SILVER-BEARING MINERALS OF THE SILVER QUEEN (NADINA) MINE, OWEN LAKE, WEST-CENTRAL BRITISH COLUMBIA (93L)

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INTRODUCTION

The Silver Queen (Nadina, Bradina) deposit of New Nadina Explorations Ltd. is located near Houston, 100 kilometres southeast of Smithers in the Bulkley Valley region of central British Columbia. The mine, which produced 98.28 kilograms of gold, 5225 kilograms of silver, 405 000 kilograms of copper, 703 000 kilograms of lead, 5 million kilograms of zinc and 15 000 kilograms of cadmium from 190 700 tonnes of ore over a brief period from 1972 to 1973, has current reserves of approximately 500 000 tonnes grading 3 grams per tonne gold and 200 grams per tonne silver, 0.23 per cent copper, 0.92 per cent lead and 6.20 per cent zinc (Nowak, 1991). Metallurgical problems arising from a complex mineralogy contributed to closure of the mine. The purpose of this study is to define the nature of the precious metal mineralization at Silver Queen mine and consider how the deposition of these minerals is related to the formation of the deposit.

GEOLOGY OF THE SILVER QUEEN DEPOSIT

Detailed geology of the area surrounding the Silver Queen mine has been presented by Leitch *et al.* (1990) and is summarized here only briefly. Rocks hosting the deposit are subdivided into five major units plus three types of dike with units numbered sequentially from oldest to youngest. A basal reddish purple polymictic conglomerate (Unit 1) is overlain by fragmental rocks ranging from thick crystal tuff (Unit 2) to coarse lapilli tuff and breccia or lahar (Unit 3); this is succeeded upwards by a thick feldspar-porphyritic andesite flow unit (Unit 4), intruded by microdiorite sills (Unit 5) and other feldspar porphyry (Unit 5a) and quartz porphyry (Unit 5b) dikes and stocks.

The stratified rocks form a gently northwest-dipping succession, with the oldest rocks exposed near Riddeck Creek to the south and the youngest in Emil Creek to the north. All the units are cut by dikes that can be divided into three groups: amygdaloidal dikes (Unit 6), bladed feldspar porphyry dikes (Unit 7), and diabase dikes (Unit 8). The succession is unconformably overlain by basaltic to possibly trachyandesitic volcanics that crop out in Riddeck Creek and farther south. These volcanics may be correlative with the Goosly Lake Formation (Church and Barakso, 1990).

Mineralized veins cut the amygdaloidal, fine-grained plagioclase-rich dikes (Unit 6), and are cut by the series of dikes with bladed plagioclase crystals (Unit 7). The former are generally strongly altered close to the veins whereas the latter are unaltered and are possibly correlative with the Ootsa Lake Group Goosly Lake volcanics of Eocene age (50 Ma). The unaltered, feldspar porphyry dikes cut the amygdaloidal dikes, and both are cut by the slightly younger diabase dikes (Unit 8).

ANALYTICAL PROCEDURE

This work is part of an exhaustive mineralogical study of the veins and altered wallrock of the Silver Queen property based on extensive use of x-ray diffraction, a scanning electron microscope - energy dispersive system (SEM-EDS), and quantitative analyses with the Cameca SX-50 wavelength dispersive electron microprobe. Operating conditions for the SEM-EDS studies were: polished specimens were run with no tilt on the energy dispersive spectrum, and the tungsten filament was used with 30-kilovolt accelerating voltage and 2.7-amp filament current. The beam current was 0.5 nanoamperes, giving a 0.5-micron (500 angstrom) beam width or resolution for backscattered electrons.

For the electron microprobe analyses, operating conditions were: 20-kilovolt accelerating voltage, 10 nanoamperes beam current and 1.0-micron beam diameter (approximately 5 micron diameter of spot-size resolution on the polished surface). Counting times were 30 seconds for peaks and 15 seconds for background. Standards used were pure metals (Ag, Bi, Mn, Cd, Ge, In) or compounds (HgTe, GaAs), natural pyrrhotite, galena, sphalerites (for Zn, S, Fe) and synthetic tetrahedrites (for Cu, S, Sb, As and Zn).

All data were reduced using a PAP correction program that corrected for atomic number, absorption and fluorescence, supplied by the probe manufacturer. Routine analyses of standards were within ±5 per cent of the accepted values. The precision of microprobe analysis is difficult to estimate, as there is no possibility of re-analyzing exactly the same point (significant "burns" occur in some minerals – especially sulphosalts, micas and carbonates). However, repeated analyses of the same grain in several locations showed that fluctuations were usually less than 5 per cent.

VEIN DEPOSITS

More than 20 separate epithermal, polymetallic veins are known in four main areas of the Silver Queen property (Leitch *et al.*, 1990): Camp-Portal vein area, main No. 3 vein area, George Lake vein and Cole Lake area; lesser veins are found in the Chisholm and Tailings Pond areas. The No. 5 and Switchback veins are included with the

Portal vein system to the west of the No. 3 vein. The No. 3 vein system is apparently the largest and is by far the best known and most easily accessible because of extensive underground development. More detailed descriptions of individual veins are provided by Leitch *et al.* (1990) and Hood (1991). The various veins have been a veritable mineralogical "gold mine" with a variety of unusual minerals having been reported (*e.g.*, Bernstein, 1987; Harris and Owens, 1973).

TABLE 2-6-1
MINERAL SPECIES IDENTIFIED AT SILVER QUEEN MINE
(this study)

PHASE	COMPOSITION	QUALITATIVE ABUNDANCE*
Ore Minerals		
Pyrite	FeS_2	C
Marcasite	FeS_2	R
Arsenopyrite	FeAsS	R
Pyrrhotite	FeS_1-x	T
Sphalerite	ZnS	C
Galena	PbS	C
Tetrahedrite	$Cu_{12}Sb_4S_{13}$	C
Tennantite	$Cu_{12}As_4S_{13}$	C
Freibergite	$(Cu,Ag)_{12}Sb_4S_{13}$	R
Bismuthinite	Bi_2S_3	T
Cuprobismutite	$CuBiS_2$	T
Proustite	Ag_3AsS_3	T
Pyrargyrite	Ag_3SbS_3	R
Covellite	CuS	T
Chalcocite	Cu_2S	T
Chalcopyrite	$CuFeS_2$	C
Bornite	Cu_5FeS_4	T
Aikinite	$CuPbBiS_3$	R
Matildite	$AgBiS_2$	R
Berryite	$Pb_2(Cu,Ag)_3Bi_5S_{11}$	R
Pearceite	$(Ag,Cu)_{16}(As,Sb,Bi)_2S_{11}$	R
Polybasite	$(Ag,Cu)_{16}(Sb,As)_2S_{11}$	T
Arsenpolybasite	$(Ag,Cu)_{16}(Sb,As)_2S_{11}$	T
Seligmannite	$PbCuAsS_3$	R
Bournonite	$PbCuSbS_3$	R
Gustavite	$Ag_3Pb_5Bi_{11}S_{24}$	T
Geocronite	$Pb_5(As,Sb)_2S_8$	T
Acanthite	Ag_2S	T
Electrum	$Ag_{0.3}Au_{0.7}$	R
Oxides		
Hematite	Fe_2O_3	C
Magnetite	Fe_3O_4	T
Rutile/Anatase	TiO_2	T
Gangue Minerals		
Barite	$BaSO_4$	C
Hinsdalite	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$	R
Svanbergite	$(Sr,Ca)Al_3(PO_4)(SO_4)(OH)_6$	R
Quartz	SiO_2	C
Calcite	$CaCO_3$	C
Mn-siderite	$(Fe,Mn)CO_3$	C
Rhodochrosite	$MnCO_3$	C
Dolomite	$MgCO_3$	R
Bitumen	(C,H,O)	R

* "C" represents minerals occurring in several or all locales in amounts greater than 2 volume percent.
* "R" represents minerals occurring in a few locales, in some cases greater than 2 volume percent.
* "T" represents minerals occurring in only a few locales, generally in trace quantities.

Ore Mineralogy

An outline of the mineralogy of the veins has been presented by Hood *et al.* (1991) who recognize a complex paragenesis with several stages of mineralization. The observed minerals are summarized in Table 2-6-1, with a general indication of relative abundances. Other minerals reported at Silver Queen include boulangerite (Marsden, 1985), guettardite meneghinite (Weir, 1973) and wurtzite (Bernstein, 1987). Hood (1991) has defined four well developed paragenetic stages in the No. 3 vein:

1. early quartz-pyrite ± barite
2. layered sphalerite-carbonate ± galena
3. galena-sulphosalt-chalcopyrite
4. late quartz-calcite

The principal sulphides are pyrite, galena and sphalerite with lesser amounts of chalcopyrite and tetrahedrite-tennantite scattered throughout. In addition, there are a variety of rare minerals, some of which are relatively abundant locally, many of which are silver-bearing, and are the principal focus of this report.

Silver Minerals

TETRAHEDRITE-TENNANTITE

Minerals of the tetrahedrite-tennantite ("fahlore") series are by far the most important silver-bearing phase at the Silver Queen deposit. Tetrahedrites (and other sulphosalt minerals) occupy a single paragenetic interval in the "Stage III" assemblage (Hood, 1991) and are commonly intergrown with galena, chalcopyrite and other sulphosalt minerals. Fracture infillings of fahlores are widespread in chalcopyrite and sphalerite, and the series commonly occurs as a matrix for pyrite and sphalerite vein breccias.

Tetrahedrite is also present as irregular masses up to several millimetres across in veins with elevated silver contents (*e.g.*, Camp veins).

Compositionally, tetrahedrite-series minerals show a broad range at the Silver Queen mine (Table 2-6-2). Silver-

TABLE 2-6-2
TETRAHEDRITE COMPOSITIONS*

Element	1	2	3	4	5	6
Cu	42.21	43.27	42.78	36.26	33.13	24.37
S	27.56	27.82	28.26	24.96	24.65	23.33
Zn	8.00	8.07	6.35	7.74	5.66	4.31
Fe	0.55	0.60	1.95	0.20	1.91	2.26
Sb	0.40	0.27	0.75	22.59	25.02	25.66
As	18.14	18.98	19.06	3.98	2.16	1.44
Pb	0.00	0.00	0.56	0.00	0.00	0.00
Ag	0.40	0.30	0.10	3.72	6.52	18.61
Bi	3.00	0.62	0.05	0.68	0.27	0.00
Hg	0.00	0.00	0.05	0.00	0.00	0.00
Total	100.26	99.93	99.91	100.13	99.32	99.98

1: Bi-rich tennantite, deep north No. 3 vein.
2: low-Bi tennantite, deep north No. 3 vein.
3: tennantite from south No. 3 vein.
4: Ag-rich tetrahedrite from south No. 3 vein.
5: tetrahedrite from shallow north No. 3 vein.
6: freibergite from Owl vein.
* values given as weight per cents

rich compositions are found in the north, deep in the southern parts of the No. 3 system, and in smaller veins most distant from the No. 3 vein. Silver contents of up to 18 per cent have been determined for tetrahedrites from the Cole and Owl veins. Variations in bismuth, antimony and zinc contents were also noted in Silver Queen tetrahedrites (Hood, 1991) and in a number of cases remarkably zoned crystals were observed (Plate 2-6-1).

MATILDITE

Matildite is uncommon in the No. 3 system, but is the most important sulphosalt mineral in the Portal vein system. It is present as symplectic intergrowths with galena and forms masses up to 3 millimetres across (Plate 2-6-2). Matildite also occurs with aikinite, electrum and berryite in the chalcopyrite-rich Portal veins.

PEARCEITE-POLYBASITE

Minerals of the pearceite-polybasite series are relatively rare at the Silver Queen deposit, but there is a wide degree of compositional variation among those that are (Table 2-6-3). Polybasite occurs deep in the southern part of the No. 3 vein as small (less than 50 microns) irregular grains intergrown with tetrahedrite and proustite-pyrargyrite. More arsenic-rich compositions are present in the Portal and Camp veins, where the minerals occur as anhedral to subhedral grains up to 1 millimetre in diameter. An unusual bismuthian pearceite is also present, occurring as small veinlets cutting chalcopyrite and other sulphosalts. In the Camp veins, pearceite is commonly symplectically intergrown with pyrargyrite, galena and argentian tetrahedrite and may form up to 50 per cent of the silver-bearing assemblage. It has also been noted in the northernmost parts of the Cole and No. 3 systems, and in the Chisholm veins.

PROUSTITE-PYRARGYRITE

The proustite-pyrargyrite (ruby silver) series is limited in distribution at the Silver Queen deposit, attaining peak abundance in the northern part of the Camp vein system. In the Camp veins, end-member pyrargyrite (*see* Table 2-6-3) occurs as symplectic intergrowths with galena, tetrahedrite and pearceite, with individual masses up to 1 millimetres across identified in polished section. Pyrargyrite also occurs as much finer grained material in the north part of the No. 3 system, Owl vein and Cole Lake veins. As with the Camp veins, pyrargyrite grains are commonly intergrown with galena, argentian tetrahedrite and pearceite.

More arsenic-rich compositions have been found only at the southern end of the No. 3 system, where proustite occurs as small (less than 100 microns) exsolved grains in massive galena. Geocronite and an as yet unidentified silver-antimony-lead sulphosalt are also present with the proustite.

TABLE 2-6-3
PEARCEITE-POLYBASITE AND RUBY SILVER COMPOSITIONS*

Element	1	2	3	4
Cu	11.30	8.58	0.12	0.13
S	16.51	16.54	17.67	17.51
Zn	0.00	0.00	0.05	0.00
Fe	0.44	0.00	0.00	0.00
Sb	0.34	0.65	21.83	19.61
As	6.57	5.48	0.67	1.82
Pb	0.00	0.00	0.00	0.00
Ag	64.40	65.86	59.77	59.76
Bi	0.26	3.21	0.13	0.00
Hg	0.05	0.00	0.00	0.00
Total	99.88	100.32	100.24	98.93

1: pearceite from small vein between No. 3 and George Lake systems.
2: bismuthian pearceite from No. 5 vein.
3: pyrargyrite from Camp veins.
4: pyrargyrite from Owl vein.
* values given as weight per cents

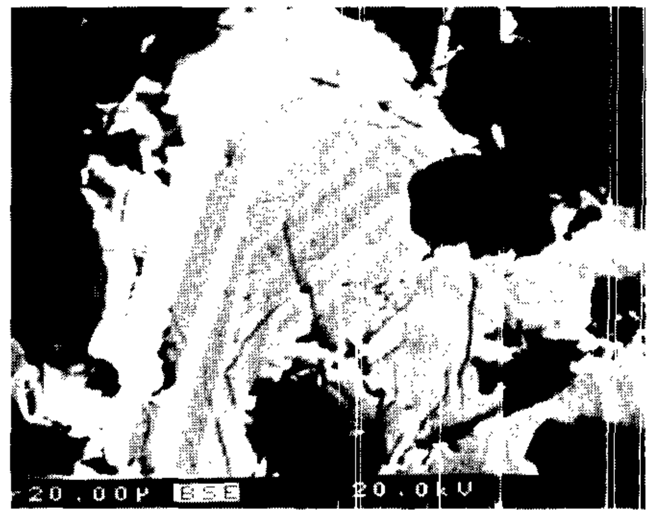

Plate 2-6-1. Backscattered electron photomicrograph of oscillatory zoned tetrahedrite from the northern No. 3 vein. Zonation is controlled by variation between antimony-rich (light) and arsenic-rich (dark) compositions. Scale bar at lower left is 20 microns.

Plate 2-6-2. Symplectic intergrowths of galena and matildite from chalcopyrite-rich Portal vein material. Note large, light-coloured electrum grain in upper right corner. Scale bar at lower right is 10 microns.

BERRYITE

Berryite (Table 2-6-4) was first identified at the Silver Queen mine by Harris and Owens (1973) and locally forms an important constituent of the sulphosalt assemblage in chalcopyrite-rich veins. Deep in the northern part of the No. 3 vein, berryite occurs as laths up to 0.3 millimetre long in a chalcopyrite matrix. Bismuthian tennantite and galena commonly replace the laths along cleavage and grain margins, although symplectic intergrowths with these minerals have also been noted (Plate 2-6-3). Berryite is also present in the Portal vein system, where it occurs with galena, matildite and gustavite.

GUSTAVITE

Gustavite (Table 2-6-4) is a relatively rare mineral at Silver Queen, restricted to the chalcopyrite-rich Portal veins. The mineral occurs as masses (in chalcopyrite) up to 0.5 millimetre across and is associated with berryite and galena, locally forming up to 50 per cent of the sulphosalt assemblage.

ELECTRUM

Electrum occurs throughout the No. 3 and associated veins and appears to be the only gold-bearing phase at Silver Queen mine. In general the mineral is present as small (less than 50 microns) rounded inclusions in galena or galena-sulphosalt intergrowths and is commonly associated with fine-grained pyrite. Locally, individual grains are up to 160 microns across and occur in embayments in larger pyrite grains associated with the host galena (Plate 2-6-4). Electrum grains are less commonly hosted by chalcopyrite, tetrahedrite, pyrite or sphalerite.

Compositionally, electrum from Silver Queen is quite silver rich, with grains from the No. 3 and Portal veins in the range of 600 to 720 fine. Electrum from the Copper vein is even more silver rich, containing gold with a fineness of approximately 500.

DISCUSSION

Precious metal values in the Silver Queen deposit result from the occurrence of electrum and the sulphosalt minerals tetrahedrite-tennantite, matildite, berryite, pearceite-polybasite, gustavite and proustite-pyrargyrite. Silver was also detected in trace amounts in galena and aikinite. The fahlores (tetrahedrite-tennantite series minerals) are the most important silver minerals, containing up to 18 weight per cent silver and locally forming up to 10 to 15 per cent by volume of the vein. Silver contents are highest in the northern part of the No. 3 vein and in veins farthest from the central No. 3 and George Lake structures. The other silver sulphosalts are less abundant, with berryite, matildite and gustavite confined to veins where chalcopyrite is a major part of the vein assemblage (*e.g.*, No. 5, deep in north No. 3 and in the Portal veins). Pearceite-polybasite and proustite-pyrargyrite are most abundant in silver-rich veins along the

TABLE 2-6-4
BERRYITE AND GUSTAVITE COMPOSITIONS*

Element	1	2	3	4
Cu	6.37	6.43	6.30	0.19
S	17.52	17.69	17.44	16.95
Zn	0.00	1.23	0.00	0.00
Fe	0.04	0.24	0.00	0.00
Sb	0.00	0.00	0.00	0.00
As	0.00	0.00	0.00	0.00
Pb	20.37	20.13	20.76	23.67
Ag	7.29	8.20	7.62	8.60
Bi	48.75	46.01	47.60	49.91
Hg	0.00	0.00	0.00	0.00
Total	100.34	99.93	99.72	99.32

1 and 2: berryite from chalcopyrite-rich No. 3 vein.
3: berryite from the No. 5 vein.
4: gustavite from the Portal veins.
* values are as weight per cents.

Plate 2-6-3. Backscattered electron photomicrograph of berryite grain (medium gray) undergoing replacement by galena (pale coloured). From the deep north No. 3 vein. Scale bar at lower right is 4 microns.

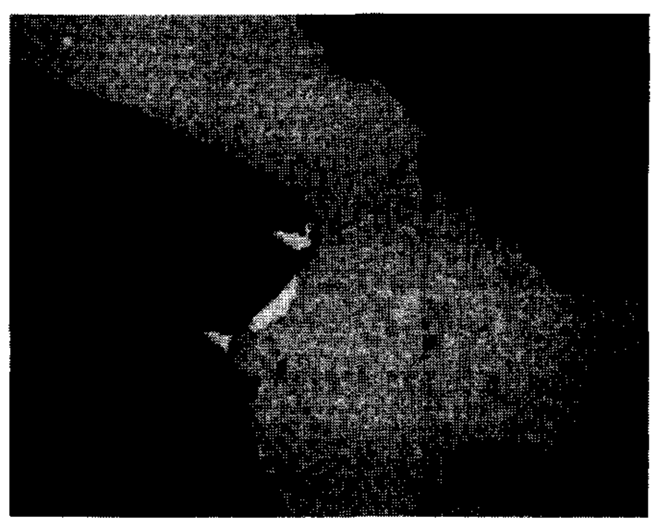

Plate 2-6-4. Electrum grains (white) occurring in embayments along the margin of large euhedral pyrite grain. Medium gray matrix is intergrown galena-matildite. From chalcopyrite-rich Portal vein material. Scale bar on lower right is 20 microns.

margins of the deposit. Symplectic intergrowths with galena are common for all silver sulphosalt species.

Electrum is the only gold mineral identified in the Silver Queen deposit, where it occurs as rare, but widely dispersed inclusions in galena or, less commonly, in sulphosalt minerals or pyrite. Electrum grains range in size from less than 5 microns to over 100 microns in diameter.

Sulphosalt minerals at the Silver Queen mine are interpreted to have been emplaced during the waning stages of a hydrothermal cycle under temperatures and pressures of less than 250°C. and 50 000 kilopascals (500 bars) (Hood, 1991). Sulphide and sulphosalt deposition was apparently controlled by mixing of hot, acidic waters with a cooler, more dilute meteoric fluid, with mineralogic zonation related to the stability of the metal-transporting species as the metal-charged fluids were carried away from the fluid source. Sulphosalt concentrations in the No. 3 and smaller veins thus represent sites of preferred deposition by copper, lead, bismuth and silver. To a lesser extent, the nature of the wallrock also appears to have influenced the deposition of sulphosalts in the No. 3 vein.

Silver sulphosalts tend to be concentrated along the outer margins of the deposit, corresponding to high silver-contents in tetrahedrite and the presence of abundant barite. As a result, the "peripheral" veins are interpreted to represent sites most distant from the fluid source (*e.g.*, Wu and Petersen, 1977) and where the influence of the cooler, more oxidized waters was most extreme (Hayba *et al.*, 1985). This particular occurrence is of importance when considering future exploration for silver and gold-rich parts of the vein system.

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