*Economic Geology*
Vol. 68, 1973, pp. 23–33

# The Age of Sulfide Mineralization at Rossland, British Columbia

JAMES T. FYLES, J. E. HARAKAL, AND W. H. WHITE

## Abstract

Mines near the city of Rossland in the West Kootenay district of southeastern British Columbia were important producers of copper and gold from 1894 to 1928 and of molybdenum since 1966 from an open-pit mine near the copper-gold camp.

Eighteen new K-Ar dates of plutonic, dike, and volcanic rocks indicate that the age of the oldest pluton (the Rossland monzonite) is more than 90 m.y. and that all the other rocks are between 46 and 52 m.y.

Geological relationships show that the molybdenite is older than the copper-gold mineralization. The molybdenite is about 48 m.y. because it is cut by 48.1 m.y. dikes and occurs in fractures which cut quartz diorite with an apparent age of 48.7 m.y.

The copper-gold mineralization is younger than lamprophyre dikes with an average age of 48.2 m.y. and is thought to be about this age.

Mineralization in the Rossland camp, therefore, is Tertiary and appears to be genetically associated with two bodies of quartz diorite and granodiorite formerly regarded as part of the Nelson plutonic suite.

## Introduction

THE cities of Rossland and Trail are less than 10 miles north of the International Boundary 250 miles east of Vancouver. They are in the West Kootenay district of southeastern British Columbia and originated about the turn of the century because of the discovery of copper-gold veins at Rossland. The progress of the Rossland camp is intimately associated with the early development of the West Kootenay district and the adjacent parts of Washington. Mining of copper-gold ore terminated 40 years ago, but recently mining of molybdenum has renewed interest in the camp.

Very little is known of the age of sulfide mineralization in the West Kootenay district although several intensive studies of individual mineral deposits and groups of deposits have been made. Traditionally, most mineral deposits in the area are thought to be related genetically to the Nelson granitic rocks (Cairnes, 1943, p. 111, Walker, 1934, p. 23) which occur widely throughout the region. Recent radiometric dates show that rocks which appear to be consanguineous and have been mapped as part of the Nelson plutonic suite range from 160 m.y. to 50 m.y. In addition, relatively few mineral deposits can be shown to be directly associated with plutonic rocks. Thus, it is not possible to generalize about the age and genetic relationships of sulfide mineralization in the West Kootenay district without detailed data. The purpose of the present study is to determine the age of the two types of mineralization in the Rossland mining camp by determining the age of several plutonic and dike rocks and the geological relationships of these rocks to the sulfides.

Mines at Rossland were important producers of copper and gold between 1894 and 1928. Among the most important mines were the Le Roi, Centre Star, War Eagle, and Josie in the core of the camp, all of which were famous during the first decade of the century. Total production of copper-gold ore from the Rossland area has amounted to 6,200,000 tons with average grade of gold 0.47 oz per ton, silver 0.6 oz per ton, and copper 1 percent (Gilbert, 1948, p. 189).

Mining of molybdenum ore began in 1966 from an open pit on the west side of Red Mountain about a mile west of the main mines. Molybdenite was known in the early years of the camp, and the ore bodies were found by drilling initiated by Torwest Resources in 1964. Total production by Red Mountain Mines to the end of 1971 amounts to more than a million tons of ore with recovery of 3.8 million pounds of molybdenum.

The age and origin of the copper-gold mineralization has been a subject of discussion for many years by geologists who have worked in the Rossland camp. The historical development of interest in this subject is summarized by Little (1963, p. 6), as follows:

"One object of this project was to determine if possible the time of emplacement of the gold-copper ore of the central mines of Rossland Camp. Brock (1906, pp. 15–18) thought the ore was earlier than the lamprophyre and basic and acidic dikes, though in the Giant and Jumbo mines he saw ore in and

around alkali syenite (Coryell) dikes. Drysdale (1915, pp. 85–93, 140, 148) contended that successive intrusions of lamprophyre occur, variously related to the Nelson (Trail), Coryell, and Sheppard intrusions. The first were cut by sulphides, with little or no gold; the second by gold-bearing veinlets; and the third were unmineralized. Drysdale considered that sulphide mineralization with minor gold was related to the Nelson and gold mineralization to the much later Coryell. He admitted the Coryell 'pulaskite' adjacent to the Spitzee and Giant orebodies is slightly impregnated by sulphides but presomably related this to his later period of mineralization. However, it is apparent that the positions of these orebodies are controlled by the 'pulaskite' contact, and the ore, therefore, in the present writer's opinion, is later than Coryell.

"Bruce (1917, p. 235) favoured two periods of mineralization, but contended that abundant sulphides accompanied the gold of the later period.

"Gilbert (1948, p. 193) could see no good evidence for two periods of mineralization, and concluded that all the dykes in the mines are older than the ore."

Little's own observations were that "pyrite stringers from the veins cut lamprophyre dykes" and "long stringers of chalcopyrite from the vein cut a mica lamprophyre." White (1949, p. 162), working with veins in the Mayflower mine area south of Rossland, noted that "The lamprophyre dykes are older than the ore minerals, with the possible exception of pyrrhotite, and consequently play an important part in localizing the deposition of ore minerals." In a long cross-cut (3045 level) driven by Falaise Lake Mines in 1969 and 1970 in the main part of the Rossland camp small chalcopyrite-filled fractures were encountered within a lamprophyre dike correlated with the Nickel Plate dike of the old workings. Hence, the latest workers agree that the sulfides in the copper-gold veins, and probably also the gold, are younger than the lamprophyre dikes.

Molybdenite, although recognized on Red Mountain by early workers, was not well exposed until the open pits of the Red Mountain Mine were made. In them diorite dikes and probably also lamprophyres are unmineralized and apparently younger than the molybdenite, which occurs in fractures in a hornfels breccia. In the workings closest to the main camp a vein of massive chalcopyrite cuts the molybdenite ore body. Hence, the molybdenite appears to be older than the copper-gold mineralization. On the other hand, molybdenite fills fractures in quartz diorite and associated felspathized hornfels. Thus, the various dikes and plutonic rocks provide a basis for determining the absolute age of the mineralization in the Rossland camp.

## Geological Setting

The Rossland mines occur within an area in which plutonic and dike rocks intrude a sequence of Late Paleozoic and Lower Jurassic volcanic and sedimentary rocks, the ages of which have been determined by a limited number of fossils (Fig. 1). The Jurassic Rossland Group is mainly andesitic volcanic breccia, lapilli tuff, volcanic sandstone and conglomerate, and lenses of gray to black siltstone. The Carboniferous Mt. Roberts Formation consists of gray siltstone, sandstone, conglomerate, and minor limestone. These rocks are variably metamorphosed and intruded by three principal groups of plutonic rocks, the Rossland monzonite, the Trail batholith and the Coryell plutonic rocks, and by a large number of dikes including diorite, lamprophyre, and syenite.

### *Rossland monzonite*

The Rossland monzonite forms an irregular stock about 5 miles east to west and 2 miles north to south and is exposed in the city of Rossland and eastward toward Trail. The contacts of the stock with the older rocks vary from relatively sharp to gradational over several tens of feet. Irregular dike-like protrusions extend into the wall rocks on the northern and western sides, and large inclusions of volcanic and sedimentary rocks are present within the stock. The Rossland monzonite is in contact with the Rainy Day stock, an offshoot of the Trail batholith, and the contact relationships although not well exposed indicate that the monzonite is older than the Rainy Day stock. Similar relationships showing the Rossland monzonite to be older than the Trail batholith are exposed on Highway 3a just west of Warfield about $2\frac{1}{2}$ miles northeast of Rossland. Also, a large dike of quartz diorite (probably an offshoot of the Rainy Day stock) transects a westerly protrusion of Rossland monzonite about half a mile northwest of the top of Red Mountain.

The Rossland monzonite is a gray to greenish-gray, fine- to medium-grained rock which varies in appearance from place to place. Fractures lined with very fine-grained hornblende are common in the northern and central parts of the stock, and it is difficult to collect samples which do not contain fractures coated with hornblende. The Rossland monzonite is surrounded by a zone of thermal metamorphism ranging from about 500 feet wide along the southern contact of the stock to more than a mile wide to the west. Metamorphism of siltstones has produced diopside and biotite hornfels which rarely contains almandine. Metamorphism of the andesitic volcanic rocks has resulted in the widespread development of hornblende which is commonly altered to biotite.

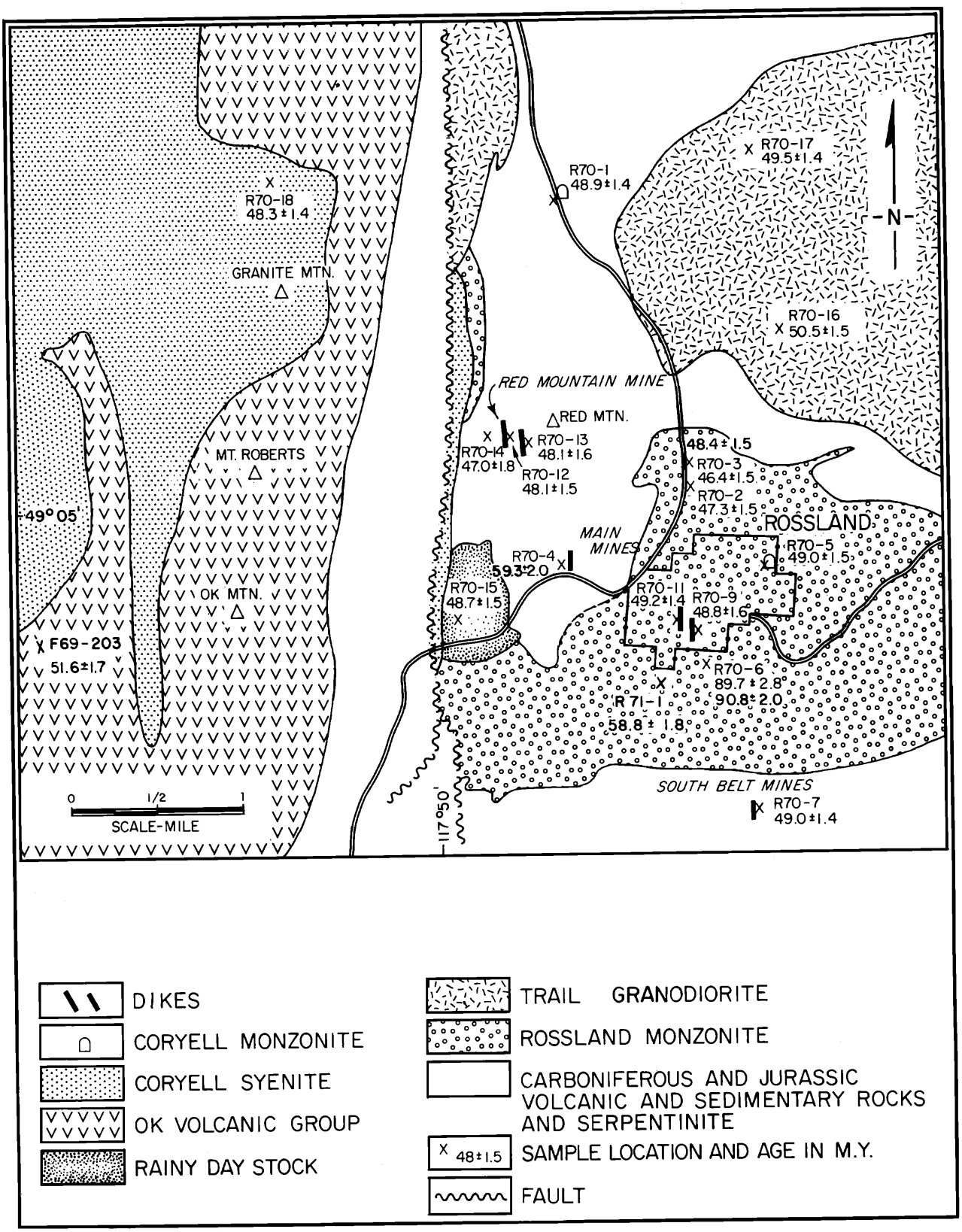


FIG. 1. Generalized geology of the Rossland area showing age determinations.

TABLE 1. Potassium-Argon Age Determinations

| Sample No. | Rock Unit | Rock Type | Mineral or Concentrate | %K ± σ* | $A^{40}$ rad** / $A^{40}$ total | $A^{40}$ rad ($10^{-6}$ ccSTP/g) | $A^{40}$ rad / $K^{40}$ | Apparent Age (m.y.) |
|---|---|---|---|---|---|---|---|---|
| F69-203 | OK Volcanic | Latite | Whole Rock | 4.29 ± 0.02 | 0.90 | 0.8882 | 0.003059 | 51.6 ± 1.7 |
| R70-12 | Diorite Dike | Hornblende Gabbro | Biotite | 7.43 ± 0.03 | 0.95 | 1.434 | 0.002851 | 48.1 ± 1.5 |
| R70-3 | Spokane Dike | Lamprophyre | Biotite | 6.30 ± 0.04 | 0.71 | 1.171 | 0.002747 | 46.4 ± 1.5 |
| R70-3 | Spokane Dike | Lamprophyre | Hornblende | 1.047 ± 0.001 | 0.78 | 0.2033 | 0.002869 | 48.4 ± 1.5 |
| R70-4 (Run 1) | Conglomerate Dike | Lamprophyre | Whole Rock | 1.82 ± 0.014 | 0.83 | 0.4254 | 0.003453 | 58.1 ± 2.0 |
| R70-4 (Run 2) | Conglomerate Dike | Lamprophyre | Whole Rock | 1.82 ± 0.014 | 0.82 | 0.4430 | 0.003596 | 60.5 ± 2.0 |
| R70-7 | Mayflower Dike | Lamprophyre | Biotite | 7.76 ± 0.02 | 0.92 | 1.526 | 0.002906 | 49.0 ± 1.4 |
| R70-9 | Nickel Plate Dike | Lamprophyre | Biotite | 7.60 ± 0.04 | 0.92 | 1.487 | 0.002891 | 48.8 ± 1.6 |
| R70-11 | Dike | Lamprophyre | Biotite | 7.22 ± 0.02 | 0.76 | 1.426 | 0.002917 | 49.2 ± 1.4 |
| R70-13 | Headwall Dike | Lamprophyre | Biotite | 5.67 ± 0.05 | 0.90 | 1.095 | 0.002852 | 48.1 ± 1.6 |
| R70-1 | Coryell | Monzonite | Biotite | 7.06 ± 0.01 | 0.90 | 1.385 | 0.002898 | 48.9 ± 1.4 |
| R70-5 | Coryell | Monzonite | Biotite | 7.61 ± 0.04 | 0.65 | 1.496 | 0.002905 | 49.0 ± 1.5 |
| R70-18 | Coryell | Syenite | Biotite | 7.55 ± 0.02 | 0.91 | 1.461 | 0.002860 | 48.3 ± 1.4 |
| R-70-14 | | Biotite Hornfels | Whole Rock | 3.70 ± 0.04 | 0.96 | 0.6974 | 0.002785 | 47.0 ± 1.8 |
| R70-15 | Rainy Day Stock | Quartz Diorite | Biotite | 6.79 ± 0.02 | 0.86 | 1.327 | 0.002888 | 48.7 ± 1.5 |
| R70-16 | Trail Batholith | Granodiorite | Biotite | 6.45 ± 0.02 | 0.86 | 1.308 | 0.002997 | 50.5 ± 1.5 |
| R70-17 | Trail Batholith | Granodiorite | Biotite | 6.71 ± 0.01 | 0.94 | 1.333 | 0.002935 | 49.5 ± 1.4 |
| R70-2 | Rossland Monzonite | Monzonite | Biotite | 5.97 ± 0.03 | 0.91 | 1.131 | 0.002800 | 47.3 ± 1.5 |
| R70-6 (Run 1) | Rossland Monzonite | Monzonite | Biotite | 7.19 ± 0.03 | 0.84 | 2.616 | 0.005376 | 89.7 ± 2.8 |
| R71-1 | Rossland Monzonite | Monzonite | Biotite | 7.45 ± 0.02 | 0.92 | 1.760 | 0.003491 | 58.8 ± 1.8 |
| R70-6 (Run 2) | Rossland Monzonite | Monzonite | Biotite | 7.02 ± 0.05 | 0.94 | 2.585 | 0.005441 | 90.8 ± 2.0 |

* $\sigma$ Standard deviation of quadruplicate analyses.

** Constants used in model age calculations: $\lambda_\sigma = 0.585 \times 10^{-10}y^{-1}$, $\lambda_\beta = 4.72 \times 10^{-10}y^{-1}$, $K^{40}/K = 1.181 \times 10^{-4}$.

The K-Ar dates of three samples of Rossland monzonite give widely divergent results (Table 1). Sample R70-2, which gave an apparent age of 47.3 ± 1.5 m.y., is highly chloritized and shows extensive development of secondary biotite. The apparent age is thought to have been influenced by the secondary biotite. Both samples R70-6 and R71-1 are fresh. The stock is fractured, altered, and cut by various intrusions, and is difficult to sample. It seems reasonable to conclude that it is at least as old as 90 m.y. (R70-6), but further sampling and testing will be necessary before the age will be known with certainty.

*Trail batholith*

The western lobe of a large mass of granodiorite known as the Trail batholith lies north of Rossland, and two subsidiary stocks lie one to the northwest and the other to the southwest of Rossland. The Trail batholith as shown on regional maps (see Little, 1960) is part of the Nelson plutonic suite and forms an irregular mass roughly 8 miles square with southern margin near Trail. It is separated from other bodies of Nelson rocks by narrow belts of pre-Nelson rocks.

In the Rossland area the Trail batholith is an irregular body with relatively sharp contacts composed of fresh, medium-grained blocky gray granodiorite transected in a few places by narrow quartz veins and fractures coated with epidote.

Two samples from the Trail batholith gave apparent ages of 50.5 ± 1.5 and 49.5 ±1.4 m.y., respectively. These contrast with ages of the Nelson batholith of about 160 m.y. determined recently by Nguyen, Sinclair, and Libby (1968) and of the Spirit pluton 20 to 25 miles to the southeast in northern Washington of about 100 m.y. (Yates and Engels, 1968), and the Trail batholith can no longer be regarded as part of the Nelson plutonic suite.

*Rainy Day stock*

The Rainy Day stock is a small irregular body of quartz diorite exposed southwest of Rossland which is important because it is highly fractured and associated with molybdenite mineralization. The stock has relatively sharp contacts, adjacent to which, at a few places, the wall rocks are bleached by felspathization. The stock has a nonporphyritic central core, a porphyritic margin on the west and is intruded by Coryell syenite. A sample of the nonporphyritic core of the Rainy Day stock gave an apparent age of 48.7 ± 1.5 m.y.

Three dikes similar in composition to the Rainy Day stock occur to the north on Red Mountain. They are irregular, discontinuous, steeply dipping, and trend easterly. The northernmost, northwest of Red Mountain, is as much as 300 feet thick and 2,000 feet long. The second is about half a mile to the south and passes through the northern part of the Red Mountain Mine. As exposed on surface it is 15 to 20 feet wide and a few hundred feet long, but it is discontinuous and more extensive than indicated by surface exposures. The third dike is 1,000 feet farther south and passes along the southern edge of the "A" molybdenite ore body of Red Mountain Mines. These dikes are locally brecciated and con-

tain molybdenite. They are associated with the local development of potash feldspar both in the wall rocks and the matrix of the breccia.

The Rainy Day stock and the three dikes to the north are probably offshoots of the Trail batholith. Molybdenite occurs in fractures in and near these bodies of quartz diorite and associated zones of feldspathization. A sample of biotite hornfels from the B zone pit of the Red Mountain Mine within a few tens of feet of a feldspathized zone gave an apparent age of the biotite of 47.0 ± 1.8 m.y.

*Coryell plutonic rocks*

The Rossland camp is 2 to 3 miles east of a large body of syenite known as the Coryell batholith (see Little, 1960, p. 90). The syenite typically is a pink, medium- to coarse-grained rock which is highly fractured and deeply weathered in all but the most precipitous areas. An apparent age of 48.3 ± 1.4 m.y. was obtained from a sample from near the eastern margin of the batholith.

Dikes and small stocks of the Coryell plutonic suite occur widely in the Rossland camp. They are mostly more mafic than the batholith, consisting of medium- to coarse-grained augite-biotite monzonite, hornblende monzonite, and rarely of biotite peridotite. Apparent ages of 48.9 ±1.4 m.y. (R70-1) and 49.0 ± 1.5 m.y. (R70-5) were obtained from samples of two small stocks of monzonite.

These dates are to be compared with those reported by Yates and Engels (1968) of samples of dikes associated with the Coryell batholith 7 to 10 miles south of Rossland. They are similar to the Coryell monzonite of the Rossland area, and the ages reported are 50.7 ± 1.5 and 50.4 ± 1.5 m.y.

Contacts of the Coryell plutonic rocks with the older rocks are sharp, with narrow, locally imperceptible zones of thermal metamorphism. On Granite Mountain west of Rossland amygdaloidal trachytes intruded by the Coryell batholith are recrystallized close to the batholith but apparently unmetamorphosed 500 feet from it. A dikelike body of syenite and monzonite west of Red Mountain intrudes gray carbonaceous siltstones, which within a few feet of the contact do not show any evidence of thermal metamorphism. Similarly hornfelsic zones only a few feet wide are present adjacent to the small bodies of Coryell monzonite within the Rossland camp. Hence, it is concluded that although intrusives of the Coryell suite are widely distributed in the Rossland area they have had little thermal effect beyond a few hunderd feet from the larger plutons and beyond a few tens of feet from the smaller ones.

*Lamprophyre dikes*

Many lamprophyre dikes of various types are present in the Rossland area. They trend north, dip steeply and are older than the copper-gold, but younger than the molybdenite mineralization.

The most common lamprophyres are porphyritic dark green dikes crowded with fine- to medium-grained subhedral phenocrysts of biotite. In the old Rossland mines these were referred to as the "mica dikes" and many, such as the Nickel Plate dike, were named and followed throughout the workings. Many of the lamprophyres are deeply weathered and not exposed at the surface. Petrographically they are porphyritic or fine to medium grained with well-formed grains of biotite, augite, olivine, and amphibole. Orthoclase-microperthite is the most common feldspar but plagioclase, usually andesine, is present in some dikes. Serpentine is the most abundant alteration. Three of the least altered dikes were analyzed. They are the Nickel Plate dike (R70-9) apparent age 48.8 ± 1.6 m.y., the Mayflower dike (R70-7) apparent age 49.0 ± 1.4 m.y., and Headwall dike (R70-13) apparent age 48.0 ± 1.6 m.y.

The sample of the Nickel Plate dike was taken in the Falaise Lake 3045 adit 520 feet from the portal. In the adit the dike contacts trend north and are vertical, and the dike has a true width of about 200 feet.

The Spokane dike (see Drysdale, 1915, p. 30), well exposed in a large rock cut near the Rossland reservoir, contains phenocrysts of plagioclase hornblende and biotite, many of which are more than a centimeter across. Apparent ages on biotite phenocrysts of 46.4 ± 1.5 m.y. and on hornblende phenocrysts of 48.4 ± 1.5 m.y. were obtained from one sample (R70-3).

The "Conglomerate" or White dike attracted interest among geologists who studied the camp in its early days (see Drysdale, 1915, p. 31; Bruce 1917, p. 17). It is a lamprophyre crowded with large rounded fragments of wall rocks, many of which do not outcrop in the vicinity of the mines. The fragments include quartzite, gneiss, syenite, quartz, and aplite, and the largest described by Drysdale is 21 inches long. The dike is porphyritic with phenocrysts of andesine, augite, and orthoclase in a matrix of biotite and serpentine. Whole rock analyses gave apparent ages of 58.1 ± 2.0 m.y. and 60.5 ± 2.0 m.y. This dike is clearly part of the lamprophyre suite which give consistent ages averaging 48.7 m.y. This discrepancy in the apparent ages may be due to the fact that the "Conglomerate" dike is highly contaminated by wall rocks, small fragments of which may have been included in the samples used for the whole rock analyses.

A coarse-grained dike composed of biotite, olivine, pale green amphibole, and interstitial labradorite was encountered in the 3045 adit of Falaise Lake Mines. The dike does not outcrop and its form and extent are not known. In the adit it is exposed between 1,250 and 1,550 feet from the portal, one contact trends north, the other east, and both are almost vertical. The dike is regarded as part of the lamprophyre suite.

Lamprophyre dikes occur in many of the mining camps of the West Kootenay district, commonly occurring in swarms following northerly trending fractures and local fracture systems. The age of two lamprophyre dikes reported by Yates and Engels (1968, p. D246) from localities as much as 25 miles from Rossland are 51.7 ± 1.5 m.y. and 49.9 ±1.5 m.y.

Lamprophyre dikes transect all the plutonic rocks, including the Coryell plutons which they resemble chemically and with which they are probably related genetically (see Mathews, 1953, p. 33; Fyles and Hewlett, 1959, p. 45).

*Diorite dikes*

A swarm of grayish-green to brownish dikes trending 160 degrees passes across the southern and western slope of Red Mountain and is well exposed in the Red Mountain Mine. These dikes are not mineralized and appear to be later than the molybdenite. They are aphanitic to fine-grained grayish-green to brownish dikes with chilled margins and locally porphyritic centers. Phenocrysts of hornblende and small bleached spots with a minute cube of pyrite in the center are characteristic features. Labradorite, hornblende, and biotite are the main minerals identified in thin sections. Biotite from one sample (R70-12) of a diorite dike gave an apparent age of 48.1 ± 1.6 m.y.

*Granitic porphyry*

Felsitic dikes described by previous workers as granite porphyry are common east of Rossland and occur only at a few places in the main camp. They are pink- to buff-weathering porphyritic rocks with prominent phenocrysts of well-formed plagioclase crystals and less prominent rounded phenocrysts of quartz in an aphanitic matrix. Angular, dark green inclusions are common (see Drysdale, 1915, p. 33; Bruce, 1917, p. 15; White, 1949, p. 159). These dikes are correlated with the Sheppard granitic intrusions (Little, 1960, p. 94–95) which cut Late Cretaceous rocks. White notes that a lamprophyre dike cuts a granite porphyry dike east of the Mayflower Mine, and regionally lamprophyre dikes cut the Sheppard Granite. Because of late magmatic alteration of rare biotite flakes in the granite porphyry dikes no material suitable for potassium-argon dating was obtained.

*OK volcanic group*

Flows and related volcanic rocks form the summits of prominent hills west of Rossland. They were described and analyzed by Daly in his geological reconnaissance along the 49th parallel and referred to as latites. Latite, andesite, and basalt flows are present and form the largest part of the group, and andesitic pyroclastic rocks and volcanic sandstones form a minor part. These rocks were mapped as part of the Jurassic Rossland volcanic group by Little (1963), but they closely resemble Tertiary lavas 6 miles northwest of Rossland, and because of this a whole rock K-Ar age determination of a specimen from the OK volcanic group was made. The apparent age is 51.6 ± 1.7 m.y. The OK volcanic group is intruded and locally metamorphosed by the Coryell syenite. Although the stratigraphic succession within the OK volcanics is not well known, the sample dated appears to be more than 2,000 feet above the base of the lava pile. The date is to be compared with ages reported by Mathews (1963; Monger, 1968, p. 32) from tuffs and syenites within the Marron Formation of porphyritic trachyte and andesite from the Greenwood area 50 miles to the west, which are 49 ± 2 and 48 ±2 m.y. Eocene lavas on Belshazzar Mountain in northern Washington 12 miles southwest of Rossland have ages of 50.4 ± 1.5 and 50.5 ± 1.5 m.y. as reported by Yates and Engels (1968).

## Samples and Age Determinations

Samples for this study were collected in late June 1970 by White and Fyles near the close of a geological mapping project and study of the molybdenite deposits of the Rossland camp by Fyles. Large samples of rock were broken clean of weather material and mineral coatings along fracture surfaces. Sample sites were selected on the basis of rock exposure and geological setting which were known because of the mapping project. The analytical data and apparent geological ages of the sample given in Table 1 were determined by Harakal. Petrographic descriptions of the samples are available from the authors on request.

## Analytical Techniques and Graphical Analyses

The techniques which are employed at the University of British Columbia for K-Ar age work are described in detail in an earlier report (White et al., 1967) and are mentioned only briefly here. Potassium analyses are performed on quadruplicate splits and the solutions atomized in Baird-Atomic KY and

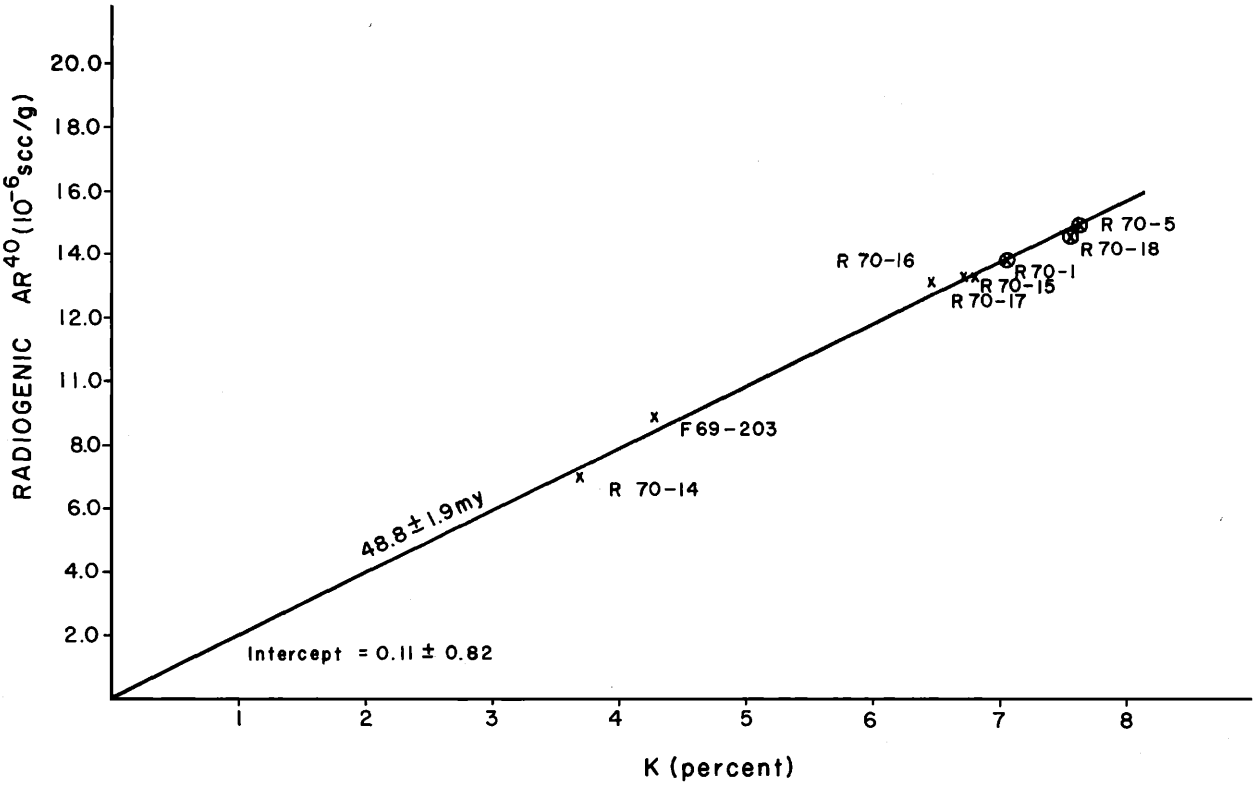


FIG. 2. Initial argon diagram for all the Tertiary rocks except the dikes.

KY-3 series flame photometers. Argon data are recorded with an AEI MS-10 mass spectrometer modified to permit rapid, static, isotopic ratio measurements on a small quantity of gas, approximately 5 percent by volume. In addition, in this study graphical methods were used to check the values of initial argon and the initial ratios for the samples in question (Hayatsu and Carmichael, 1970; Roddick and Farrar, 1971). For each argon run, the fusion system and sample were baked to 130°C for approximately 18 hours to eliminate or reduce the effects of atmospheric argon contamination.

Table 1 presents the analytical data obtained by conventional methods on suitable mineral and whole rock concentrates. For most samples the assigned limit in this study is about 3 percent of the apparent age.

The results of the graphical methods are shown in Figures 2 through 5. Initial argon and K-Ar isochron diagrams were drawn for the Tertiary plutonic rocks (Trail, Rainy Day, and Coryell, Figs. 2 and 3) and the lamprophyre dikes (Figs. 4 and 5). A least squares cubic regression (York, 1966) was used to fit the best straight line to the data, and an age was calculated from the resultant slope. The intercepts on the initial argon diagrams, within the analytical limits, indicate a negligible initial argon contamination. The isochron diagrams indicate that it is reasonable to assume for the conventional age calculations an initial $Ar^{40}/Ar^{36}$ ratio of 295.5. A comparison of the ages obtained by the two methods shows very good agreement. The conventional mean ages for the plutonic rocks and the dikes are 49.2 ± 1.0 and 48.3 ± 0.6 m.y., respectively, while the graphical analyses yielded 47.9 ± 1.4 and 48.6 ± 0.8 m.y., respectively.

For the Rossland monzonite samples, on the other hand, a coherent pattern was not obtained, and the points scattered when the data were plotted on isochron and initial argon diagrams. The conventional ages are also discordant and, although the discrepancy was not resolved here, it is very probable that the monzonite is exhibiting the effects of a partial degassing by the younger intrusives or the dike swarm, or the samples may have contained some secondary hydrothermal biotite.

Widespread heating of the rocks by Coryell batholith and the many small bodies of Coryell plutonic rocks may have taken place, but the evidence suggests that it has not affected the K-Ar ratios. The isochron plots (Figs. 2 to 5) which are sensitive to argon loss would be invalid, as they are in the case of the Rossland monzonite, if subsequent heating had been significant. The striking uniformity of the ages

determined from different mineral and whole rocks analyses and the short interval that they represent would not be expected to result from reheating by the complex Coryell plutonic suite. Finally, bodies of Coryell rocks have been very narrow aureoles of thermal metamorphism. Although additional analytical work is necessary to prove that the heating effect of the Coryell rocks is insignificant, the present K-Ar results, except those for the Rossland monzonite and the Conglomerate dike, are considered to represent the true ages of the rocks.

### Sequence of Intrusion and Tertiary Volcanism

The absolute ages determined in this study show that a large number and wide variety of Tertiary intrusive rocks occur in the Rossland camp. They were emplaced after the Rossland monzonite, as indicated by the geological relationships and by the radiometric dates, and at about the same time as the OK volcanic rocks were being extruded. Diagnostic and relatively complete geological relationships between the intrusives and the OK volcanics have been observed in the field. The K-Ar data, including the range in the apparent age which results from the precision of the analyses shown in Figure 6, are arranged according to their observed geological ages. The analyses show that, considering the limits of accuracy, the Trail batholith, Rainy Day stock, Coryell plutonic rocks, and the dikes were emplaced at one time. The range in apparent ages is very small and is not great enough to distinguish between them, but in most cases the average ages are not inconsistent with the geological relationships.

The apparent age of the OK volcanic sample is

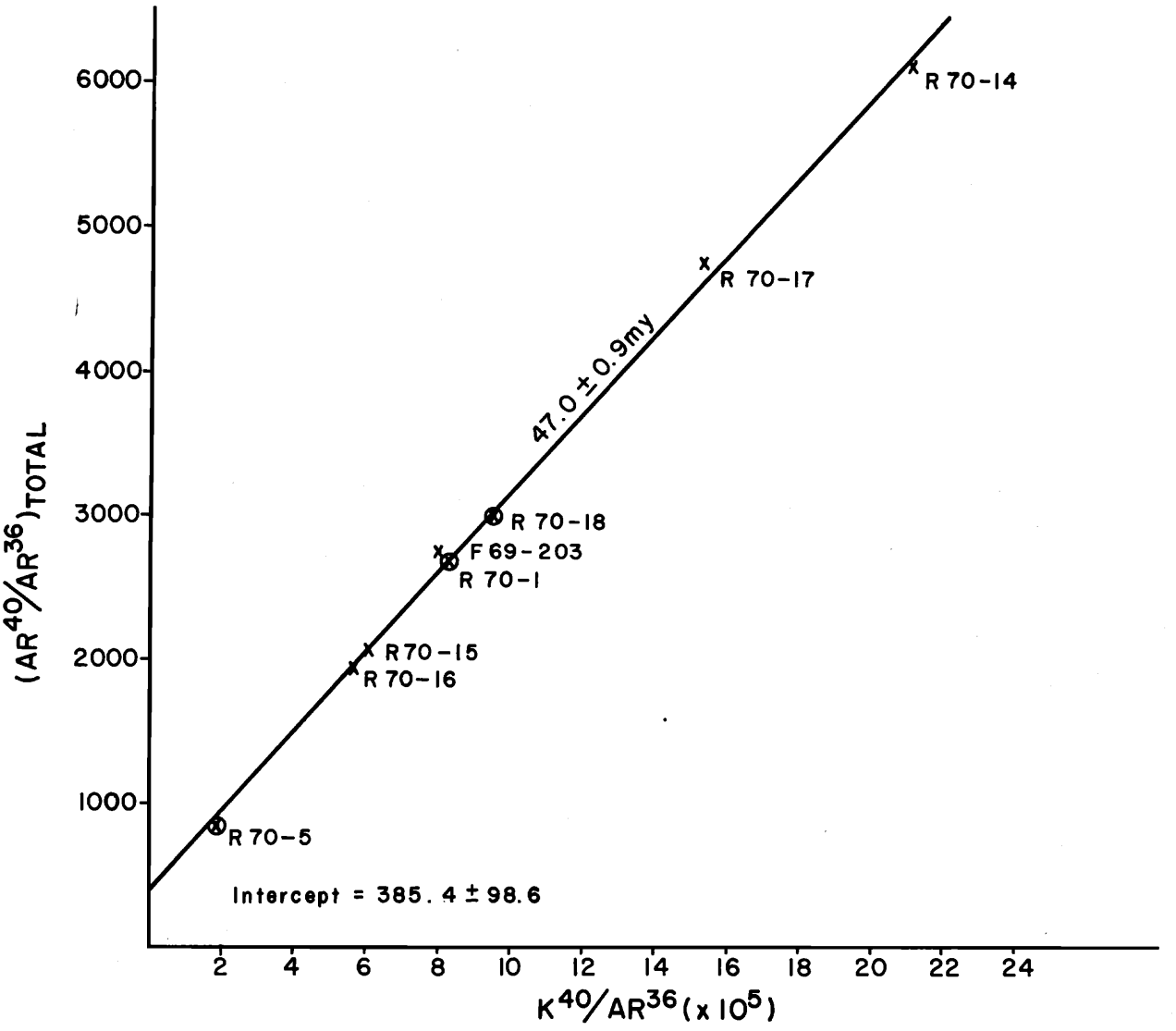


FIG. 3. Isochron diagram for all the Tertiary rocks except the dikes.

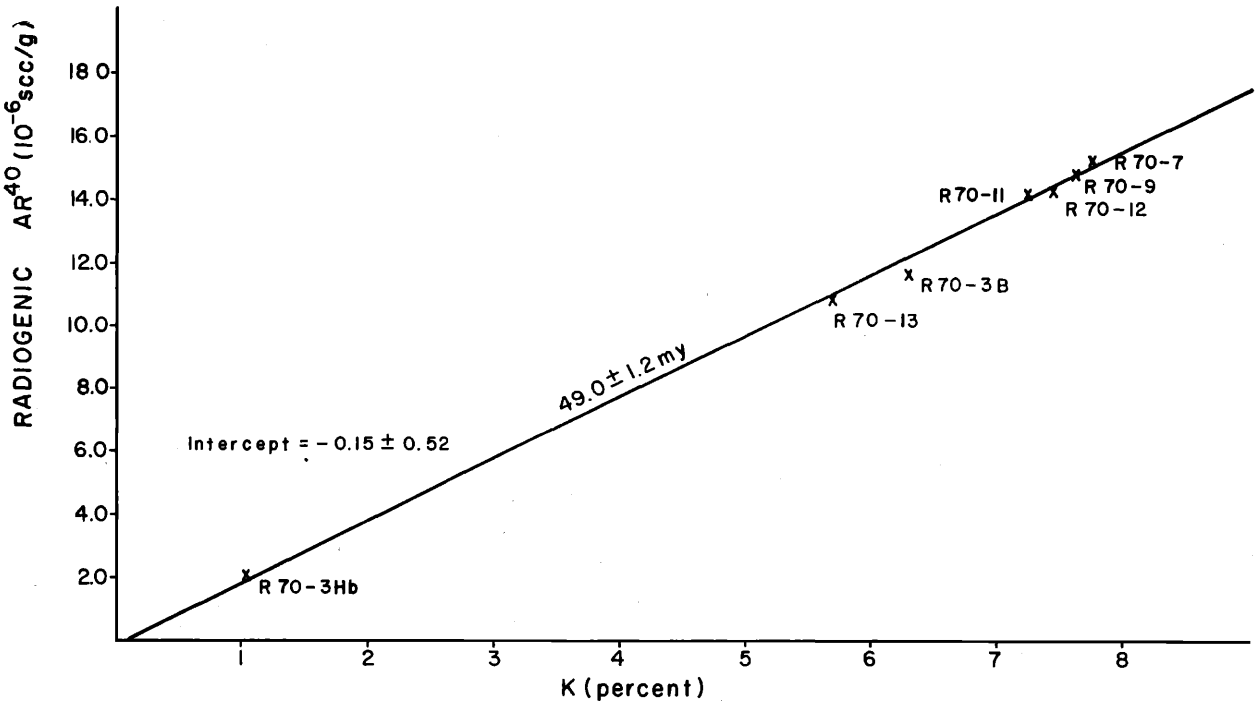


FIG. 4. Initial argon diagram for the Rossland area dikes.

consistent with the geological observation that the Coryell syenite intrudes and has locally metamorphosed the volcanic rocks. The volcanics are not known to be intruded by dikes of the suites that have been dated, and they are not in contact with the other plutonic rocks.

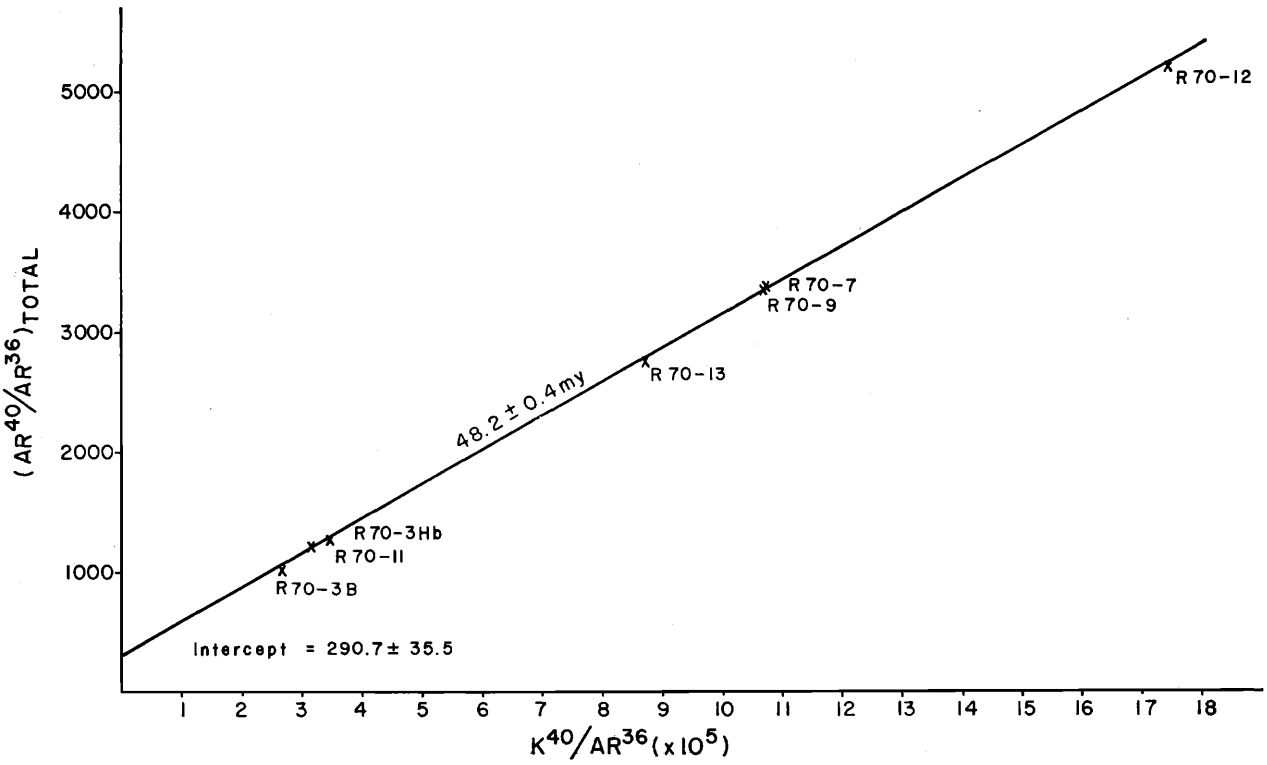


FIG. 5. Isochron diagram for the Rossland area dikes.

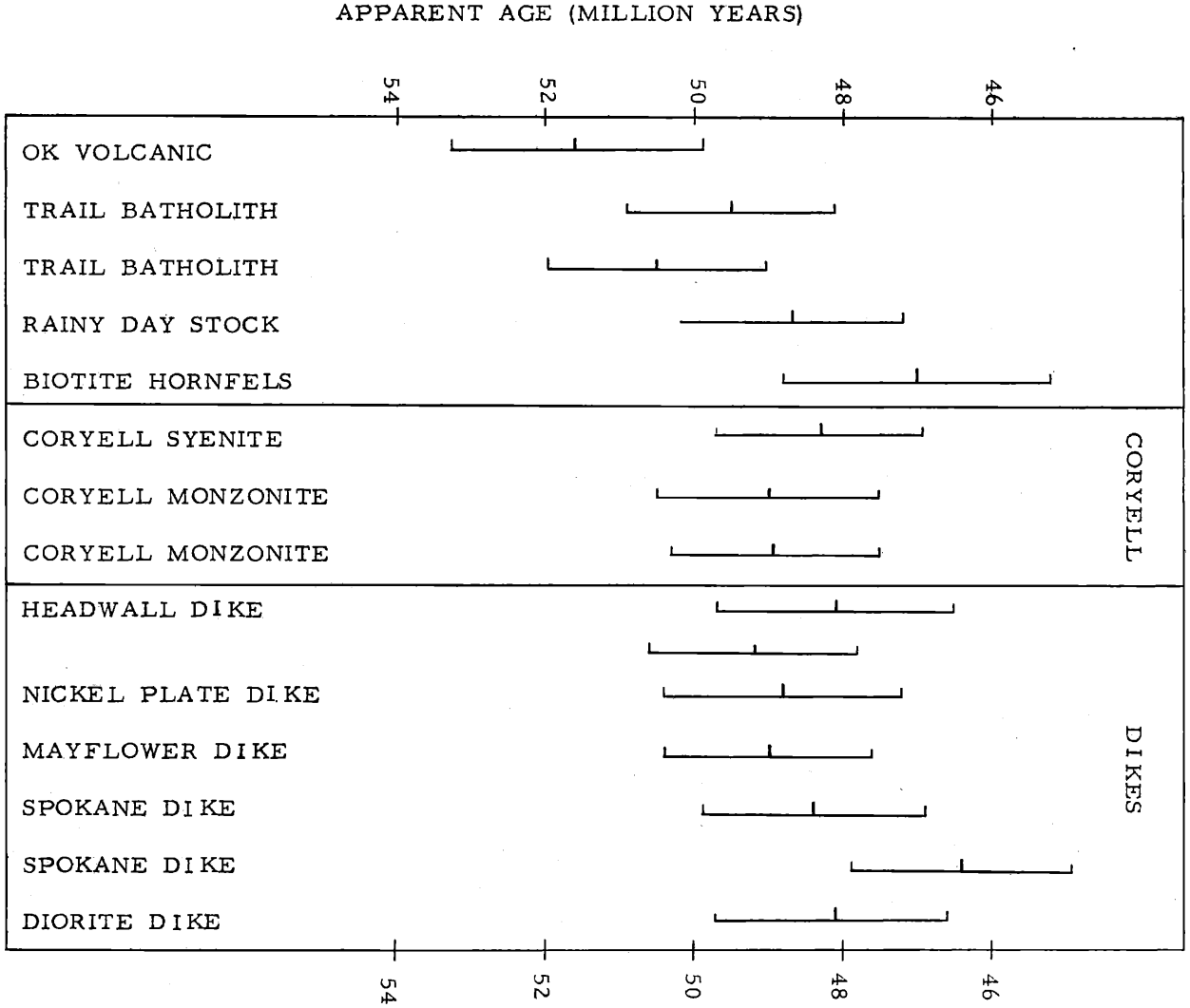


FIG. 6. Diagram showing the relative ages of Tertiary rocks in the Rossland area.

The average age of the two samples from the Trail batholith (50.0) is somewhat greater than that of the Rainy Day stock (48.7) and the average of the three ages of the Coryell plutonic rocks (48.4). Coryell rocks intrude the Rainy Day stock along its western margin. All the plutonic rocks are intruded by the mafic dikes the average age of which (ignoring the Conglomerate dike) is 48.3 m.y.

### Age of Mineralization

Of the two types of sulfide mineralization in the Rossland camp the molybdenite is the older. Molybdenite and pyrrhotite occur in small, closely spaced irregular fractures throughout a breccia complex composed mainly of hornfelsic siltstone. The origin of the breccia complex is uncertain, but it is an old breccia consisting of slightly disoriented blocks up to 50 feet across and smaller highly jumbled blocks, all of which have been thermally metamorphosed, altered and intruded by dikes. Easterly trending dikes of quartz diorite related to the Rainy Day stock have zones of potash feldspar associated with them. Molybdenite occurs in fractures in both the quartz diorite and the zones of potash feldspar and is, therefore, younger than 48.7 m.y. The Headwall dike and the Diorite dike, both of which are 48.1 m.y., transect molybdenite-bearing fractures and appear to be later than the sulfides. The close spatial relationship of the molybdenite with the quartz diorite dikes and the Rainy Day stock suggests a genetic relationship between the sulfides and these intrusions.

The copper-gold mineralization consists of pyrrhotite, chalcopyrite, altered wall rock, and minor quartz and carbonates (Gilbert, 1948) in well-defined veins. The veins have three principal trends, north 60–70° east, east and south 30° east and dip steeply

to the north. The main veins have been mined to depths as great as 2,400 feet below the surface, and at least one appears to be continuous on surface for about a mile. The sulfides in the veins are later than the lamprophyre dikes, as indicated earlier (see Introduction), and the veins transect and are later than the molybdenite in the breccia complex. Consequently the copper-gold mineralization is younger than the average age of the lamprophyre, 48.3 m.y. An upper limit to the age cannot be set with certainty but it seems reasonable to assume that the mineralization is genetically related to one of the plutonic masses, probably the Trail batholith, and is therefore not far from 48 m.y. in age. A study of the vein mineralization by Thorpe (1962) showed a regional zoning of minerals in the veins and a higher temperature of deposition in the central zone. The central zone contains the main mines of the camp and suggests that the immediate source of the metals was in this area.

## Conclusion

This study of the K-Ar age of plutonic and dike rocks in the Rossland camp indicates that the age of the sulfide mineralization is about 48 m.y. Geological relationships suggest that the crust in the immediate area at about this time was in a state of extension which led to the opening of fracture sets, many of which were inherited from older stress systems. The sulfides were deposited in short, almost momentary periods of time geologically, in response to two pulses in crystallization history of the Trail batholith: an earlier one which engendered the molybdenite deposits, and a later, deeper one, which gave rise to the copper-gold veins. The mineralization was generated in an active subvolcanic environment.

In the analytical work it has been shown that initial argon and isochron studies yield information which can be used to test some of the basic assumptions made in conventional K-Ar age determinations.

## Acknowledgments

This work has been in part supported by operating grants from the National Research Council. In addition, one of us (J. Harakal) wishes to thank P. Christopher and J. Blenkinsop for their helpful discussions regarding the potassium-argon isochron method. V. Bobik also assisted with mineral separations and potassium analyses. This paper is published by permission of the Chief, Mineralogical Branch, British Columbia, Department of Mines and Petroleum Resources. While the paper was in the final stages of editing, Dr. W. H. White, Professor of Economic Geology at the University of British Columbia, died. His inspiration and help is gratefully acknowledged by his co-authors. This paper is one of a series of studies of the age of sulfide mineralization in the Cordillera of British Columbia which have been an important part of Dr. White's research for the last 10 years.

JAMES T. FYLES
BRITISH COLUMBIA, DEPARTMENT OF MINES AND PETROLEUM RESOURCES
VICTORIA, B. C., CANADA

J. E. HARAKAL
DEPARTMENT OF GEOLOGY
UNIVERSITY OF BRITISH COLUMBIA
VANCOUVER 8, B. C., CANADA
*April 10, June 27, 1972*

## REFERENCES

Brock, R. W., 1906, Preliminary report on the Rossland, British Columbia mining district: Canada Geol. Survey Rept. 939.
Bruce, E. L., 1917, Geology and ore deposits of Rossland, B. C.: British Columbia Dept Mines Bull. 4.
Cairnes, C. E., 1934, Slocan Mining Camp, B. C.: Canada Geol. Survey Mem. 173.
Drysdale, C. W., 1915, Geology and ore deposits of Rossland, B. C.: Canada Geol. Survey Mem. 77.
Eastwood, G. E. P., 1966, Minister of Mines, B. C., Ann. Rept., p. 200–207.
Fyles, J. T., 1967, Minister of Mines, B. C., Ann. Rept., p. 236–238.
—— and Hewlett, C. G., 1954, Stratigraphy and structure of the Salmo lead zinc belt: British Columbia Dept. Mines Bull. 41, p. 44–46.
Gilbert, G., 1948, Rossland camp, *in* Canadian Inst. Mining Metallurgy, Geol. Div., Structural geology of Canadian ore deposits (Jubilee vol.), p. 189–196.
Hayatsu, A., and Carmichael, C. M., 1970, K-Ar isochron method and initial argon ratios: Earth Planet. Sci. Letters, v. 8, p. 71–76.
Little, H. W., 1960, Nelson map-area, west half, British Columbia: Canada Geol. Survey Mem. 308.
—— 1963, Rossland map-area, British Columbia: Canada Geol. Survey Paper 63–13.
Mathews, W. H., 1953, Geology of the Sheep Creek Camp: British Columbia Dept. Mines Bull. 31, p. 31–35.
—— 1963, Thirteen potassium argon dates of Cenozoic volcanic rocks from British Columbia: Univ. British Columbia Dept. Geology Rept. 2.
Monger, J. W. H., 1968, Early Tertiary stratified rocks, Greenwood map-area: Canada Geol. Survey Paper 67–42.
Nguyen, K. K., Sinclair, A. J., and Libby, W. G., 1968, Age of the northern part of the Nelson batholith: Candian Jour. Earth Sci., v. 5, p. 956–959.
Roddick, J. C., and Farrar, E., 1971, High initial argon ratios in hornblendes: Earth Planet. Sci. Letters, v. 12, p. 208–214.
Thorpe, R. I., 1962, Mineralogy and zoning of the Rossland area: Unpub. Ph.D. thesis, Univ. Wisconsin.
Walker, J. F., 1934, Geology and mineral deposits of the Salmo map-area: Canada Geol. Survey Mem. 172.
White. W. H., 1949, Rossland south belt: Minister of Mines, B. C., Ann. Rept., 1949, p. 157–163.
—— Erickson, G. P., Northcote, K. E., Dirom, G. E., and Harakal, J. E., 1967, Isotope dating of the Guichon Batholith, B. C.: Canadian Jour. Earth Sci., v. 4, p. 677–690.
Yates, R. G., and Engels, J. C., 1968, Potassium-argon ages of some igneous rocks, in northern Stevens County, Washington: U. S. Geol. Survey Prof. Paper 600-D, p. D242–D247.
York, D., 1966, Least squares fitting of a straight line: Canadian Jour. Physics, v. 44, p. 1079–1086.