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Keystone porphyry molybdenum occurrence, south-central British Columbia

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ABSTRACT

The Keystone porphyry molybdenum deposit, located in south-central British Columbia, is hosted by intrusive rocks of the Cretaceous Mount Lytton batholith and the early Tertiary Keystone quartz diorite stock. The molybdenite mineralization is associated with rhyolite porphyry dikes flanking a large 1300 m by 2100 m breccia complex. Recognition of the potential for the buried molybdenum porphyry system was based on quartz-molybdenite vein fragments within the hydrothermal breccias.

The full extent of the molybdenum mineralization is not known. The few deep drill holes along one corner of the breccia complex defines strong metal zoning of molybdenum and associated elements of F, Mn, Zn, Pb, Au, Ag, Fe and W about the molybdenum stockwork mineralization that may be useful for guiding additional exploration. The best mineralization occurred near the base of the deepest drill hole with 0.114% Mo in rhyolite porphyry near the edge of the breccia pipe at a depth of 1350 m.

The exploration history of the deposit has been complex, focussing on both porphyry-style mineralization and precious metal veins and stockworks on the periphery of the porphyry system. Exploration to date has defined an attractive porphyry molybdenum system with uneconomic grades at great depth; however, there remains significant potential to define economic mineralization elsewhere in the Keystone porphyry system and adjoining occurrences.

Introduction

This paper records the exploration history that led to the discovery of the buried Keystone porphyry molybdenum deposit, and describes the geology, alteration and lithogeochemistry of the deposit.

The Keystone porphyry molybdenum deposit is located in south-central British Columbia, approximately 65 km southwest of Merritt, within the Nicola Mining Division (Fig. 1). The deposit lies on the west side of the Coldwater River and was accessible by gravel roads from Merritt, Princeton and Hope during the period of active exploration. Now, the new Coquihalla Highway (Hwy. 5) crosses the southeast edge of the property.

The property is at an elevation of 1060 m to 1200 m in the moderately subdued topography that characterizes the valley of the Coldwater River and Interior Plateau. Glacial cover is locally extensive, providing few outcrops, particularly on the surface expression of the deposit. Forest cover is locally thick.

Regional Geologic Setting

The Keystone and Juliet Creek molybdenum occurrences lie along the eastern edge of the northwest-trending Cretaceous Mount Lytton batholith within the Intermontane Tectonic Belt. The eastern margin of the batholith is in contact with Upper Triassic Nicola Group and Upper Cretaceous Kingsvale Group volcanic and sedimentary rocks (Roddick et al., 1973). Along this margin the batholith consists of Cretaceous foliated Eagle granodiorite cut by a younger, non-foliated Cretaceous or Tertiary (?) Keystone quartz diorite pluton. Both intrusive units are cut by younger breccias, as well as mafic and felsic dike rocks. Molybdenum and precious metal mineralization appear associated with the intrusions that caused the breccia event.

The dominant structural features in the Keystone area are the northwest-trending margin of the Mount Lytton batholith, foliation within the Eagle granodiorite, and the north-trending valley of the adjacent Coldwater River which immediately flanks the mineralized area to the east. Other structural features may be reflected by the northeast trending valleys of Mine Creek and Blue Gold Creek.

Exploration History

Early exploration history in the area is documented in British Columbia Minister of Mines Annual Reports. Numerous assessment reports are available through the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Keystone Area

The Keystone area (Fig. 1) has a relatively long history of exploration and development. The area is named after the Keystone base-precious metal vein which was first discovered in 1901 and later explored by three short adits and surface stripping (British Columbia Ministry of Mines, 1936). The vein is up to 30 cm wide with values of 2.06 g/t Au, 775 g/t Ag, 2.1% Pb and 4.9% Zn. Renewed activity in 1954 and 1955 led to the shipment of 81 tonnes of crude ore. The nearby Stonewall vein occurrence was also trenched and explored at this time (Fahrni, 1954). Anaconda conducted soil geochemistry and induced polarization surveys in the area around the Keystone adits and 580 m of trenching over a large zinc soil anomaly. Although not recognized at that time, this work started to define the pyritic north edge of a large breccia body.

The Julie occurrence, approximately 1200 m south of the Keystone adits, lies along the southwestern edge of the breccia complex. It was explored by Dorian Mines Limited in 1965. Dorian stripped the surface cover over a large zinc soil anomaly and drilled 32 short diamond drill holes totalling 2018 m. A near-surface drill indicated reserve of 96 765 tonnes grading 8.5 g/t Ag, 0.1% Cu and 0.6% Zn was reported within a pyrite-hematite altered zone containing stringers of sphalerite, galena, magnetite and rhodochrosite.

In 1967, Jack Nott of Penticton undertook extensive trenching 800 m southeast of the Julie showing. This area was drilled by Noranda in 1969. The creek draining the Keystone and Julie prospects became known as Mine Creek. Exploration in the Mine Creek area continued in 1969 with Noranda Exploration Company drilling five holes (NC-69 series holes, Fig. 1) in a pyritic zone on

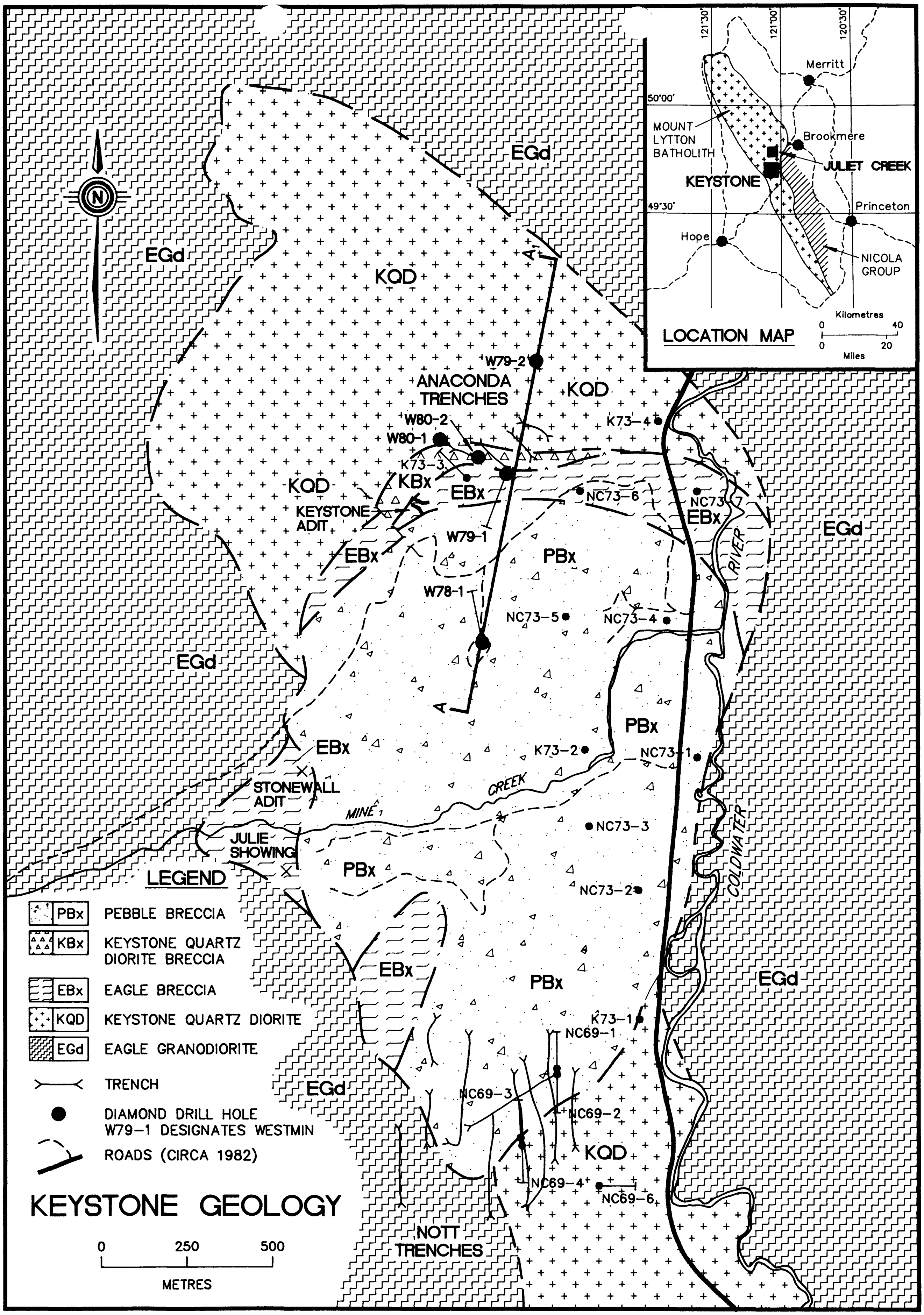

FIGURE 1. General location and property geology map.

an intrusion-breccia contact, later to be recognized as the south edge of the large Keystone breccia complex.

In 1970, Corval Resources Ltd. acquired the property and completed induced polarization and magnetometer surveys north and south of Mine Creek, in the area of the Keystone vein and Julie showing. This work defined a large annular chargeability anomaly around a 1400 m by 1200 m core of low chargeability that corresponds to the large Keystone breccia body (Gutrath, 1973). Zinc, lead and silver soil anomalies coincide with the chargeability anomaly. Geochemical anomalies correspond with the Keystone vein on the north, Julie showings on the west, and the area of trenches by Nott.

Noranda Exploration Company and Denison Mines optioned the remainder of the property from Corval Resources Ltd. in 1973 and drilled eleven shallow holes totalling 1044 m in the NC-1-73 and DDH-1-73 series of holes (Fig. 1). The holes tested the north and east parts of the chargeability anomaly along the contact of the breccia and intrusive rocks.

Juliet Creek Area

In 1973, El Paso Mining and Milling Company staked claims on the south side of Juliet Creek approximately 5000 m northwest of the Keystone vein workings. Location of the claims was based on weak copper and molybdenum stream sediment anomalies. Geologic mapping and soil geochemical sampling were conducted in 1973 followed by trenching of the copper and molybdenum soil anomalies. This work defined a broad zone of brecciated Eagle granodiorite with sparse molybdenite in some breccia fragments and quartz veins.

Discovery of a Deep Molybdenum Porphyry System

During the summer of 1977, Wayne Livingstone of JMT Services Corp. staked claims covering all the previously known showings in the Mine and Juliet creek areas and optioned them to Western Mines Limited, a predecessor to Westmin Resources Limited. The Juliet Creek and Keystone areas, and the Blue Gold showing midway between these two previously explored areas of porphyry mineralization, were geologically mapped in the fall of 1977 and sampled for alteration studies and lithogeochemistry (Livingstone, 1978). During this program molybdenite-bearing quartz fragments were noted in drill core of Keystone quartz diorite breccia in Noranda drill hole DDH-3-73 and were interpreted to have been derived from a buried porphyry molybdenum deposit.

A joint venture was completed July 1978 between Western Mines Limited and Amax of Canada Limited. A new grid was established and the venturers completed geologic mapping, induced polarization surveys and silt, soil and rock geochemistry surveys on all three mineralized areas. The latter included lithogeochemistry on core from previous Noranda drill holes. One 859-m vertical diamond drill hole (W-78-1) was drilled in the north part of the breccia complex, approximately 400 m south-southeast of the Keystone workings (Saleken, 1979a).

In 1979, two new holes were drilled on the Keystone property, and hole W-78-1 was deepened (Saleken, 1980). Down-hole induced polarization surveys were completed in drill holes W-78-1 and W-79-1. The three holes form a north-south fence across the north breccia-intrusive rock contact with hole W-78-1 being the most southerly and wholly within the breccia, hole W-79-1 approximately 510 m to the north and situated on the breccia complex contact, and hole W-79-2 drilled 330 m further north within Keystone quartz diorite (along section A-A′). Despite deepening, hole W-78-1 failed to get out of the breccia unit. W-79-1 intersected brecciated Keystone quartz diorite and Eagle granodiorite with significant molybdenum mineralization below 1000 m. Hole W-79-2 was entirely within fresh to weakly altered Keystone quartz diorite with no significant mineralization. Amax of Canada withdrew from the joint venture in March 1980.

Two additional holes were drilled to the northwest of hole W-79-1 in the summer of 1980 to test for extensions of the mineralization intersected by W-79-1 (Randall, 1980). Hole W-80-2, 230 m northwest of W-79-1, intersected relatively fresh Keystone quartz diorite in the upper 70 m, brecciated and altered quartz diorite between 70 m and 550 m depth and fresh quartz diorite from 550 m to 642 m. Hole W-80-2, situated 100 m northwest of W-79-1, intersected brecciated Keystone quartz diorite from 35 m to 620 m, and relatively fresh quartz diorite from 620 m to the end of the hole at 775 m. Molybdenite fracture fillings were noted in the lower brecciated parts of both drill holes.

There has been no reported exploration of the molybdenum porphyry since 1980. The Julie zone and Keystone vein were again explored for their precious metal potential by Westmin in 1981 (Ferguson, 1981).

Geology

Discussion will focus on the Keystone area where there is drill hole information, and the geology, alteration and mineralization are better understood. Furthermore, the advancement of the geologic thinking through the various exploration programs will be highlighted. Unfortunately, many of the details of geological understanding that contributed to the deep drilling proposals have been lost through the years.

Eagle Granodiorite

The Eagle granodiorite is part of the Mount Lytton batholith and is the main host lithology in the area. The Eagle granodiorite has been dated at 104 ± 2 Ma by the K-Ar method on biotite, although muscovite in pegmatite has given an age of 71.7 ± 1.2 Ma and biotite from a quartz vein cutting Eagle granodiorite an age of 85.4 ± 4 Ma (Roddick and Farrar, 1972).

The Eagle granodiorite is a foliated, biotite-bearing, leucocratic, hypidiomorphic-textured rock containing irregular inclusions of paragneiss and small irregular patches of pegmatite. It is a generally fine-grained, foliated rock with blotchy coarse biotite. The regional foliation trends 140° to 160° and dips steeply (Rice, 1947).

Keystone Quartz Diorite

The Keystone quartz diorite is an irregular-shaped pluton that intrudes the Eagle granodiorite. It appears to have been elongate along the direction of the northwest-trending foliation in the Eagle granodiorite before it was truncated by the breccia complex. The present surface expression is approximately 1500 m by 1400 m in the area north of the breccia complex, and 600 m wide on the south edge of the breccia complex. This implies a pluton length of 3500 m in a north-northwest direction and a maximum width of 1400 m. The Keystone quartz diorite was not dated by Roddick and Farrar (1972); however, Wallace (1981) reports a 53.5 Ma age from K-Ar dating of biotite by McMillan of the British Columbia Ministry of Energy, Mines and Petroleum Resources (1979).

The quartz diorite is a non-foliated, equigranular rock with a 2 mm to 3 mm grain size, having a "salt and pepper" texture. It is typically fresh in appearance, except near the breccia, where it is hydrothermally altered. It is composed of 50% to 60% plagioclase, 15% quartz, 10% biotite and 5% hornblende with accessory sphene, apatite, zircon and magnetite (Saleken, 1979a).

Dike Rocks

There are numerous dikes of various composition including andesite, felsite, biotite-quartz-feldspar porphyry dacite, diorite, aplite and pegmatite. The andesite dikes are most abundant and are dark green, massive, commonly porphyritic or trachytic textured. They are generally less than 1 m in thickness and trend parallel to the regional foliation. They intrude not only the Eagle granodiorite and the Keystone quartz diorite, but also the Keystone breccia complex (Saleken, 1979a).

Felsite dikes are observed within the Nott and Anaconda trenches, Stonewall adit and trenches at the Julie showing. They also cut the Keystone breccia complex. The felsites are light grey to white microcrystalline, siliceous dacite or rhyolite. Drill core shows that they are commonly fractured or brecciated, with variable sericite alteration and disseminated pyrite. Some felsic dikes are quartz or feldspar porphyritic and exhibit banding or flow textures. They commonly strike northeasterly and occur as less than 1 m thick, bodies cutting Eagle granodiorite, Keystone quartz diorite and the breccia.

In drill core the felsites have been logged as feldspar porphyry or quartz-feldspar porphyry rhyolite. They have 10% to 15%, up to 3 mm, feldspar phenocrysts and up to 10% quartz phenocrysts to 4 mm in size. Locally, the feldspar phenocrysts appear to have been replaced by K-feldspar. The matrix and phenocrysts are variably altered to sericite, calcite and anhydrite.

Biotite-quartz-feldspar porphyry dacite dikes contain euhedral to rounded phenocrysts of quartz, plagioclase feldspar and biotite in a dark grey, fine-grained matrix of quartz, sericite, chlorite and clay minerals. These dikes are mainly peripheral to and northeast of the Keystone quartz diorite cutting the Eagle granodiorite.

Fine-grained diorite dikes appear to be darker or more mafic offshoots of the Keystone quartz diorite. They occur in the Nott trenches on the south side of the breccia complex, cutting Keystone quartz diorite, and cutting Eagle granodiorite in the area immediately north of the Keystone quartz diorite pluton.

Aplite and pegmatite occur mainly in Eagle granodiorite as narrow dikes and irregular veins; they also cut the breccia complex. They are particularly abundant northwest of the Keystone quartz diorite toward the Blue Gold showing. The rocks are pink to grey, varying from fine to coarsely crystalline quartz and feldspar.

Keystone Breccia Complex

The Keystone breccia complex is a multi-phase, elliptical body that is elongate north-south. It has maximum surface dimensions of approximately 2100 m by 1300 m, and cuts both the Eagle granodiorite and Keystone quartz diorite (Saleken, 1979a). The subsurface shape of the breccia complex is poorly understood; however, it appears to be a steeply plunging pipe-like body; steep inward dips have been observed at its north contact.

The core of the Keystone breccia complex consists of a pebble breccia. Near its periphery it grades into brecciated Eagle granodiorite or Keystone quartz diorite. They are referred to herein as Pebble breccia, and Eagle granodiorite breccia or Keystone quartz diorite breccia, depending on the host or dominant fragment lithology. At surface, the Eagle and Keystone breccias form an envelope 100 m to 250 m wide on the Pebble breccia.

Pebble Breccia

Pebble breccia makes up approximately 85% of the breccia complex. It consists of a heterogeneous mix of fragments of Eagle granodiorite, Keystone quartz diorite, and all the dike rocks. The breccia is layered with bands of alternating fine clastic material with less than 2 mm grain size, and sand- to pebble-sized material with a few fragments that range to 4 cm in diameter. All the matrix and fragment material is believed to be derived from the intrusive rocks. Internal layering in surface outcrops and in drill core in W-78-1 suggest inward dipping layering; however, the 20° to 50° dips are much shallower than the steep dip of the breccia contact suggested by drill hole W-79-1 (Fig. 2).

Fragments in the Pebble breccia are generally rounded and well sorted in a chalky white, porous matrix of sericite, clay, quartz, pyrite, chlorite, albite and carbonate. Composition of rock types in the coarse fraction is 40% Keystone quartz diorite, 35% Eagle granodiorite, 10% quartz breccia and 15% quartz vein, dacite, dacite porphyry, felsite, aplite and andesite dike fragments. Approximately 1% of the clasts contain pyrite, sphalerite, galena, chalcopyrite, hematite, molybdenite or unidentified sulphosalt minerals. Many of the granodiorite or quartz diorite fragments are silicified and cut by quartz-pyrite veinlets. Other fragments consist entirely of quartz. The matrix is comminuted rock flour that is locally cemented with Fe-, Mg- and Mn-rich carbonates.

Quartz breccia is a variety of fragment in Pebble, Eagle or Keystone breccias wherein there is extensive silicification and lesser pyritization of the matrix and granitic fragments. This silicified breccia has been rebrecciated and occurs as clasts in the Pebble breccia, particularly in the upper part of hole W-79-1 and deeper part of W-78-1.

Eagle Granodiorite Breccia

Eagle breccia is peripheral to the Pebble breccia and grades outward, through an irregular zone up to 250 m wide, into non-brecciated Eagle granodiorite. The character of the breccia varies from matrix-supported rotated fragments of Eagle granodiorite near the Pebble breccia; outward it forms an in-situ crackled stockwork appearance with little fragment rotation. Granodiorite fragments range from sand size to large blocks, averaging approximately 20 cm, and are commonly altered with sericite, chlorite and epidote replacing feldspars and mafic minerals. Fragments have sharp contacts with the compositionally similar matrix material. Matrix generally makes up less than 5% of the breccia, except near its inner gradational contact with the Pebble breccia.

Keystone Quartz Diorite Breccia

Keystone quartz diorite breccia was intersected in drill holes W-79-1, W-80-1 and W-80-2 and is transitional between the Pebble breccia and crackled and fractured Keystone quartz diorite. The relationship with Eagle breccia is not well defined but intermixing of Eagle granodiorite and Keystone quartz diorite fragments is apparent in some breccias. Locally the Keystone breccia consists of large to small angular fragments of Keystone quartz diorite and fewer rhyolite fragments in a silicified matrix of finer rock fragments. The breccia grades into crackle brecciated Keystone quartz diorite that is veined by quartz and pyrite. Fragments generally have sharp contacts and are variably silicified and sericitized. Local argillic alteration of fragments occurs nearer the Pebble breccia. In drill holes the Keystone breccia alternates with variably quartz veined quartz diorite and with quartz, pyrite and molybdenite stockwork at depth.

Alteration

The intensity of alteration increases sharply in proximity to the breccia complex, with depth in the porphyry system and near mineralization. The Eagle granodiorite is weakly altered, except adjacent to the breccia complex and in the area north of the Keystone quartz diorite. Similarly, the Keystone quartz diorite is also quite fresh and unaltered away from the breccia complex.

The alteration assemblages and sequence of development have not been studied in detail; however, there appear to be three main types: propylitic, phyllic and carbonate. The various alteration mineral assemblages also exhibit relative timing and spatial relationships, which vary according to host rock type.

Propylitic Assemblage

Propylitic alteration occurs in both Keystone quartz diorite and Eagle granodiorite. It is well developed in the most northerly drill hole (W-79-2) that was completed to a depth of 918 m in Keystone quartz diorite. The quartz diorite is characterized by patchy, light green alteration within feldspars replaced by sericite and carbonate, and chloritized mafic minerals. The variably altered quartz diorite is also cut by numerous thin veinlets and veins up to several centimetres thick of chlorite, specular hematite, epidote and carbonate with or without anhydrite-pyrite or quartz-pyrite. These veins also host variable amounts of sphalerite, chalcopyrite, galena or magnetite, generally with vein quartz. Occasionally, minor molybdenite

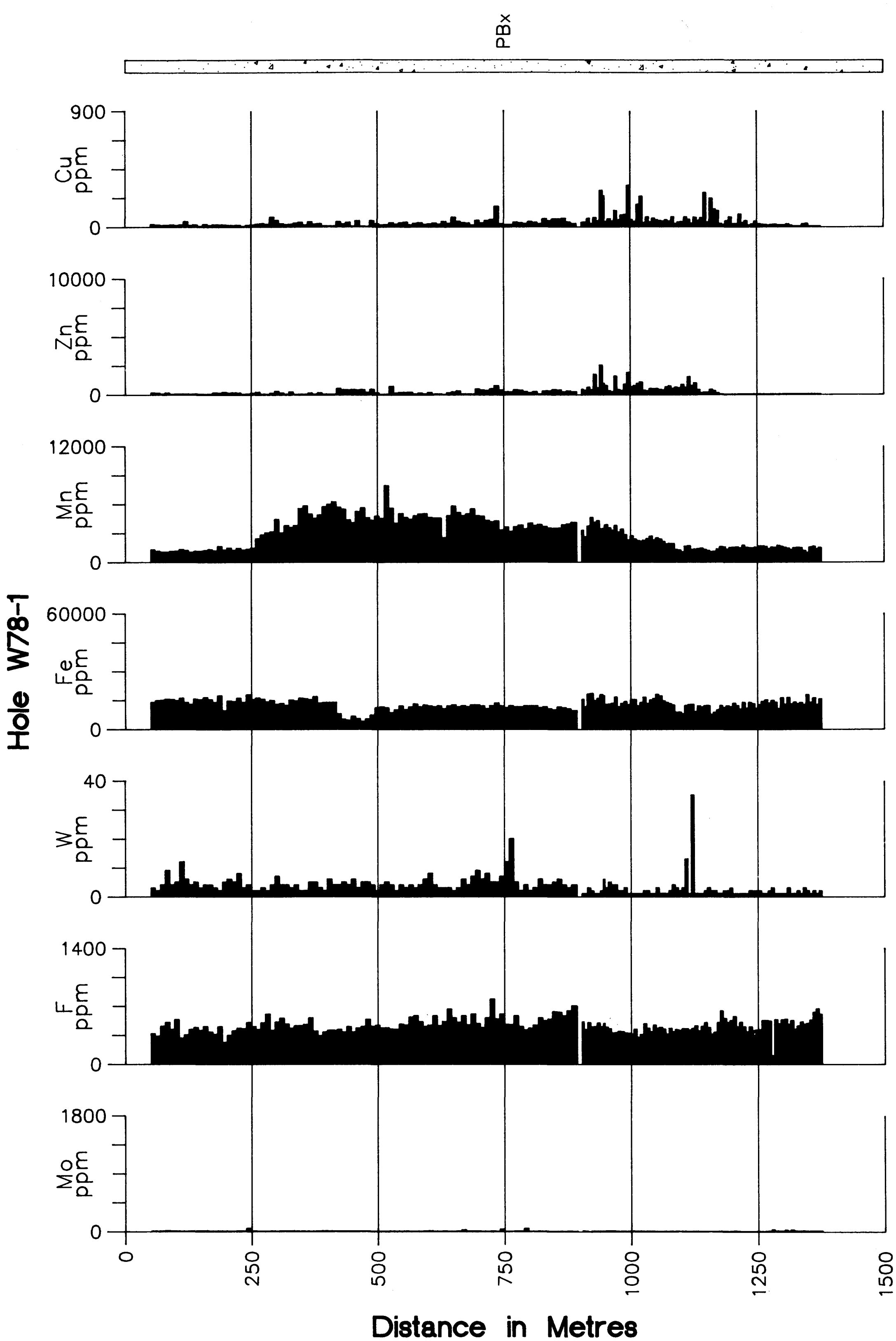

FIGURE 2. Schematic geologic cross-section, A-A′.

occurs on chloritic fractures with gypsum. In the deeper part of the hole, quartz-pyrite-anhydrite veinlets become more common, giving way to quartz-pyrite veins near the bottom of the hole, where sericitization becomes more intense.

Phyllic Assemblage

Mineralogy of the phyllic assemblage is sericite, quartz and pyrite with lesser anhydrite and chlorite (note: drill core logging did not consistently discriminate between anhydrite and gypsum). The distribution and character of phyllic alteration is quite variable. Sericitization of feldspar is common in irregular or patchy zones in the propylitic zone and sericitic envelopes are common on chlorite-specular hematite fracture fillings in the quartz diorite.

The most intense sericite-pyrite alteration is associated with breccia and crackle breccia in quartz diori in matrix and fragments in Pebble breccia, and in quartz-pyrit. ckwork zones in quartz diorite and felsic dikes. The latter is characterized by abundant quartz veining with or without molybdenite and pyrite, and is locally recognizable as a separate silicification event.

Sericite-pyrite alteration in breccia and crackle breccia commonly produces concentric rims of varying colour on larger fragments from a bleached cream colour to grey in the more siliceous core of veins and matrix of breccias. Intense sericite alteration is also accompanied by 1% to 2% more pyrite as disseminations and on fractures. More intensely altered crackle breccia generally contains numerous quartz-pyrite veinlets with sericite envelopes within and between fragments. It commonly grades into and alternates with less altered quartz diorite with chloritized mafic minerals and chlorite-sericite-quartz fracture fillings.

Sericite in the matrix of the Pebble breccia is commonly intermixed with clay minerals, particularly in the presence of carbonate and sphalerite-pyrite-galena vein and vug fillings.

Locally, a silica-pyrite assemblage has been recorded to identify more silica and pyrite-rich portions of the phyllic assemblage. It is accompanied by strong sericitization of the host rock and variably abundant quartz-pyrite-molybdenite veinlets. This is the alteration-mineralization assemblage that characterizes the molybdenite-bearing quartz vein fragments in the Pebble breccia that intrigued early explorationists and led to the drilling of the deep holes. It is also likely the source of the quartz breccia fragments observed in the Pebble breccia.

The silica-pyrite alteration assemblage is best displayed in some parts of the crackle breccia in the deeper parts of drill hole W-80-2, and in W-79-1 where sheeted quartz-sericite-pyrite veins cut the quartz diorite and are most frequent. It is best developed below 1000 m in W-79-1 with the occurrence of rhyolite porphyry dikes. These dikes and surrounding host rocks are generally strongly quartz-veined and pervasively silicified.

Carbonate Assemblage

Carbonate alteration appears to be a late event associated with widespread weak base metal mineralization. This alteration is very extensive, cutting both the breccia complex and the surrounding Eagle granodiorite and Keystone quartz diorite. The carbonate minerals occur as late vein and vug fillings and are associated with clay alteration in the Pebble breccia and the upper parts of drill holes in Keystone quartz diorite. The carbonate mineralogy has not been studied in detail; however, rhodochrosite is a common vein filling. These carbonate veins contain abundant coarse-grained sphalerite, galena and pyrite. Chalcopyrite is common in these carbonate veins in the upper parts of drill holes testing Keystone quartz diorite breccia and quartz diorite, but is sparse at depth, where quartz and anhydrite are more common gangue minerals. Within propylitic alteration zones, chlorite and specular hematite may also occur within the carbonate-base metal veins.

Carbonate, base metal sulphide veins are generally only a few centimetres wide; however, in the Keystone vein occurrence they are up to 0.5 m wide. These veins cut all other alteration and fracture controlled mineralization, and continue to depths of at least 1200 m in the porphyry system.

Potassic Alteration: K-Feldspar and Biotite

K-feldspar and biotite alteration in drill holes W-80-1, W-80-2 and W-79-1 are part of a poorly defined potassic alteration assemblage. In hole W-80-1 clusters of fine-grained biotite occur in quartz diorite adjacent to felsite or dacite porphyry dikes. Staining for K-feldspar in the deeper part of W-80-1 indicates the occasional K-feldspar veinlet and K-feldspar in the matrix of the quartz diorite.

In hole W-79-1, a K-feldspar alteration zone with minor secondary biotite was recognized from 818 m to 1070 m in quartz diorite (Saleken, 1979b). Thin section studies describe a narrow vein consisting of quartz, K-feldspar, anhydrite, apatite and pyrite from a sample at 1003 m in W-79-1. At 1035 m, plagioclase phenocrysts in porphyritic rhyolite variably replaced by K-feldspar. At 1061 m, fine-grained secondary biotite replaces primary altered biotite in quartz diorite (Payne, 1979).

Anhydrite/Gypsum

Anhydrite and/or gypsum occur as vein fillings in all drill holes, but are more abundant in the deeper parts of the drill holes. They are late-stage fillings in pyrite-sericite, quartz-pyrite or quartz-pyrite-molybdenite veinlets, and show a spatial association to areas of intense sericite alteration, such as below 1000 m in drill hole W-79-1. In thin section, plagioclases in the intensely sericitized zones in Keystone quartz diorite and rhyolite porphyry dikes are variably altered to sericite, anhydrite/gypsum and calcite. Anhydrite also occurs in quartz-K-feldspar-apatite-pyrite veinlets that cut quartz diorite, and in vein alteration envelopes (Payne, 1979). Locally, anhydrite/gypsum appears to have been an early vein stage that was subsequently cut by other vein assemblages, including a gypsum-filled fracture. Anhydrite/gypsum veining and alteration may therefore have been both an early- and a late-stage event.

Mineralization

Molybdenum

In the Keystone area, molybdenite has not been observed in surface outcrops of Keystone quartz diorite or Eagle granodiorite. It was first recognized in quartz clasts in drill core of the Pebble breccia. Most molybdenite occurrences in Keystone quartz diorite are at depths of 700 m or more; first occurrences in holes W-80-1 and W-80-2 are as molybdenite "paint" on dry fractures. Molybdenite was not observed in hole W-79-2 located 250 m north of the contact with the breccia complex.

Molybdenite also occurs in quartz veins in surface outcrops of chloritized Eagle granodiorite on the Blue Gold occurrence, approximately 2700 m northwest of the Keystone drill area. In this area the granodiorite is intruded by biotite feldspar porphyritic dacite and quartz porphyry rhyolite dikes.

At the Rover occurrence, a further 4200 m northwest, molybdenite occurs in quartz veins in Eagle granodiorite adjacent to a large multiple-phase breccia body. It also occurs in fragments of quartz porphyry rhyolite in a polymictic phase of the breccia, and as disseminated grains in the sericitic and pyritic matrix of the breccia (Livingstone, 1978). There are several similarities between these occurrences and molybdenite mineralization of the Keystone area.

In the Keystone area, the quartz-pyrite vein event preceded the main quartz-molybdenite-pyrite vein event. Molybdenite also occurs as thin films on more steeply dipping "dry" fractures that offset the quartz-pyrite-molybdenite veins. Similarly, brecciated quartz-molybdenite veins in rhyolite porphyry at 1302 m in hole W-79-1 are cut by thin fractures coated with molybdenite. All observed molybdenite is fine grained.

Analytical data for hole W-79-1 illustrates a progressive increase in molybdenum content with depth (Fig. 4). The best grades are in ribboned quartz-molybdenite veins in the rhyolite porphyry at the bottom of hole W-79-1, where grades of up to 0.114% Mo over 3 m were obtained. Molybdenite also occurs as disseminated grains in well-mineralized rhyolite porphyry in this hole. The interval from 1050 m to 1358 m has an average grade of 0.044% Mo.

The molybdenite-bearing quartz veins and fracture fillings have angles to core axis of 10° to 60°. Steeper fractures at 10° to 20° to core axis (70° to 80° true dip) commonly offset shallower dipping fractures at 30° to 40° to core axis (50° to 60° true dip). In hole W-79-1 the shallower fractures host the quartz-molybdenite-pyrite veins and are more common than the steeper fractures and veins.

The molybdenite-bearing quartz veins are generally less than 1 cm wide, with a few veins up to 3 cm. Vein density is one vein per 1 m to 2 m, in addition to more numerous molybdenite-bearing

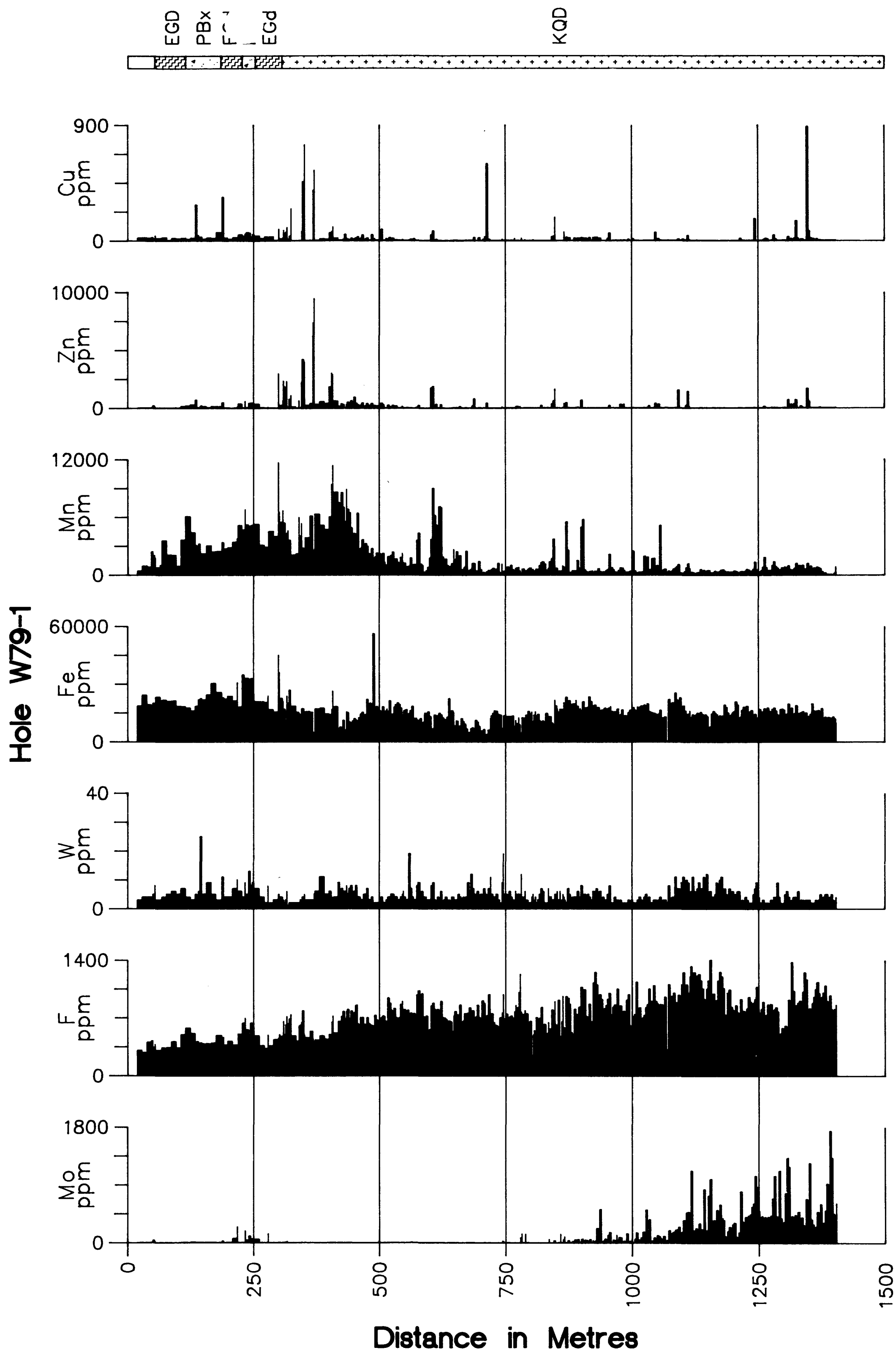

FIGURE 3. Multi-element bar graph, W-78-1.

fractures. Quartz-molybdenite veins also contain pyrite, sericite and anhydrite/gypsum. Wall rocks are generally strongly sericitized and silicified. Lithogeochemistry shows that molybdenum mineralization is associated with increased fluorine concentrations; however, fluorite has not been identified (Saleken, 1980).

Base Metal Veins

Sphalerite, galena, chalcopyrite and pyrite mineralization are common in late-stage carbonate veins that cut all rock types, and all veins related to the molybdenite mineralization. The carbonate veins, with lesser quartz, chlorite, clay minerals and hematite, vary from less than a centimetre to more than 0.5 m in width. The sulphide minerals are generally coarse-grained and fill vugs in the banded veins. The base metal sulphides and carbonate gangue generally have open space filling characteristics and probably represent a late-stage mineralizing event associated with the porphyry molybdenum event.

The carbonate-base metal veins include the Keystone, Stonewall and Julie occurrences in the Keystone area, and similar veins in the Blue Gold and Rover occurrences. These veins locally contain significant gold and silver sufficient to warrant their exploration as precious metal deposits. A vein intersected in W-80-1 gave an assay of 23.3 g/t Au, 41.1 g/t Ag, 0.04% Pb and 0.44% Zn over a length of 18 cm.

Carbonate-base metal veins have been intersected in all lithologies in drill holes in the Keystone area. They are particularly well developed in Keystone quartz diorite flanking the breccia complex. They have been observed to a depth of 1300 m in hole W-79-1.

Lithogeochemistry

Systematic lithogeochemistry was conducted on surface outcrops and drill core as a guide to determining the metal zoning and alteration patterns in the Keystone porphyry system (Livingstone, 1978; Saleken, 1979a, 1980). Lithogeochemical plots for drill holes W-78-1 in Pebble breccia, W-79-1 on the contact between Pebble breccia and brecciated Keystone quartz diorite, and W-79-2 in weakly altered and mineralized quartz diorite, provide a 760 m long section through the northern edge of the breccia and altered Keystone quartz diorite. Hole W-79-1 is approximately 485 m north of W-78-1, and hole W-79-2 about 275 m to the north of W-79-1. The down hole plots for Mo, F, Fe, Mn, Zn, Pb and Cu are provided in Figures 3, 4 and 5. Metal contents for each 3 m analyzed core interval are composited into 9.1 m intervals for presentation purposes in the figures. The lithogeochemical results will be reviewed for each of the elements and compared for the three holes.

Molybdenum

Sampling of surface outcrops in the Keystone area, and of the 1973 drill holes, indicated that most values for molybdenum were near detection limit of 1 ppm molybdenum, except in the Pebble breccia where mean values of 10 ppm to 30 ppm molybdenum were obtained for the 1973 drill holes (Livingstone, 1979). These concentration levels are confirmed by the sparse molybdenite observed in the three drill holes.

In W-79-2, the barren hole north of the breccia, the molybdenum content in the relatively fresh Keystone quartz diorite is generally 1 ppm to 2 ppm with a few intervals as high as 10 ppm to 20 ppm molybdenum. Molybdenum values in the Pebble breccia (hole W-78-1) are similarly low with a few erratic highs up to 21 ppm in the upper part of the hole. However, at the bottom of the hole from 1222 m to 1338 m the molybdenum content is between 15 ppm and 28 ppm. The elevated molybdenum content reflects the observed increase in quartz-molybdenite and quartz breccia fragments in the Pebble breccia.

Hole W-79-1 has the highest molybdenum content and ends in well-developed quartz-molybdenite stockwork mineralization in rhyolite porphyry. Approximately half of the sample intervals in the upper part of the hole are greater than 20 ppm molybdenum to a depth of 270 m, after which molybdenum content decreases to 1 ppm to 4 ppm with occasional values of 20 ppm molybdenum or greater. The anomalous molybdenum contents of up to 182 ppm molybdenum in the upper part of the hole are in Pebble breccia dikes containing numerous quartz-molybdenite and quartz breccia fragments. Quartz-molybdenite fragments would appear to be more numerous in these Pebble breccia dikes than in the core of the Pebble breccia complex as tested by hole W-78-1.

Below 828 m in hole W-79-1 the molybdenum content is initially erratic, but generally greater than 20 ppm molybdenum; it gradually increases to more than 100 ppm molybdenum below 898 m, and greater than 200 ppm molybdenum below 1049 m. The highest grade intersected is 0.114% Mo for the interval 1347.2 m to 1350.2 m in quartz porphyry rhyolite. The increase in content below 828 m in crackled Keystone quartz diorite corresponds with the occurrence of K-feldspar on fractures and development of quartz-sericite-pyrite stockworks. The abundance of quartz veining and intensity of sericitization and silicification increase progressively down the hole, particularly in and adjacent to rhyolite porphyry dikes.

Fluorine

Sampling of surface outcrops and the 1973 drill holes suggested anomalous fluorine contents of up to 945 ppm fluorine in the brecciated Keystone quartz diorite adjacent to the Pebble breccia and in drill hole 73-3 along the northern edge of the breccia complex. The Pebble breccia has a lower fluorine content of 480 ppm to 520 ppm (Livingstone, 1978) than country rocks.

Fluorine content in the Keystone quartz diorite in drill hole W-79-2 generally ranges between 400 ppm and 600 ppm. A few higher concentrations occur in a zone of quartz-pyrite-gypsum veins and sericitic alteration from 372 m to 408 m. Other short intervals deeper in the hole with contents of 1325 ppm and 1005 ppm fluorine appear related to intervals of more intense sericite alteration. The Pebble breccia in hole W-78-1 generally has fluorine contents of less than 600 ppm, although a few higher concentrations were obtained below 615 m. Fluorine contents in W-79-1 are also generally less than 600 ppm in the upper part of the hole. Below 300 m, the values generally increase to a peak of more than 1000 ppm fluorine in the interval of intense sericitization and the start of quartz-molybdenite-pyrite veins between 1061 m and 1143 m, after which it decreases slightly to between 800 ppm and 1000 ppm fluorine. As fluorite has not been observed, it is suggested that the fluorine is contained in sericite or apatite.

Iron

Analyses from the three drill holes indicates a modest variation in iron content. The highest iron contents generally occur in pyritic zones in hole W-79-1. Sporadic high iron contents in W-79-1 coincide with anomalous manganese, copper and zinc contents related to carbonate-base metal veins. The average iron content of the quartz diorite in hole W-79-2 ranges from 1.2% to 2.2%, and is generally higher than that in the Pebble breccia in W-78-1, but lower than for altered and mineralized quartz diorite in W-79-1. The Pebble breccia generally has 1.1% to 1.4% Fe, but, short intervals with less than 1% Fe are common. Quartz diorite and quartz-diorite breccia and felsite dikes in W-79-1 generally have 1.7% to more than 2.5% Fe in the upper part of the hole; however, below 315 m, iron contents generally range from 0.7% to 1.8%, increasing to 1.4% to 2.1% below 828 m to 1357 m. The higher iron contents in the upper part of the hole presumably reflect specularite in chlorite fractures and in carbonate-base metal veins, whereas the increased iron content in the bottom part of the hole is related to pyrite mineralization. The rhyolite porphyry also has a low iron content (1.0% to 1.4%).

Manganese

The early-stage lithogeochemistry indicated relatively low average manganese contents of 1120 ppm to 2760 ppm in the Pebble breccia and more anomalous contents up to 11 490 ppm, in brecciated quartz diorite in drill hole 73-3. The manganese values in hole W-78-1 are generally less than 3000 ppm in the upper part of the Pebble breccia, but increase to 6200 ppm over the interval 332 m to 954 m, and then decrease to less than 2000 ppm in the lower part of the hole. Similarly, in hole W-79-2, the manganese contents appear to decrease with depth and are generally less than 2000 ppm below 200 m; the anomalous sections are related to carbonate-base metal veins. Manganese contents in W-79-1 are generally greater than 2000 ppm to a depth of 500 m, after which

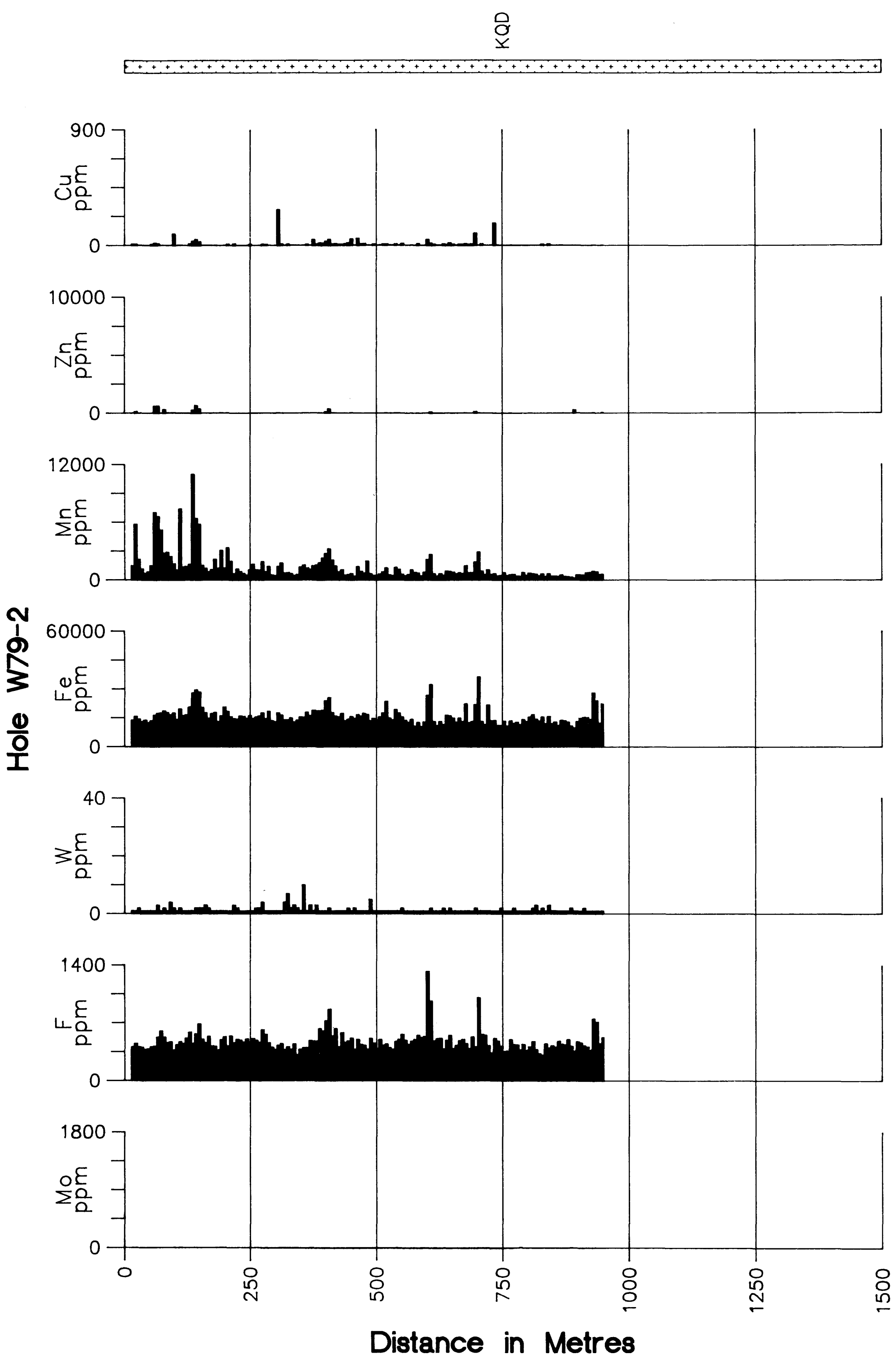

FIGURE 4. Multi-element bar graph, W-79-1.

there are a few erratic highs. Manganese contents near the bottom of the hole are generally less than 1000 ppm, except where there are carbonate-base metal veins.

Zinc

Early lithogeochemical sampling indicated anomalous zinc and lead values in both the Pebble breccia and surrounding host intrusive rocks. Zinc content in hole W-78-1 is generally less than 1000 ppm in the upper part of the Pebble breccia, but increases to greater than 4800 ppm over the interval 698 m to 1094 m. The zinc content in hole W-79-1 is generally greater than 1000 ppm over the interval 290 m to 404 m; below this, the values are generally less

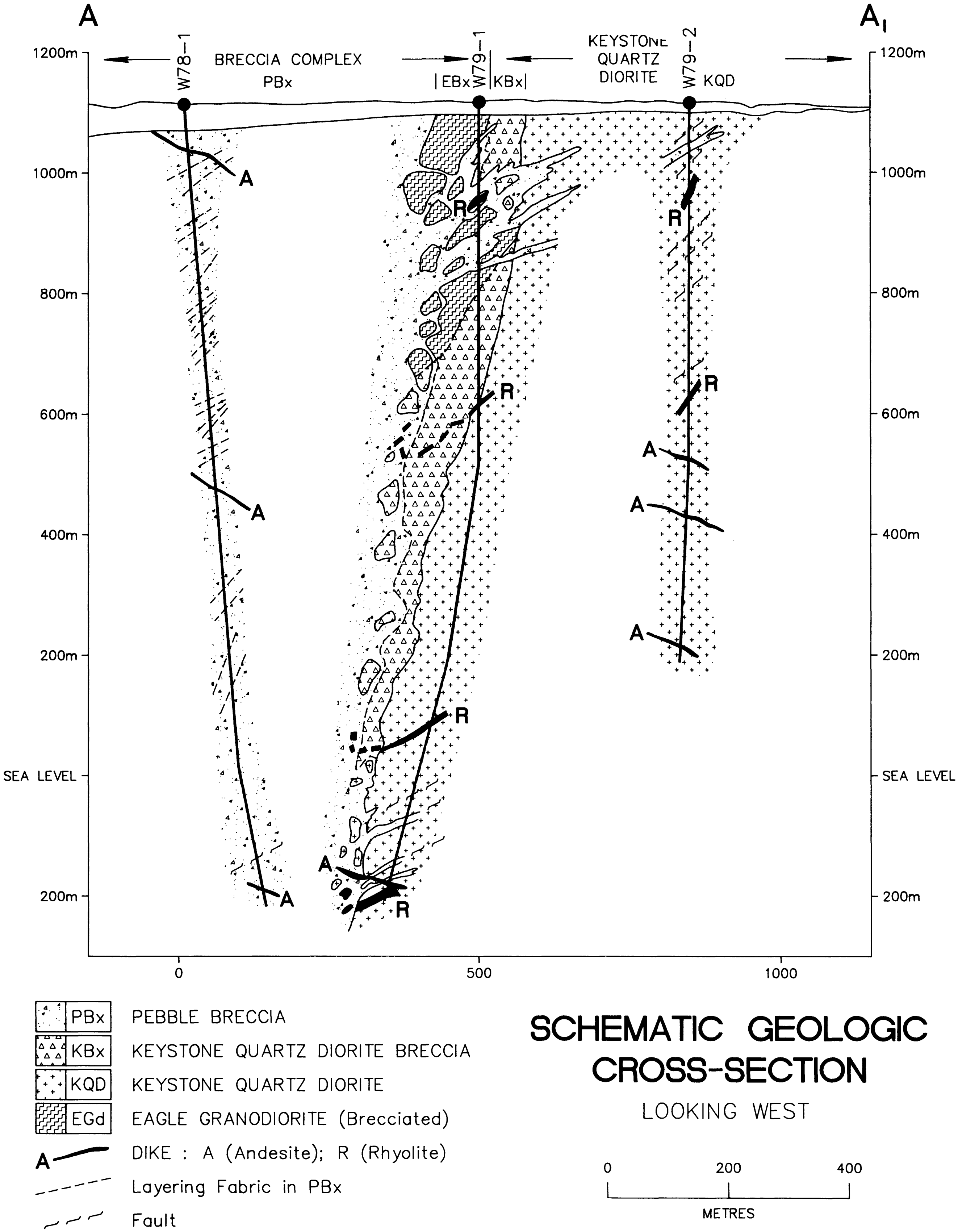

FIGURE 5. Multi-element bar graph, W-79-2.

than 1000 ppm, although occasional high zinc values continue to near the bottom of the hole. Zinc contents in hole W-79-2 are generally less than 200 ppm with a few higher values associated with carbonate-base metal veins.

Lead

Anomalous lead contents of more than 100 ppm occur to depths of 530 m in Pebble breccia in hole W-78-1, and 1076 m in quartz diorite in hole W-79-1. Lead values in the relatively unmineralized quartz diorite of hole W-79-2 are generally less than 30 ppm with peak values much lower than those in holes W-78-1 and W-79-1.

Copper

Copper contents are generally low in all three drill holes. Erratic anomalous copper contents of greater than 200 ppm occur in the upper part of the Pebble breccia in hole W-78-1 and at depth in the interval 908 m to 1136 m. In hole W-79-1, there are a few intervals having anomalous concentrations to 890 ppm in the interval 305 m to 360 m; these are associated with carbonate-base metal veins. However, the values decrease with depth to generally less than 100 ppm copper below 360 m depths, and are less than 20 ppm below 925 m. Copper concentration in hole W-79-2 is very low.

Silver

Silver concentrations are generally low in the Pebble breccia, and in hole W-79-2. Silver content is much more anomalous in hole W-79-1 and ranges up to 18.5 ppm where there are base metal vein intervals in quartz diorite; however, below 450 m the silver content decreases to generally less than 2 ppm.

Tungsten

Tungsten concentrations are generally very low (less than 10 ppm). A few anomalous tungsten values occur near the bottom of hole W-78-1 and are scattered through most of W-79-1. The highest concentration is 25 ppm.

Discussion of Lithogeochemistry

The Keystone molybdenum porphyry system provides a good example of metal zoning about a stockwork molybdenite deposit. The halo of manganese, zinc, lead and copper enrichment provide some evidence of the underlying molybdenum mineralization. Perhaps with analyses of more drill holes, a three-dimensional model could be developed to serve as a guide to exploration for similar buried molybdenum deposits.

Wallace (1981) considered the gradient of increase in molybdenum grade in the lower part of hole W-79-1 to be characteristic of "good" molybdenum porphyry systems; however, the fluorine contents are lower than normal. Keystone has a fluorine content of approximately 1000 ppm for a grade of 0.044% Mo, compared with a fluorine content of 1200 ppm to 2000 ppm for a grade of 0.16% Mo for Yorke-Hardy, and a fluorine content of 1800 ppm to 2500 ppm for a grade of 0.12% to 0.25% Mo for the Lime Creek deposits (Wallace, 1981). He concluded that Keystone is similar to these other two deposits in British Columbia, and dissimilar to the Climax and Henderson deposits in Colorado where fluorine contents are higher and fluorite is found above and peripheral to the molybdenum mineralization.

Conclusions

Recognition of quartz-molybdenite fragments in an early drill hole in the Keystone breccia complex led explorationists to re-evaluate the property and explore the deeper portions of the breccia complex and adjacent intrusive rocks. The five deep drill holes completed in 1978 through 1980 failed to intersect ore grade molybdenum mineralization; however, hole W-79-1 was lost at a depth of 1357 m in well mineralized quartz-molybdenite veined rhyolite porphyry that is so characteristic of higher grade porphyry molybdenum deposits. Furthermore, only a very small part of the porphyry system has been explored by the deep drilling. As well, it is uncertain how much of the molybdenum porphyry system has been destroyed by the breccia complex. The geometry and extent of both the breccia body and porphyry mineralization are poorly understood.

Although the highest grade molybdenum appears to be associated with the rhyolite porphyry dikes that are thought to be of Tertiary age, no larger genetically related source pluton for the rhyolite dikes is recognized in the area. The Eagle granodiorite and Keystone quartz diorite are thought only to be attractive host rocks for the deposit.

The trace element geochemistry of the breccia and host intrusive rocks suggests a well developed halo of Mn, Zn, Pb, Cu and precious metal mineralization peripheral to the molybdenum mineralization. The lithogeochemistry for these drill holes may provide a basis for evaluating the periphery of the breccia complex, to define areas where the favourable mineralization is not so deeply buried as a result of structural uplift along one or more of the numerous faults.

Fluorine contents are low compared to porphyry molybdenum deposits of the Climax-Henderson District, Colorado, but similar to other molybdenum deposits in British Columbia. The gradient of increase in molybdenum grade as observed in drill hole W-79-1 is encouraging and indicates the potential for considerably higher molybdenum grade in the deposit.

Results of the last phase of exploration for molybdenum on the Keystone deposit met with considerable success. They suggest that other parts of the porphyry system and the other molybdenum occurrences in the area warrant additional exploration.

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