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GEOLOGY AND GEOCHEMISTRY OF THE ALICE ARM MOLYBDENUM DEPOSITS

J. R. Woodcock[1] and N. C. Carter[2]

ABSTRACT

A number of molybdenum-bearing granitic stocks, referred to as the Alice Arm intrusions, are emplaced in sedimentary rocks marginal to the east contact of the Coast Plutonic Complex between Stewart and Terrace. Several deposits are known in the vicinity of Alice Arm, of which the most important is Lime Creek.

The Alice Arm intrusions occur as small stocks of quartz monzonite porphyry, most of which exhibit the features of multiple intrusion. All plutons are cut by lamprophyre dykes of post-mineral age. Sedimentary rocks adjacent to stock contacts are thermally metamorphosed to biotite hornfels.

Several stages of molybdenite mineralization are contained in quartz veinlet stockworks best developed near stock contacts. Late stage polymetallic veins are known at most deposits.

Geochemical investigations of the Lime Creek deposit show that distribution patterns for alteration minerals and geochemical elements define the main geological events inasmuch as some elements correlate with original unaltered rock while others are related to contact metasomatism or stages of hydrothermal alteration and mineralization.

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[1] J. R. Woodcock Consultants Ltd.

[2] B.C. Department of Mines and Petroleum Resources.

PROPERTY FILE

K-Ar ages indicate that the age of intrusion and mineralization are nearly synchronous at about 53 m y.

INTRODUCTION

A number of porphyry molybdenum deposits and prospects occur along the eastern margin of the Coast Plutonic Complex between Stewart and Terrace in northwestern British Columbia (Figure 1). The greatest clustering of these deposits is in the vicinity of Alice Arm, at the head of an inlet of the same name 160 km north of Prince Rupert. To date, the most significant of these deposits is the former producing mine, British Columbia Molybdenum, situated on Lime Creek 6.5 km south of Alice Arm (Figure 1).

This paper is divided into two parts: the first part describes the general geological setting of the molybdenum deposits while the second part is devoted to a more extensive description of each deposit, and in particular the geology and geochemistry of the Lime Creek deposit.

HISTORY

Molybdenite mineralization in the Alice Arm area was first recognized during early prospecting for silver-bearing veins. Part of the Lime Creek deposit was first staked in 1911 by W. McLean but the main feature of interest at that time was a narrow silver-lead-zinc vein later determined to be peripheral to the molybdenite deposit.

The first molybdenite production in the area was from the Tidewater deposit in 1916 (Figure 1) where 345 tonnes averaging 1.60 percent molybdenite was mined from quartz veins in sedimentary rocks just south of a small granitic stock.

Intensive exploration for molybdenite deposits took place in the late 1950's when Kennco Explorations, (Western) Limited did limited work on the Roundy Creek and Tidewater properties and, in 1959, acquired an option on claims at Lime Creek from Gunn Fiva of Alice Arm. Diamond drilling was carried out from 1959 to 1963 when British Columbia Molybdenum Limited, a wholly owned subsidiary, was incorporated. A decision to put the property into production was made in late 1964. Mining and milling operations began in 1967 and were suspended in August 1972 due to weak molybdenum markets. Production totalled 10,400 tonnes of molybdenum. Remaining reserves are estimated to be in the order of 36 million tonnes of slightly less than 0.20 percent molybdenite.

Climax Molybdenum Corporation of British Columbia, Limited acquired the property in 1973 and has been conducting geological and feasibility studies since that time.

Exploration in the area for similar deposits during the 1960's resulted in the discovery of several good prospects including the Ajax, Bell Molybdenum, and Roundy Creek properties in the immediate Alice Arm area and a number of other prospects such as the THM, Hoan Creek, and those south of the Nass River (Figure 1).

GEOLOGICAL SETTING

Molybdenum-bearing granitic stocks, referred to collectively as the Alice Arm intrusions (Carter, 1974), occur near the western edge of the Bowser successor basin and marginal to the Coast Plutonic Complex (Figure 1). The Alice Arm intrusions occur in the form of small stocks, generally not exceeding 0.8 km in diameter. Porphyritic quartz monzonite is the dominant rock type, and this distinguishes the molybdenum-bearing stocks from equigranular satellitic stocks related to the Coast Plutonic Complex. While molybdenum-bearing stocks generally intrude Bowser assemblage siltstones, greywackes, and shales of Late Jurassic age, some do occur within the Coast Plutonic Complex. Examples of these are Molly Mack and Penny Creek prospects.

Evidence for both forceful and passive emplacement of the intrusions is well documented. In the Alice Arm area, sedimentary rocks have been arched and domed around the stocks. Elsewhere, little disturbance of the country rock is seen and the elongate nature of some of the intrusions indicates that they probably were emplaced along major fault zones.

South of Alice Arm, several molybdenum-bearing stocks are clustered near remnants of flat-lying Quaternary basalt which probably overlie their feeders. In the Nass River area, small stocks occur south and west of the Recent lava flow.

Many of the stocks apparently have been localized at or near intersections of east-northeast and north-northwest faults (Seraphim, et al., this volume). Several of the stocks (Bell Molybdenum, Roundy Creek, Kay) in the Alice Arm to Nass River area are elongated in an east-northeast direction which may also represent some control by faults or by the attitude of the sedimentary rocks. Also, a crude east-northeast distribution of the stocks is evident in the cluster south of Alice Arm and south of the Nass River (Figure 1). Some stock contacts are rectilinear in plan, again reflecting the dominant fault and fracture patterns. A good example of this is seen at the Ajax molybdenum deposit northeast of Alice Arm (Figure 2).

COMPARATIVE GEOLOGY OF THE MOLYBDENUM DEPOSITS

Molybdenum deposits are associated with the Alice Arm intrusions, which usually occur as small oval or elongate stocks. Some intrusions, most notably those at Roundy Creek and Tidewater near Alice Arm, are sheet or sill-like in form and are related to small feeder pipes. Intrusions at Alder Creek, near Lava Lake (Figure 1) and Molybdenum Creek, north of Terrace, are northwest-striking dyke swarms intruding sedimentary rocks. Major geologic features of four deposits are illustrated on Figure 2.

Quartz monzonite porphyry is the prevalent host rock at most deposits. Phenocrysts range in size from 2 mm to 1 cm and include, in decreasing order of abundance, euhedral plagioclase, K-feldspar, and both euhedral and anhedral quartz eyes. Quartz monzonite porphyry is characteristically mesocratic with both biotite and hornblende as primary mafic minerals. Leucocratic quartz feldspar porphyry phases of quartz monzonite to granite composition also are prominent at most of the deposits and at some they constitute the bulk of the intrusive rocks. Muscovite is the mica mineral of this phase.

Some intrusions are zoned, most notably the intrusion that is host to the Lime Creek deposit. Here, a core of quartz monzonite porphyry is bordered by more basic granodiorite and quartz diorite, which may be in part older than the quartz monzonite phase.

Most molybdenum-bearing stocks exhibit several stages of intrusion. The first stage forms the bulk of the stock and is represented by quartz monzonite and/or quartz feldspar porphyry and lesser quartz diorite such as Lime Creek. This main phase may be intruded by fine-grained, equigranular alaskite that consists essentially of quartz, K-feldspar, and myrmekite. Alaskites, which are very common at the Lime Creek and Roundy Creek properties (Figure 2), occur as dykes and irregular masses and are host to better grades of disseminated and lens-like molybdenite mineralization.

Other inter-mineral intrusions include dykes and irregular lenses of intrusive breccia, best developed along the northern stock contact at the Lime

Creek deposit (Figure 2). Angular fragments 1 to 2 cm in size, of both intrusive and country rock, are contained in a granulated matrix of quartz, plagioclase, and K-feldspar.

Several deposits feature intrusive phases that are very late in the intrusive-mineralization sequence. These also are quartz monzonite in composition. Examples include an unexposed plug at Lime Creek, the southwest portion of the Bell Molybdenum stock (Figure 2), and post-mineral dykes at some of the Nass River deposits (Figure 1).

Post-mineral lamprophyric and basalt dykes cut virtually all of the molybdenum-bearing stocks. These usually strike northeasterly, dip vertically, and truncate all pre-existing rocks and structures, including mineralized fractures.

Northwesterly striking faults that are younger than the plutons and lamprophyric dykes are found at Bell Molybdenum, Roundy Creek, and Nass River deposits.

Sedimentary rocks adjacent to the Alice Arm intrusions have been thermally metamorphosed to biotite hornfels in an aureole which may extend outward from the stock contact for 100 to 150 m. Biotite hornfels is a brown, indurated, fine grained rock with a granoblastic texture that consists of quartz, minor feldspar, and abundant felted, brown biotite. Some cordierite and andalusite are developed in the hornfels adjacent to intrusive contacts.

Alteration patterns within and marginal to the molybdenum-bearing stocks are similar to other porphyry deposits. At many of the deposits, a central zone of potassic alteration is partially coincident with molybdenite mineralization. At Lime Creek the most intense potassic alteration occurs in a circular zone in the northern part of the stock (Figure 2). Rock within this core of intense alteration is laced with barren quartz veinlets rimmed by secondary K-feldspar, such that the original quartz monzonite porphyry has been converted to a rock consisting mainly of quartz and K-feldspar. In the outer part of this alteration zone is an annular zone of molybdenite mineralization where secondary K-feldspar is restricted to the margins of quartz-molybdenite veinlets. Other deposits also feature secondary K-feldspar but not to the same degree as at Lime Creek. Secondary biotite, an alteration of primary hornblende, is present to a limited degree in several of the deposits. At Lime Creek, this alteration of hornblende, particularly in the quartz diorite, may be in part deuteric. At Roundy Creek, the potassic alteration zone contains quartz-muscovite veins.

The potassic zone at most deposits is gradational outward to a phyllic (quartz-sericite-pyrite) zone. Where coincident with the margins of the plutons it is superimposed on the effects of thermal metamorphism. This zone is represented at many deposits by a bleaching of the biotite hornfels to a cream or light green colour marginal to fractures and quartz veinlets and is due to the development of very fine-grained quartz, sericite, and some epidote. This type of alteration may be weakly developed, as at many of the deposits, or so intense that the original biotite hornfels has been largely transformed to a buff or light green-coloured rock within a zone several tens of metres outward from the stock contact, as at the Lime Creek and Ajax deposits. Pyrite is a common constituent in this alteration zone, occurring both in quartz veinlets and as disseminations. The intensity of pyritization may be related in part to thermal metamorphism, which involves formation of pyrite and pyrrhotite in the hornfels.

Better grades of molybdenite mineralization in the Alice Arm intrusions are dependent on structural and lithologic controls. Fracturing and attendant quartz-molybdenite veining are best developed near stock contacts. Later alaskite intrusive phases may contain disseminated to nearly massive molybdenite. The ore zone at Lime Creek is annular or ring-shaped in plan, occurring in the northern half of the stock (Figure 2) with molybdenite occurring as selvages in a network of east-northeast and west-northwest quartz veinlets. A similar style of mineralization occurs at most of the other deposits.

Disseminated molybdenite is contained in the alaskite intrusive phase at the Lime Creek deposit. At Roundy Creek, the alaskite contains nearly massive lenses, pods, and parallel bands of molybdenite and much of this is in the form of feather-like intergrowths with the feldspar. Disseminated rosettes of molybdenite occur in leucocratic quartz-feldspar porphyry phases at the Tidewater and Kay properties.

Most of the deposits exhibit several stages of quartz-molybdenite, pyrite, and quartz-pyrite veining. Virtually all of the Alice Arm molybdenite deposits feature late-stage polymetallic quartz-carbonate veins which contain pyrite, galena, sphalerite, tetrahedrite, chalcopyrite, minor molybdenite, and at Lime Creek, four silver-lead-bismuth sulphosalts.

Pyrite halos may extend outward from the molybdenite zone for 150 m to 300 m. Where exposed, the pyrite zone is weathered to a prominent gossan, particularly at the Ajax and Snafu properties.

Two molybdenite deposits are known to occur within granite rocks of the Coast Plutonic Complex. These are the Molly Mack prospect near Anyox and the Penny Creek showing south of Alice Arm (Figure 1). At the Molly Mack property, coarse-grained molybdenite is abundantly disseminated in a small zone of biotite granite contained within a stock-like body of leucocratic quartz monzonite porphyry which is similar in appearance to some phases of the Alice Arm intrusions. The Penny Creek occurrence consists of rosettes of molybdenite in a biotite quartz monzonite, a late phase of the Coast Plutonic Complex.

Numerous showings of molybdenite occur near the eastern margin of the Coast Plutonic Complex and in the satellite stocks related to the complex.

DETAILED GEOLOGY AND STYLE OF MINERALIZATION

Brief descriptions of four porphyry molybdenum deposits in the immediate Alice Arm area are contained in this section. The Lime Creek deposit is discussed in more detail, with particular reference to rock geochemistry.

Tidewater

The Tidewater deposit is situated 1.6 km north and 6.4 km west of the head of Alice Arm Inlet (Figure 1) (Lat. 55° 28', Long. 129° 32', NTS 103P/5E, El. 450 m). Limited underground mining between 1916 and 1931 resulted in the recovery of 5,920 kg of molybdenite from northeasterly striking quartz veins in sedimentary rocks some 274 m south of a small (610 by 460 m) stock of quartz monzonite porphyry.

Exploration work in the 1960's included 550 m of underground diamond drilling and 290 m of drilling in the quartz monzonite porphyry stock. The latter work indicated sporadic molybdenite mineralization near the south contact of the stock in 1 cm wide quartz veinlets that occur in both hornfelsed sedimentary rocks and quartz monzonite porphyry.

Bell Molybdenum

The Bell Molybdenum property is situated 10 km southeast of Alice Arm (Figure 1) (Lat. 55° 27', Long. 129° 20', NTS 103P/6W, El. 670 m). Discovered in 1965 by Mastodon Highland Bell Mines Limited, the property was tested by 5,465 m of diamond drilling in 1966 and 1967, which indicated 32.2 million tonnes having an average grade of 0.11 percent molybdenite.

Molybdenite mineralization is associated with an elliptical stock of quartz monzonite porphyry, elongate in an east-northeast direction and measuring 670 by 335 m. The stock intrudes a sequence of dark grey to black siltstones and greywackes which are thermally metamorphosed to biotite hornfels a distance of 365 to 460 m outward from the stock contact.

Quartz monzonite porphyries of the stock include three major types. The main type, leucocratic quartz monzonite porphyry, occupies the central part of the stock. Two to 4 mm phenocrysts of quartz, oligoclase, and perthitic orthoclase make up 30 percent of the rock, and are set in a fine grained matrix of quartz and feldspar. Original biotite is bleached to a mixture of chlorite and sericite.

Near the stock contacts and in dykes peripheral to the stock, the leucocratic quartz monzonite porphyry is gradational to a quartz monzonite or granodiorite porphyry. This rock contains a more calcic plagioclase, a lesser amount of orthoclase, and fresh biotite and hornblende.

The southwestern part of the stock is composed of a crowded 'quartz-eye' porphyry of distinctive appearance. Phenocrysts which make up 50 percent of the rock by volume include 4 mm quartz anhedra, 2 to 4 mm euhedral crystals of plagioclase, and randomly distributed 1 to 2 cm euhedral crystals of perthitic orthoclase. The distinguishing feature of this phase is its relative lack of alteration. A similar porphyry was encountered at depth in a drill hole near the central part of the stock where it appeared to have a gradational contact with the leucocratic quartz monzonite porphyry. The relative lack of quartz veinlets and fractures and attendant mineralization suggests that the 'quartz-eye' quartz monzonite porphyry represents a late, possibly post-mineral, intrusive phase.

Narrow granitic dykes cut the leucocratic quartz monzonites in the central part of the stock. One drill hole intersected dykes of fine grained alaskite about 1/3 of a metre wide that consist of interlocking grains of quartz, perthitic orthoclase, sericite, and some granophyre. Near the stock contacts short sections were noted of fine grained grey-green quartz monzonite porphyry breccia. These cut the quartz monzonites and are distinguished by the presence of 1 cm angular hornfels fragments in a granulated matrix. Narrow dykes of fine grained light green quartz feldspar porphyry were noted in several drill holes.

Two varieties of basic dykes cut the granitic rocks of the stock. These include a fine to medium grained porphyritic lamprophyre consisting of plagioclase, hornblende, and clinopyroxene, and fine grained basalt and andesite dykes that are locally vesicular and which may be related to young lava flows nearby. Both varieties generally have a northeasterly strike and are about half a metre wide.

Within the stock, the central leucocratic quartz monzonite porphyry exhibits the greatest degree of alteration. Most prevalent is sericite-carbonate alteration of plagioclase. In addition, plagioclase locally is altered to K-feldspar, particularly along the margins of quartz veinlets. Secondary reddish brown biotite was noted in both the 'quartz-eye' quartz monzonite porphyry and the quartz monzonite to granodiorite porphyry in the marginal areas of the stock. In both rock types, the original biotite has been altered to a mixture of chlorite and sericite. Intense argillic and sericite alteration is common in fault zones, as are chlorite-coated slip surfaces. Biotite hornfels exhibits minor pale green chlorite-sericite bleaching marginal to fractures and quartz veinlets.

The major structural trends in the area of the porphyry stock are east-northeast and north-northwest, as reflected by the elongation of the stock itself, the strike of fractures, joints, faults, and basic dykes, and by the trend of creeks and airphoto lineaments. The stock contact, which dips steeply outward, is not well defined as it consists of a transitional zone of hornfels cut by numerous porphyry dykes. A large horse of hornfelsed sedimentary rocks within the stock, measuring 300 by 60 m, parallels the long direction of the stock (Figure 2) and is cut by numerous porphyry dykes. Drilling information suggests that this block of country rock decreases in size with depth.

Major faulting preceded the period of intrusion and intersections of east-northeast and north-northwest faults and fractures were undoubtedly important in the localization of the stock. Later movement along these faults particularly the north-northwest set, is documented by the apparent offsetting of the stock contacts along two major faults (Figure 2) and by the presence of numerous post-mineral shears noted in drill core.

Molybdenum mineralization occurs in both the quartz monzonite porphyry and biotite hornfels adjacent to the central and eastern stock contacts (Figure 2).

Molybdenite occurs mainly as selvages to steeply dipping quartz veinlets 0.5 to 1 cm thick, that follow major fracture directions. Four stages of quartz veining and mineralization have been noted. A first stage of barren quartz veinlets is followed by the second, most important stage, consisting of quartz-molybdenite-pyrite veinlets that are steeply inclined. These are offset locally by flat quartz-molybdenite veins and hairline fractures. The final stage consists of 2 cm and larger veins of quartz and carbonate that contain variable amounts of pyrite, pyrrhotite, galena, and sphalerite. A 25 cm wide quartz-carbonate vein containing pyrite, pyrrhotite, galena, and sphalerite was noted in a shear zone in argillaceous sediments 460 m east of the stock.

Roundy Creek

This property is situated south of Alice Arm Inlet on Roundy Creek, 2.4 km from tidewater (Figure 1) (Lat. 55° 25', Long. 129° 39', NTS 103P/6W, El. 305 m).

The property was originally discovered in the early 1900's. Exploration and development work between 1965 and 1971, primarily by Sileurian Chieftain Mining Company Limited, consisted of 9,300 m of diamond drilling and 780 m of underground development. The property was purchased by Climax Molybdenum Corporation of British Columbia, Limited in 1975.

Molybdenum mineralization is associated with an elongate, small composite intrusion of quartz monzonite porphyry. The intrusion is partly stock-like and partly sill-like. It has been segmented by northwest faults along and adjacent to Roundy Creek (Figure 2).

The intrusion consists of a number of similar but distinguishable phases. The most widespread of these is a leucocratic 'quartz-eye' quartz monzonite porphyry that forms the core of the intrusion. This phase is composed of 2 to 4 mm phenocrysts of subhedral quartz, perthitic K-feldspar, and euhedral oligoclase set in a very fine grained matrix of quartz and feldspar. The rock contains only minor biotite and sericite is the chief micaceous mineral. Where intensely sheared and fractured, the 'quartz-eye' quartz monzonite porphyry grades into brecciated quartz monzonite in which feldspar phenocrysts are partially shattered and the many randomly oriented fractures are coated with chlorite, sericite, carbonate, and molybdenite.

The 'quartz-eye' quartz monzonite porphyry is apparently gradational to biotite quartz monzonite, which is most abundant in the central and border areas of the intrusion. This rock type has a seriate texture and consists essentially of 2 to 4 mm grains of quartz, fresh euhedral oligoclase, and perthitic orthoclase, plus scattered flakes of biotite that are partially altered to chlorite and sericite.

Dykes and irregular masses of fine grained white alaskite cut all of the aforementioned rock types. Alaskites consist of a fine grained mosaic of quartz, sodic plagioclase, granophyre, and some sericite. In some areas the alaskite is gradational to a quartz feldspar porphyry.

A late intrusive phase seen in one of the underground levels and a few drill holes forms narrow dykes of fine grained, light grey biotite quartz monzonite. This last phase contains only trace amounts of molybdenite.

Narrow hornblende and biotite lamprophyre dykes that strike northeastward and dip steeply cut all granitic rocks and mineralized veinlets and fractures. Many terminate at, or are offset by, northwesterly trending faults (Figure 2).

Sedimentary rocks have been metamorphosed to biotite hornfels in a zone roughly 60 m wide surrounding the intrusion. Structural relationships of the intrusion are complex. Drill evidence indicates inward dipping lower intrusive contacts that suggest parts of the intrusive may be sheet-like in form surrounding a central feeder pipe. The eastern segment is apparently tabular in section.

Alteration of the intrusive rocks includes a potassic zone, which is best developed within and marginal to better grades of molybdenum mineralization. Potassic alteration, particularly in the leucocratic quartz monzonite porphyry, occurs as fracture-coated planes with abundant sericite and lesser biotite. Secondary biotite, principally on fractures, is best developed in the biotite quartz monzonite peripheral to the main zones of mineralization.

Two zones of molybdenum mineralization are known within the intrusion (Figure 2). The eastern segment is host to uniform grades of molybdenite occurring as selvages in numerous randomly oriented quartz veinlets and as fracture fillings. Drilling has indicated the presence of 7 million tonnes of 0.11 percent molybdenite in this zone. High-grade molybdenum mineralization occurs in the central and southern part of the intrusive where drilling and underground work has indicated 1.35 million tonnes of 0.347 percent molybdenite in the southern zone and some 35,000 tonnes grading 0.668 percent in a small zone to the north.

In both zones, higher grades of molybdenum mineralization are contained in alaskites. In the upper underground heading, closely spaced 1 to 2 cm bands of molybdenite are oriented crudely parallel to the trend of an enclosing alaskite body and appear to be an integral part of the magmatic crystallization. One cm rosettes of molybdenite also are uniformly distributed within the alaskite.

Molybdenite also occurs in numerous randomly oriented hairline fractures with chlorite in brecciated quartz monzonite and in closely spaced 0.5 to 1 cm wide quartz veinlets in alaskites and leucocratic 'quartz-eye' quartz monzonite porphyries.

Drilling and underground exploration indicate that the zones of molybdenum mineralization are lens-like in form and extremely erratic in lateral and vertical extent. The distribution of the higher grade zones suggests they are spatially related to the intrusive centre or feeder pipe.

Ajax

The Ajax property is on the east slope of Mount McGuire, 13 km northeast of Alice Arm (Figure 1) (Lat. 55° 35', Long. 129° 24', 103P/11W, El. 900 m).

Lead-zinc-silver mineralization, peripheral to the molybdenite zone, was explored by prospectors in the early part of the century. A reference to molybdenite mineralization, contained in the 1927 Minister of Mines Annual Report, prompted S. J. Barclay to locate the property for Newmont Mining Corporation in 1965. Some 8,100 m of diamond drilling was carried out on the property between 1965 and 1967.

A sequence of sedimentary rocks with minor interbedded volcanic rocks which form part of the eastern limb of the northwestward trending anticlinal structure are intruded by four small closely spaced stocks of quartz monzonite porphyry (Figure 2). These four stocks are grouped together in an elliptical area oriented northwesterly and measuring 900 by 750 m. The stocks, of varying sizes (Figure 2), are roughly rectilinear in plan and continue downward to the limits of drilling without merging into one intrusive body. However, the area between the stocks is laced with a network of dykes of similar composition.

The largest stock and the one immediately northwest of it are composed of leucocratic white to pink quartz feldspar porphyry. Twenty-five to 30 percent of the rock consists of 3 to 6 mm phenocrysts of anhedral quartz, subhedral sericitized plagioclase, and ragged perthitic orthoclase set in a fine grained matrix of quartz, feldspar, and sericite which is partly an alteration of biotite.

The other two intrusive bodies, which are essentially a network of closely spaced east-northeast and north-northwest dykes, are of similar composition but differ from the quartz feldspar porphyries by being medium grey in colour and by having a biotite content of between 7 and 10 percent and some chlorite and hornblende. Two to 4 mm phenocrysts of quartz and normally zoned oligoclase-andesine make up 25 percent of the rock. In contrast to the quartz feldspar porphyries, plagioclase is essentially fresh and K-feldspar is largely restricted to the matrix. Some of the narrow dykes have a seriate texture.

Northeasterly striking dykes of fine-grained hornblende and biotite lamprophyre about 2 m wide occur south and east of the quartz monzonite porphyry stocks. These dykes weather a brown colour, have chilled contacts and are of post-mineral age.

Contact metamorphism associated with the intrusion of the porphyry stocks has converted argillaceous sedimentary rocks to brown and purple coloured biotite hornfels in an area 900 m outward from the stock. Within an inner zone, 150 to 300 m from the stocks, secondary bleaching has converted biotite hornfels to a light green rock consisting essentially of sericite and quartz. East of the stocks and near the outer limits of the bleached zone, a narrow band of limestone has been skarnified.

Alteration of the intrusive rocks, which is most widespread in leucocratic quartz feldspar porphyries, includes sericitization of plagioclase phenocrysts, alteration of biotite to muscovite, and development of ragged porphyroblasts of K-feldspar. Flakes of biotite in the quartz monzonite porphyries may be of secondary origin. Drilling information indicates light grey pervasive silicification adjacent to quartz veinlets in deeper parts of the intrusive bodies.

Sedimentary and volcanic rocks underlying Mount McGuire are part of the steep east limb of a regional anticline. East and west of the porphyry stocks, strikes are uniformly north-northwest, while attitudes north and south of the stocks are contorted. Attitudes adjacent to the stocks indicate the presence of a large dragfold modified by doming associated with the intrusion of the stocks.

Most creeks on Mount McGuire follow faults which strike north-northwest and east-northeastward. The importance of major faults and fracture patterns in governing orientation of contacts and dyke trends is reflected by the rectilinear nature of the stock contacts.

Sulphide mineralization exhibits a zoning pattern which near the outer limits of the biotite hornfels zone consists of sparse pyrrhotite as disseminations and in widely spaced fractures. Proceeding inwards toward the intrusive complex, hairline fractures contain chlorite and pyrrhotite. Nearer the intrusive complex, these fractures become wider and are filled with quartz which carries pyrrhotite as well as coatings and minute bands of molybdenite.

Sulphide minerals constitute less than 2 percent by volume of the rock with pyrrhotite in the major amount. Molybdenite is always associated with quartz and occurs in the pyrrhotite-bearing veinlets and in the hairline fractures as stringy lenses or smears along shears. Molybdenite is usually concentrated along selvages of the veinlets. The quartz veins or quartz stockwork are present in both intrusive rocks and in the contact zone of the hornfels. Very minor amounts of scheelite have been noted within the quartz veinlet zone or associated with garnet skarn within areas of hornfels.

The deposit has several significant features evident on plans and cross sections. In the upper part of the mineralized area the strata dip about 60° northeast compared to dips greater than 70° at lower parts of the stocks. The strata near the surface are cut by numerous parallel or subparallel faults. The molybdenite mineralization is controlled by these pre-existing structures and the grade contours form bands that are subparallel, but definitely crosscutting the stratification. At a lower level a somewhat arcuate form for the molybdenite zone is evident in which there is a relatively lower grade core area that parallels the many northeasterly striking, steeply dipping faults. The outer diameter of the molybdenite zone at this level is about 425 by 520 m.

At a much lower level, the molybdenite zone has expanded to 350 by 610 m, oriented in a northwesterly direction. The ore area has a definite partial ring or arcuate shape with steeply dipping internal structures as indicated by the grade contours and with a definite barren core measuring 490 by 300 m and also oriented northwesterly. However a zone of molybdenite mineralization about 180 m wide trends northeasterly through the middle of the barren core. This represents mineralization controlled by faults and shear zones. At higher levels this fault controlled linear zone merges with the northwest side of the main arcuate zone leaving the barren core with an apparent northeast trend.

Post-ore faulting has displaced the mineralization in places.

Four stages of sulphide mineralization are evident, including initial quartz-pyrrhotite mineralization, followed by at least two stages consisting of quartz-molybdenite-pyrrhotite and a final stage represented by coarse grained quartz veins several centimetres wide, containing sphalerite and lesser amounts of pyrite, galena, and chalcopyrite.

Lime Creek

The Lime Creek deposit is situated 6.5 km south of Alice Arm (Figure 1) (Lat. 55° 25′, Long. 129° 25′, NTS 103P/6W, El. 610 m).

Although one of the earliest discovered mineral deposits in the Alice Arm camp, the major period of exploration took place between 1959 and 1963 when 13,150 m of diamond drilling was completed. British Columbia Molybdenum Limited carried out open pit mining operations between 1967 and 1972 and undertook 3,750 m of exploratory drilling during this period. Since acquisition of the property by Climax Molybdenum Corporation of British Columbia, Limited in 1973, a further 3,450 metres of drilling has been done.

Molybdenite mineralization at Lime Creek is associated with a small elliptical stock of quartz monzonite to quartz diorite composition which intrudes siltstones and greywackes of Late Jurassic to Early Cretaceous age (Figure 3). The main stock is 1,000 m in diameter and composed largely of porphyritic rocks. An eastern appendage to this body that is about 500 m long is composed of quartz diorite with normally zoned plagioclase (An_{42-45}). Several of the geochemical patterns (e.g., pyrrhotite distribution, Figure 4) suggest that this more basic eastern appendage is an old phase of the intrusive system.

The main stock is composed of granitoid rocks of several types and ages with a central zone of quartz monzonite porphyry. Several phases of quartz monzonite porphyry can be distinguished in the central part of the stock on the basis of texture and crosscutting relationships. The rock is essentially medium grained and leucocratic with euhedral to subhedral phenocrysts of normally zoned plagioclase (An_{25-30}) and poikilitic K-feldspar making up the major part of the rock. Hornblende and biotite are the chief mafic minerals.

Quartz diorite, which forms much of the western and southeastern parts of the main stock, is a medium grained white to grey massive rock with sparse phenocrysts of plagioclase. Fine grained secondary biotite has replaced the hornblende crystals in much of the rock. In places large K-feldspar crystals have formed, many over 1 cm across. These megacrysts contain relicts of plagioclase and mafic minerals. Similar poikilitic megacrysts also occur in the quartz monzonites.

Dykes and lenses of white to pink equigranular alaskite intrude the quartz monzonite porphyries and the quartz diorite, particularly in the contact areas of the main stock. This rock consists essentially of anhedral quartz and K-feldspar and commonly contains disseminated crystals or rosettes of molybdenite and occasionally crystals of fluorspar. The molybdenite mineralization of this type significantly enhances the grade of the stockwork deposit.

Intrusive into all rock types and apparently confined to the northern half of the main stock are irregular lenses and dykes of relatively fine grained quartz monzonite and granodiorite porphyry, and intrusive breccias. These are of intermineral age and commonly contain angular fragments of biotite hornfels, quartz monzonite porphyry, quartz diorite, and alaskite in a fine grained granulated matrix.

The latest granitic phase is a post-molybdenite quartz feldspar porphyry that truncates the northeast part of the stock at depth. This rock type, observed only in drill core, apparently terminates the ore grade mineralization of the northeastern part of the ore zone.

Lamprophyre dykes, varying in width from 1 to 10 m, cut all rocks in the main stock, but are especially abundant near the eastern contact. These dykes, which occur in northeasterly trending swarms, include both biotite and pyroxene varieties and have sharp chilled contacts.

The siltstones and greywackes in the general region contain chlorite, sericite, minor epidote and albite plagioclase, hence are within the greenschist metamorphic facies. Emplacement of the stock was accompanied by contact metasomatism of the greywackes to biotite hornfels. The hornfels contains up to 30 percent biotite near the Lime Creek stock. Outward the biotite content drops to zero at the 'biotite line', 500 to 1,000 m away from the stock. Adjacent to the stock, subsequent hydrothermal alteration has converted some of the biotite to sericite.

Hydrothermal alteration is represented largely by quartz, orthoclase, and sericite. These minerals form an almost circular zone of intense alteration centred in the northern half of the Lime Creek stock. Within the central part of the zone, the hydrothermal alteration trends toward a complete replacement of the pre-existing rock by quartz and orthoclase in varying proportions both as veinlets and as pervasive alteration. Any plagioclase remnants within this zone are completely sericitized. The secondary orthoclase rims mineralized quartz veinlets and occurs as grains (up to 5 mm) replacing plagioclase in the rock matrix.

The central intense zone changes quite abruptly to an outer zone of less intense alteration including sericitization of plagioclase plus abundant quartz-orthoclase veinlets. The outer limit of the quartz-orthoclase veinlets forms a circular boundary with diameter of approximately 1,000 m (Figure 5). Within the stock the sericitization is largely confined to the plagioclase; within the biotite hornfels it is mainly along small quartz veinlets and small fractures. The abundance of sericite alteration decreases outward in the stock, and in the southern part of the stock only minor sericite and clay alteration are apparent.

Argillic and sericite alteration of plagioclase feldspar is relatively intense in and adjacent to northeasterly striking faults and shears within all parts of the alteration zone.

Within the alteration zone there is a change in texture of the porphyries. The matrix is recrystallized to a coarser grain size and the phenocrysts are reduced in size by replacement. Thus there appears to be a trend toward an equigranular rock. This end point is never reached and the resulting rock has an almost seriate texture of very irregular crystals.

The zone of molybdenite mineralization is a ring structure, slightly elliptical in outline and elongated east-west (Figure 3). This ring occurs in the within and outward from the intense quartz-orthoclase alteration zone. The annular mineralized zone conforms roughly to the north, east, and west contacts of the stock, whereas the southern part of the zone cuts across the stock at its midpoint. The ring of mineralization has its best grades adjacent to the hornfels contact. Molybdenite content decreases toward the centre of the zone so that a barren core contains only traces of molybdenum.

Molybdenite mineralization occurs along the boundaries of 0.3 to 0.6 cm quartz veinlets, and in hairline fractures. Disseminated molybdenite is found only in the alaskites. Quartz veinlets are closely spaced and appear randomly oriented in a stockwork pattern, but as a general rule the majority of the veins are vertical and strike north-northeast. Recent mapping of the pit by geologists of Kennecott Copper Corporation (Giles and Livingstone, 1975) and Climax Molybdenum Corporation of British Columbia, Limited indicates four separate but superimposed substages of molybdenite mineralization followed by a polymetallic vein stage. The first substage is related to the alaskite dykes and is represented by disseminations and rosettes and by fracture fillings of molybdenite. The second and third substages are represented by quartz-orthoclase-pyrite-molybdenite veinlets in a closely spaced stockwork pattern in the northern parts of the stock and the adjacent biotite hornfels. Subsequently, quartz monzonite breccias were intruded and these are in turn cut by banded quartz-molybdenite veins up to 0.3 m thick.

Higher grades of molybdenite mineralization occur in areas of intense fracturing and faulting, particularly in the northeast contact area of the stock. However the intensity of fracturing has also provided channelways for the later lamprophyre dyke swarms thus reducing overall grade in this area.

The final stage of mineralization is represented by polymetallic quartz veins up to 1 m wide. These occur in two conjugate fracture sets that cut the molybdenite zone. A north-northeast set is generally predominant. However, in places, the northwest set is predominant and in places both sets are present. The quartz veins contain pyrite, galena, sphalerite, molybdenite, tetrahedrite, chalcopyrite, fluorite, ankerite, dolomite, and a variety of lead bismuth sulphosalts including the rare mineral neyite, first recognized here and named after Charles Ney (Drummond, et al., 1969).

Pyrite occurs as disseminations along and within the stock. Pyrite of the fractures has been introduced with many substages. It can occur in quartz veins, in quartz-molybdenite veins, and by itself. Total pyrite content forms a annulus or halo partly overlapping the molybdenite ring (Figure 8).

Deep drill holes within the stock have encountered anhydrite. Deeper holes also indicated a decrease in hydrothermal alteration at depth (Giles and Livingstone, 1975).

Alteration and Geochemistry at Lime Creek

The rock samples and specimens used for geochemical and petrographic studies were collected from surface exposures and from drill core. Oxidation was not an important factor as most of the pyrite was still intact. Sample spacing, which was closest in the mineralized area, depended on availability of outcrop and of drill core. Sample sites are shown on Figures 4 through 8.

Analyses were by a variety of methods including colorimetric, spectrographic, and XRF techniques. Mineralogical quantities were obtained from semi-quantitative X-ray diffraction estimates (aided by XRF analyses) and adjusted by thin-section studies.

Studies of the Lime Creek molybdenite deposit have shown that specific main stages plus some substages can be recognized in the geological sequence of events. The distribution patterns for the alteration minerals and the geochemical elements support this general thesis. Many of the distribution patterns are duplicated by one or more elements. Some patterns can be correlated with the distribution of the original unaltered rock; some can be related to the changes of contact metasomatism attendant on intrusion; some can be correlated with the main stage of hydrothermal alteration and mineralization; and some can be correlated with late polymetallic quartz veins.

The hornfels at the north contact of the stock imparts a discontinuity to many of the distribution patterns. The intensity of mineralization for some elements is lower in hornfels than in igneous rock.

Contact Metasomatic Stage

The formation of the biotite hornfels adjacent to the intrusions of the district and the conversion of some of the biotite to sericite by subsequent hydrothermal alteration has been mentioned. The distribution of the biotite is illustrated on Figure 4.* Most of the pyrrhotite (Figure 4) formed with the hornfels.

Other changes are also apparent in the mineralogy of the hornfels. The anorthite content of the plagioclase shows an increase (over a width of 300 m) toward the contact of the stock where it is comparable to the anorthite content of the rocks within the stock. The nickel content of the stock and in the surrounding hornfels (for widths up to 300 m) is lower than that found in the remainder of the hornfels zone. The porosity of the hornfels, except for a narrow band at the intrusive contact, is sharply lower than the porosity of the sedimentary rocks outside the biotite line.

Hydrothermal Alteration

Abundant quartz + orthoclase, in erratically varying proportions, form

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*Amphibole and pyroxene noted in three samples are included with the biotite estimates.

much of the central zone of intense alteration.* Outside of this central intense alteration zone, the abundance of quartz + orthoclase drops off rapidly; however quartz-orthoclase veinlets can be found outward to the limits of hydrothermal alteration (Figure 5). Any plagioclase remnants within the central core of intense alteration are completely sericitized (Figure 5).

The alteration is reflected by the distribution patterns of many of the rock-forming elements. The potassium pattern (Figure 5) reflects the composition of the original rock plus the orthoclase added during the hydrothermal alteration. Barium, which has also been added, shows a pattern more restricted to the alteration zone. Iron, cobalt (Figure 6), and sodium have been depleted and form negative anomalies in the zone of intense alteration. Arsenic (Figure 6) also shows a negative anomaly over the zones of alteration and molybdenum mineralization.

There has been an overall depletion of elements in the alteration zone. Bulk density measurements show a small but definite negative anomaly with a maximum decrease of density amounting to about 6 percent (Figure 6).

Main Stage of Mineralization

Sulphide mineralization closely associated with the alteration stage introduced molybdenum, sulphur (pyrite), and fluoride which are distributed in overlapping concentric zones around the zone of intense alteration (Figure 7). The copper has been depleted in the centre of the alteration zone, but added to the outer part of the alteration zone as a halo element (Figure 3). The sulphur pattern (Figure 7) reflects the contribution by the pyrite (Figure 8) and by the pyrrhotite (Figure 4). The pyrite halo partially overlaps the negative iron anomaly.

Post-ore Intrusion and Tungsten Mineralization

A post-ore stock intrudes the northeast part of the molybdenite deposit. This stock, although nearly devoid of molybdenum, does have traces of tungsten.

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*Orthoclase, quartz, or sericite when plotted separately give very erratic patterns.

Tungsten mineralization, in the form of scheelite, was accompanied by some pyrrhotite. This relatively late introduction of pyrrhotite accounts for some of the erratic pyrrhotite values appearing within the stock (Figure 4).

Tungsten does not form a good halo to the molybdenite mineralization. It occurs throughout the Lime Creek stock and the adjacent hornfels in a fairly erratic pattern (Figure 3).

Polymetallic Veins

The late polymetallic quartz veins occur within the area of anomalous molybdenum but they are not concentric to the main stage of hydrothermal alteration and mineralization. The pattern for lead (Figure 8) reflects the erratic nature of its distribution. Closer sample spacing would probably make the erratic nature of the pattern even more evident. Patterns for silver, bismuth, gallium, antimony zinc, and cadmium are very similar to the lead pattern.

K-Ar AGE DETERMINATIONS

Potassium-argon ages obtained from samples collected in the Alice Arm-Nass River area are shown on Figures 1 and 2. Analytical data for these and other samples are contained in a preceding paper (Christopher and Carter) in this volume.

Most samples were collected to date the age of intrusion and mineralization. Several, however, were collected to date other geologic units and to assess their relationship to the molybdenum deposits. These include samples collected from the Coast Plutonic Complex and from the basalt outliers south of Alice Arm. With the exception of whole rock samples of biotite hornfels and basalt, all analyses were carried out on biotite separates.

Samples for dating were collected from molybdenum-bearing quartz monzonite porphyries and related intrusive phases at six of the deposits.

Potassium-argon results from the main mineralized phase at these deposits fall within the range of 52.0±3 m y to 53.3±3 m y (Figures 1 and 2). Quartz diorite border phases at British Columbia Molybdenum and Bell Molybdenum are 51.4±1.5 m y and 51.7±2.2 m y respectively, both within the limits of analytical error for the main quartz monzonite phase.

Late intrusive phases, which exhibit definite crosscutting relationships with the first phase, were sampled at British Columbia Molybdenum. A dyke of intrusive breccia near the northern contact of the stock has an age of 53.6±1.7 m y, almost identical to the age obtained from the geologically older quartz monzonite porphyry phase (53.2±3 m y). An age of 48.3±1.6 m y was obtained for a sample of a later, nearly post-molybdenite phase of quartz monzonite occurring at a depth of 300 m below the exposed northeast part of the stock. This age determination corroborates the geological evidence that this is a younger porphyry phase which post-dates the main period of molybdenite mineralization and provides an upper limit for the age of molybdenite mineralization. A similar post-mineral porphyry dyke that cuts the quartz monzonite porphyry host rock at one of the Nass River deposits (Figure 2) yields a potassium-argon age of 49.0±2 m y.

A whole rock sample of biotite hornfels from outside the mineralized zone at Bell Molybdenum was dated at 48.7±1.5 m y. Although such a sample should reflect the age of intrusion, the somewhat younger age could be explained by partial argon loss inherent in a whole rock sample.

Two molybdenum deposits returned somewhat anomalous ages. The 48.3±1.9 m y age determined for the Molly Mack occurrence south of Anyox (Figure 1) might be explained by partial resetting of a slightly older age by the emplacement of the adjacent Coast Plutonic Complex granitic rocks. The 36.1±1.6 m y age for the Penny Creek occurrence southwest of Alice Arm (Figure 1) possibly could be due to a complete resetting of the original age by a younger lamprophyre dyke although none was seen during field examination. However, it should be noted that similar Oligocene ages for granitic rocks have been reported in the Prince William Sound area of southern Alaska by Lanphere (1966) and on Vancouver Island by Carson (1969).

Potassium-argon results obtained from previous and contemporary studies in the Alice Arm area are in good agreement with those reported here.

Woodcock, et al. (1966) reported a potassium-argon age of 53.3 m y for a sample collected near the south contact of the British Columbia Molybdenum stock. Later work on the same deposit in 1971 by D. L. Giles, formerly of the Geological Research and Laboratory Division of Kennecott Copper Corporation (Giles and Livingstone, 1975), indicated an age of 53.7 m y for secondary biotite from the alaskite phase.

Giles and Livingstone (1975) also reported an age of 63.2 m y for a biotite from fresh intrusive rock in a drill hole at a depth of 730 m below the open pit. This age is interpreted to represent the age of intrusion of the main granodiorite to quartz monzonite phase. This result is at variance with the interpretation of results described here, where biotite hornfels samples which could be expected to reflect the age of initial intrusion, returned ages in the 50 m y range. Giles' sample could have returned an anomalous age due to accumulation of excess argon.

Potassium-argon ages for four samples collected from granitic rocks of the Coast Plutonic Complex between Alice Arm and Lava Lake (Figure 1) range from 48.8±1.5 to 50.7±2.1 m y. These are in agreement with ages obtained by the Geological Survey of Canada in the same area and are somewhat younger than the mean age of 53 m y determined for the molybdenum-bearing porphyry stocks. Although within the limits of analytical error, these consistently younger ages found along the eastern margin of the Coast Plutonic Complex over a relatively large geographic area (Figure 1) suggest that the molybdenum-bearing stocks were intruded a measurable amount of time prior to the emplacement of the Coast granitic plutons.

Prior to potasssium-argon work, the flat-lying basalts south of Alice Arm were regarded as being of Early to Middle Tertiary age. A sample collected from north of the Bell Molybdenum stock has an age of 0.62±0.6 m y which is an average of three determinations. A similar sample from a basalt remnant east of Lime Creek has an age of 1.6±0.3 m y. This apparent disparity in age can be attributed to a lower level of accuracy in the conventional potassium-argon method in this geologically young age range.

SYNTHESIS

Molybdenite deposits in the Alice Arm area are genetically related to small intrusions of quartz monzonite composition.

These intrusions, known collectively as the Alice Arm intrusions, are clustered near the east flank of the Coast Plutonic Complex, although potassium-argon ages suggest that the stocks were emplaced a few million years prior to the intrusion of the Coast Plutonic Complex.

The Alice Arm intrusions were probably localized by deep-seated faults and fracture systems (Seraphim and Hollister, this volume). Supporting this concept are initial strontium isotope ratios (Giles and Livingstone, 1975) which indicate that the igneous rocks and mineralization were derived from mantle material with only minor crustal contamination.

The distribution of Quaternary and Recent basalts south of Alice Arm and Nass River suggests that they may have been localized by the same regenerated fault and fracture systems. The incidence of young volcanic activity nearby molybdenite deposits is not uncommon in the Canadian Cordillera.

The age of molybdenite mineralization is virtually congruent with the age of intrusion as determined by radiometric (K-Ar) methods. The mineralizing intrusive phase are the alaskites, a feature particularly evident at the Lime Creek and Roundy Creek deposits. Intense fracturing attendant with intrusion of the stocks has resulted in most of the economic and sub-economic molybdenite mineralization occurring in the contact areas of the stocks.

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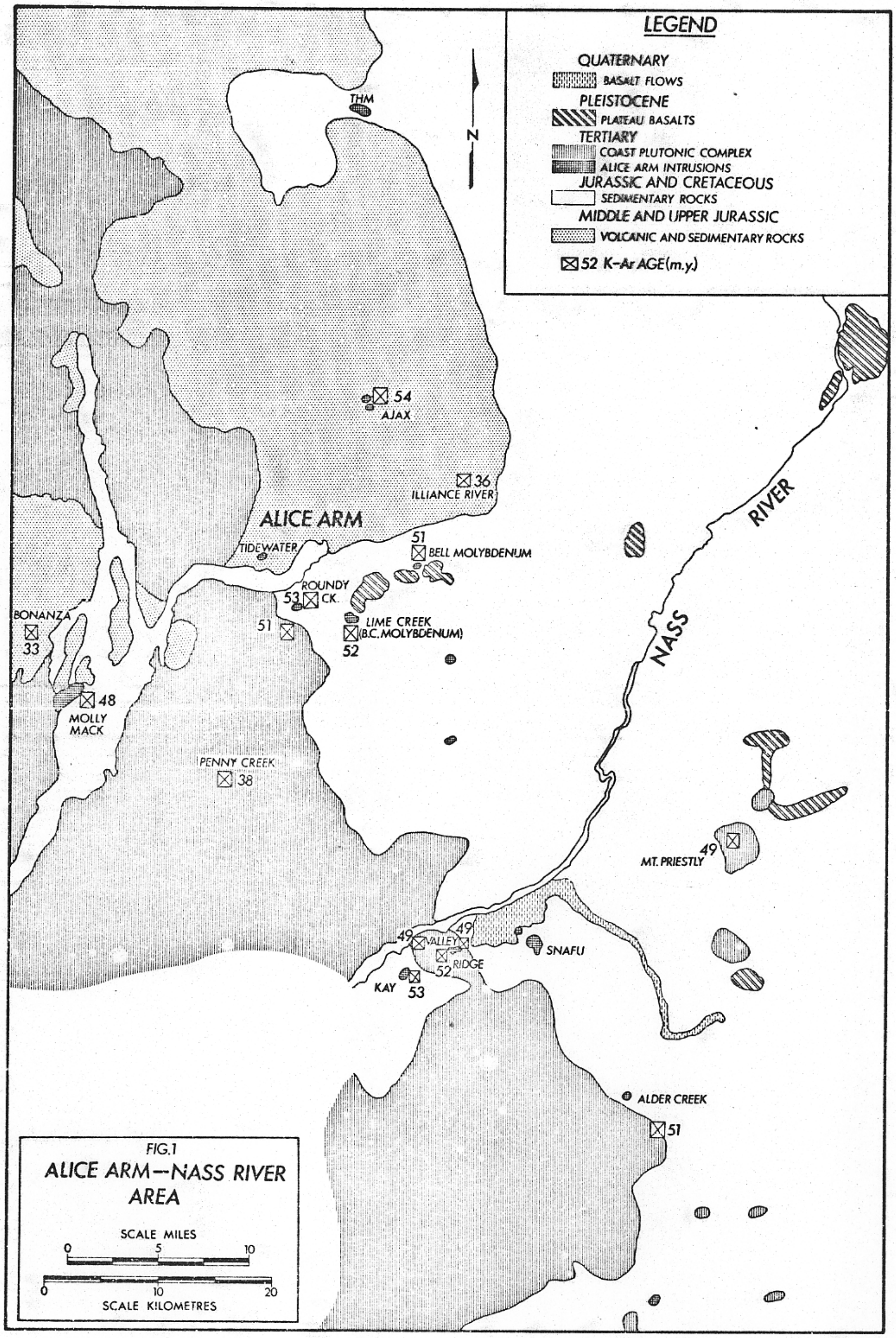

FIG.1
ALICE ARM—NASS RIVER AREA

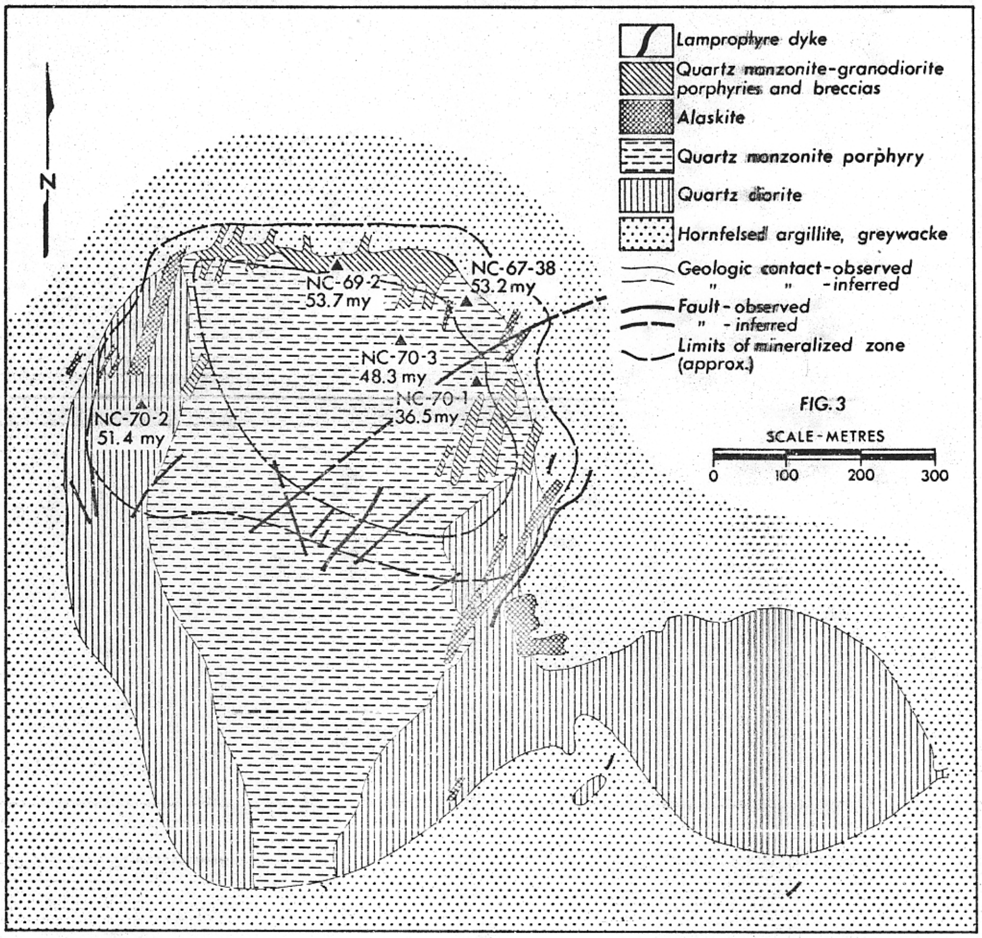

FIG. 3

FIG. 3 GEOLOGY OF THE LIME CREEK STOCK