51-74.

Dewey, J.F. and Bird, J.M. (1970) Mountain belts and the new global
    tectonics: Jour. Geophys. Res., v. 75, p. 2625-2647.

Ely, N. (1961) Summary of mining and petroleum laws of the world:
    U.S. Bur. Mines, Inf. Circ. 8-17, 215 p.

Emmons, W.H. (1940) The principles of economic geology: McGraw-Hill
    Book Co., New York, p. 287.

Fahrni, K.C. (1966) Geological relations at Copper Mountain, Phoenix
    and Granisle Mines in Tectonic history and mineral deposits of the
    western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 315-320.

Fenneman, N.M. (1931) Physiography of the Western United States:
    McGraw-Hill Book Co., New York, p. 200-205.

Flawn, P.T. (1966) Mineral resources: Rand-McNally & Co., New York,
    406 p.

Flint, R.F. (1935) Glacial phenomena in Okanogan County, Washington:
    Geol. Soc. Amer. Bull., v. 46, p. 169-194.

Fox, K.F. and Rinehart, C.D. (1971) Distribution of copper and other
    metals in gully sediments of part of Okanogan County, Washington:
    U.S. Geol. Surv., Open File Report.

Gabrielse, H. and Reesor, J.E. (1964) Geochronology of plutonic rocks
    in two areas of the Canadian Cordillera in Geochronology in Canada:
    Royal Soc. Can., Spec. Pub. 8, p. 96-138.

Gilluly, J. (1963) Tectonic evolution of the Western United States:
    Geol. Soc. London, Quart. Jour., v. 119, p. 133-174.

-------------- (1965) Volcanism, tectonism and plutonism in the Western
    United States: Geol. Soc. Amer., Spec. Paper 80.

Helgeson, H.C. (1964) Complexing and hydrothermal ore deposition:
    MacMillan Co., New York.

Kents, P. (1964) Breccias associated with hydrothermal deposits: Econ.
    Geol., v. 59, p. 1551-1563.

Kerr, P.F. (1959) Optical mineralogy: McGraw-Hill Book Co., Inc., New
    York, 442 p.

Kessler, S.E. (1973) Copper, molybdenum and gold abundances in porphyry copper deposits: Econ. Geol., v. 68, p. 106-112.

King, P.B. (1969) Tectonics of North America: U.S. Geol. Surv., Prof. Paper 628-A, p. 65-69.

Krauskopf, K.B. (1941) Intrusive rocks on the Okanogan Valley and the problem of their correlation: Jour. Geol., v. 49, p. 1-53.

—————————— (1957) The heavy metal content of magmatic vapor at 600 degrees C.: Econ. Geol., v. 52, p. 786-807.

Landau, N.J. and Rheingold, P.D. (1971) The environmental law handbook: Ballantine Books, Inc., New York, 496 p.

Lowell, J.D. and Guilbert, J.M. (1970) Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373-408.

Macdonell, H. (1965) Comparative analysis of American and Canadian hard mineral laws in Tenth Annual Rocky Mountain Mineral Law Inst.: Matthew Bender & Co., New York, p. 423-466.

Mathews, W.H. (1964) Potassium-argon age determination of Cenozoic rocks from British Columbia: Geol. Soc. Amer. Bull., v. 75, p. 465-468.

McKinstry, H. (1959) Mineral assemblages in sulfide ores: Econ. Geol., v. 54, p. 975-1001.

Meyer, C. and Hemley, J.J. (1967) Wall rock alteration in Geochemistry of hydrothermal ore deposits: Holt, Rinehart & Winston, Inc., New York, p. 166-235.

Moore, J.G. (1959) The quartz diorite boundary line in the Western United States: Jour. Geol., v. 67, p. 198-210.

Moorhouse, W.W. (1959) The study of rocks in thin section: Harper & Row, Inc., New York, 514 p.

Ney, C.S. (1966) Distribution and genesis of copper deposits in British Columbia in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 295-303.

Park, C.F. and MacDiarmid, R.A. (1970) Ore deposits: W.H. Freeman & Co., San Francisco, 582 p.

Parsons, A.B. (1933) The porphyry coppers: Amer. Inst. Min. Met. & Petrol. Engrs., First Ed., p. 7.

Perry, V.D. (1961) The significance of mineralized breccia pipes: Min. Engrg., v. 13, p. 367-376.

Petroscheck, W.E. (1965) Typical features of metallogenic provinces: Econ. Geol., v. 60, p. 1620-1634.

Rinehart, C.D. and Fox, K.F. (in press) Geology and mineral deposits of the Loomis Quadrangle, Okanogan County, Washington: Wash. Div. Mines and Geol. Bull.

Schwartz, G.M. (1959) Hydrothermal alteration: Econ. Geol., v. 54, p. 161-183.

Sillitoe, R.H. (1972) A plate tectonic model for the origin of porphyry copper deposits: Econ. Geol., v. 67, p. 184-197.

Smirnov, V.I. (1968) The sources of the ore-forming fluid: Econ. Geol., v. 63, p. 380-389.

Smith, F.G. (1954) Composition of the vein forming fluids from fluid inclusion data: Econ. Geol., v. 49, p. 205-210.

Snook, J.R. (1965) Metamorphic and structural history of the Colville Batholith gneisses, North-Central Washington: Geol. Soc. Amer. Bull., v. 76, p. 380-389.

Sullivan, J. (1957) Ore and granitization: Econ. Geol., v. 43, p. 471-498.

Tipper, H.W. (1959) Quesnel, British Columbia: Geol. Surv. Can., Map 12-1959.

—————————— (1960) Prince George, British Columbia: Geol. Surv. Can., Map 49-1960.

Titley, S.R. and Hicks, C.L. (1966) Geology of the porphyry copper deposits: Univ. Ariz. Press, Tucson, 287 p.

Turneaure, F.S. (1955) Metallogenic provinces and epochs: Econ. Geol., 50th Anniv. Vol., p. 38-91.

Waters, A.C. and Krauskopf, K.B. (1941) The protoclastic border of the Colville Batholith: Geol. Soc. Amer. Bull., v. 52, p. 1355-1418.

Wheeler, J.O. (1966) Eastern tectonic belt of the western cordillera in British Columbia in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 27-46.

White, D.E. (1968) Environments of generation of some base metal ore deposits: Econ. Geol., v. 63, p. 301-335.

White, W.H. (1966) Problems of metallogeny in the western cordillera in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 349-353.

——————————, Erickson, G.P., Northcote, K.E., Dirom, G.E., and Harakal, J.E. (1967) Isotopic dating of the Guichon Batholith, British Columbia: Can. Jour. Earth Sci., v. 4, p. 677-690.

Wisser, E. (1960) Relation of ore deposition to doming in the North American Cordillera: Geol. Soc. Amer., Mem. 77.

Woodcock, J.R., Bradshaw, B.A., and Ney, C.S. (1966) Molybdenum deposits at Alice Arm, British Columbia in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 335-339.

Yates, R.G., Becraft, G.E., Campbell, A.B., and Pearson, R.C. (1966) Tectonic framework of Northeastern Washington, Northern Idaho, and Northwestern Montana in Tectonic history and mineral deposits of the western cordillera: Can. Inst. Min. Met., Spec. Vol. 8, p. 47-60.

LITHOLOGIC UNITS

Qal	Quaternary alluvium and glacial drift
Td	Tertiary hornblende dacite porphyry
Tcs	Tertiary granodioritic boulder conglomerate
JTrsb	Intrusive breccia unit and associated tactite mineralization
JTrsg	Medium to coarse grained locally porphyritic quartz diorite
JTrsm	Fine to medium grained locally mafic diorite
TrPm	Triassic-Permian metamorphic greenstone, quartzite, phyllite, marble, undiff.
Mts	Pre-Silver Nail Pluton tuff-siltstone unit visible only in drill holes

Jurassic-Triassic Silver Nail Pluton

EXPLANATION

Rock contacts; definite, inferred

Faults, showing relative movement

A—∿—A'   Geologic cross section line

Strike-Dip Symbols
- rock contacts
- igneous and metamorphic foliation
- shear trend
- sulfide bearing vein

Drill Holes
- P-4   Canadian Superior percussion
- R-5   Canadian Superior rotary
- K-3   St. Joe core
- 70   Amex core (nos. 54, 64, 70)
- 59   Amex percussion (remaining nos.)

Roads
- paved highway
- improved dirt
- unimproved vehicle trail

Plate I
Geologic Map (U.S.)

Kelsey Property
Okanogan County, Washington
Base Map: Enlarged USGS 15' Oroville, Wash., Quadrangle

January 1973   1" = 400'   1:4800   M. W. Roper

TRUE MAG
21.5°
N

U.S.-Canada Border
Port of Entry
OSOYOOS LAKE
OSOYOOS LAKE
Silver Nail Lake
Kruger Mtn.
Hot Lake
Swamps
Swamp

TrPm   JTrsm   Qal   Tcs   Td   JTrsg   JTrsb

T 40 N
R 26 E   R 27 E

LITHOLOGIC UNITS

Qal	Quaternary alluvium and glacial drift
Td	Tertiary hornblende dacite porphyry
Tcs	Tertiary granodioritic boulder conglomerate
JTrsb	Intrusive breccia unit and associated tactite mineralization
JTrsg	Medium to coarse grained locally porphyritic quartz diorite
JTrsm	Fine to medium grained locally mafic diorite
TrPm	Triassic-Permian metamorphic greenstone, quartzite, phyllite, marble, undiff.
Mts	Pre-Silver Nail Pluton tuff-siltstone unit

Jurassic-Triassic Silver Nail Pluton

EXPLANATION

	Rock Contacts
T	Faults showing relative movement, with 'T' indicating strike-slip movement toward viewer
	Shear zones
P-23	Canadian Superior percussion drill holes
R-1	Canadian Superior rotary drill holes
K-7	St. Joe core drill holes
70	Amex core drill holes (nos. 54, 64, 70)
62	Amex percussion drill holes (remaining nos.)

A — Looking N — A'

B — Looking N — B'

C — Looking N — C'

Plate II
Geologic Cross Sections

Kelsey Property

Okanogan County, Washington

1" = 400'   1:4800

January 1973   M. W. Roper

LITHOLOGIC UNITS

| Qal | Quaternary alluvium and glacial drift |

| Td | Tertiary hornblende dacite porphyry |

| Tcs | Tertiary granodioritic boulder conglomerate |

| JTrsb | Intrusive breccia unit and associated tactite mineralization |

| JTrsg | Medium to coarse grained locally porphyritic quartz diorite |

| JTrsm | Fine to medium grained locally mafic diorite |

| TrPm | Triassic—Permian metamorphic greenstone, quartzite, phyllite, marble, undiff. |

| Mts | Pre-Silver Nail Pluton tuff-siltstone unit |

Jurassic-Triassic Silver Nail Pluton

E — E'

2000
1600
1200
800
400

56 60 61 62 65 70 69 K-3 K-5

Granite Hornfels
Quartz Monzonite
JTrsg JTrsm TrPm JTrsg JTrsm TrPm JTrsg
TrPm Mts
TrPm Mts

-20000 N

Looking SW

EXPLANATION

Rock Contacts

Faults showing relative movement, with 'T' indicating strike-slip movement toward viewer

Shear zones

P-23	Canadian Superior percussion drill holes
R-1	Canadian Superior rotary drill holes
K-7	St. Joe core drill holes
70	Amex core drill holes (nos. 54, 64, 70)
62	Amex percussion drill holes (remaining nos.)

D — D'

See Figure 6.
See Figure 8.

1600
1200
800
400

K-6 P-4 P-7 P-9 P-23 K-2 P-16 74

Tcs TrPm JTrsb JTrsm JTrsg JTrsm
Mts Mts

-20000 N

Looking SW

Plate III
Geologic Cross Sections

Kelsey Property

Okanogan County, Washington

1" = 400'

January 1973   1:4800   M. W. Roper

TRUE   MAG

21.5°

N

LITHOLOGIC UNITS

| Qal | Quaternary alluvium and glacial drift |

| Klp | Gneissic quartz diorite to granodiorite | Lakeview Pluton |

| JTrsm₁ | Medium grained felsic to fine grained mafic diorite | Mafic diorite phase Silver Nail Pluton (JTrsm) |
| JTrsm₂ | Very fine grained mafic diorite | |

TrPm₁	Phyllitic greenstone
TrPm₂	Complex intermixed limestone, chert, and calcareous greenstone	Undifferentiated Triassic-Permian metamorphic rocks (TrPm) on U.S. geologic map
TrPm₃	Schist and slaty beds
TrPm₄	Calcareous schist

EXPLANATION

Rock Contacts

Faults, thrusts with symbol on upper plate

rock contacts, foliation, bedding

sulfide bearing veins

shear trend

Strike-Dip Symbols

7.6   Amex percussion drill holes

Improved dirt roads

Unimproved vehicle trails

Note: Numerous unlabeled bodies of JTrsm₂ included in JTrsm₁ unit.

Plate IV
Geologic Map (Can.)

Kelsey Property
South Central British Columbia

Base Map: Enlarged B.C. Topographic Maps 82E/3, 82E/4

January 1973   1"=400'
1:4800

M. W. Roper

Geology by D.P. Simpson, Osoyoos Mines, 1940, partly field checked and expanded upon by the writer

Canada - U.S. Border

K-75   K-73
        K-72
                        K-27   U.S.-Canada Border

K-94   K-83
                                                                    N

K-20   SILICIFIED
                        SERICITE   K-36   CHLORITIZED ZONE
K-21   ZONES

            K-23

                        K-108
                Tertiary
                Sediments   Quaternary
                                              K-112   K-50   Alluvium
                                                      K-49   K-155
                                                                                    EXPLANATION
                                                      K-156
                                                      K-157
                        K-38   SILICIFIED SERICITE ZONE
                                                      K-10
Tertiary   K-51   Alteration zone boundaries
                        K-179
                                                              K-192
Volcanics   K-181   K-192 Thin section sample positions
                                      K-160
(Plug)   K-41   Paved highway
                        K-44
                        K-43   K-45   K-198
                                                      K-11   Improved dirt roads
                                                      K-199
                                      K-53   K-18   Unimproved vehicle trails
                        K-274 K-283
                                                              CHLORITIZED
                                      K-222   ZONE   P-7   Canadian Superior percussion
                        K-220   TACTITE K-234
                                      ZONE   R-1   Canadian Superior rotary
                                K-285   K-14   K-1   St. Joe core
PARTLY CHLORITIZED   70   Amex core (54, 64, 70)
                                                                                         60   Amex percussion (remaining nos.)
METAMORPHIC ROCKS

                                              K-15
                                              K-16

                                                                        Tertiary
                                      SULFIDE ZONE   K-57   Sediments
                                                                                   Plate V
                                                                                   Alteration Map
            K-65
                                                                                   Kelsey Property
      MASSIVE   Okanogan County, Washington
                                                                                   Base Map: Enlarged USGS 15' Oroville, Wash. Quadrangle

                                                                                   January 1973   1"=400'   M. W. Roper
                                                                                                   1:4800

INTERLIBRARY LOAN

MAY 13 REC'D
INTERLIBRARY LOAN

INTERLIBRARY LOAN

INTERLIBRARY LOAN

2 WEEKS USE

NAME AND ADDRESS

INTERLIBRARY LOAN
RALPH E. GREEN
236 So. main, Cedar City, Utah

INTERLIBRARY LOAN
INTERLIBRARY LOAN

INTERLIBRARY LOAN

INTERLIBRARY LOAN

RLIBRARY LOAN

N378
R682
Cop. 2