Brewery Creek gold deposit, central Yukon

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ABSTRACT

The Brewery Creek mine is a bulk tonnage gold deposit located 57 km east of Dawson City, in central Yukon, within the foothills of the Ogilvie Mountains along the northeastern boundary of the Tintina Trench. High-level fracture-controlled gold mineralization is hosted within Cretaceous monzonite sills and Devonian Earn Group siliciclastic rocks of the Selwyn Basin. Structural controls include northeast and southeast sub-vertical shears bounded by moderately south-dipping, southeasterly-extending listric normal faults; listric faulting and sill emplacements are localized along pre-existing graphitic thrust faults. Gold occurs as sub-micron particles in solid solution with pyrite and arsenopyrite as growth bands around larger sulphide grains that are disseminated within fine quartz veinlets. The open-pit heap leach operation produces 75,000 - 80,000 ounces annually, with a stripping ratio of 1.5:1 and a cash cost of US$200/oz or less. The mineable reserves at the end of 1997 stood at 13.3 MT @ 1.44 gpt (613,000 oz).

RÉSUMÉ

Située à 57 km à l'est de la ville de Dawson (Yukon), la mine Brewery Creek exploite un gisement d'or à fort tonnage dans le piedmont des monts Ogilvie, le long de la limite nord-est du sillon de Tintina. Une minéralisation peu profonde, contrôlée par des fractures, est encaissée dans des filons-couches de monzonite du Crétacé et des roches siliciclastiques du groupe dévonien d'Earn du bassin de Selwyn. Les contrôles structuraux incluent des cisaillements sub-verticaux orientés nord-est et sud-est qui sont limités par des failles courbes normales de direction sud-est de pendage modéré vers le sud; les failles courbes et les emplacements des filons-couches se situent le long de failles graphitiques chevauchantes pré-existantes. L'or prend la forme de particules de moins d'un micron, en solution solide avec de la pyrite et de l'arsénopyrite dans des bandes d'accroissement autour de grains de sulfure plus grossiers qui sont disséminés dans de fines veinules de quartz. L'exploitation à ciel ouvert utilisant la lixiviation en tas produit de 75 000 à 80 000 onces (plus de 2 millions de grammes) d'or par année à un coefficient de recouvrement de 1,5/1 et à un coût au comptant de 200 $ US l'once ou moins. Les réserves exploitables s'élevaient à 13,3 Mt renfermant 1,44 g/t (613 000 onces ou 17,4 millions de grammes) à la fin de 1997.

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INTRODUCTION

The property consists of 803 contiguous quartz claims and mining leases covering 12,975 hectares and is owned and operated by Viceroy Minerals Corporation, a subsidiary of Viceroy Resource Corporation.

Brewery Creek is a bulk tonnage gold deposit located 57 km due east of Dawson City. Noranda Exploration Co. Ltd. discovered the property in 1987, using soil geochemistry, and outlined reserves in eight zones extending over a strike length of 12 km (Fig. 1). Loki Gold Corporation optioned the property in 1990 and obtained a 100% interest in 1993. Following two years of development work and an extensive environmental review, Loki obtained a water license in August, 1995 and began construction of the heap leach pad and facilities. Loki merged with Viceroy Resource Corporation in May, 1996 and realized first gold production in November. Commercial production was reached in May, 1997. At December 31, 1997, mineable reserves on the property were 13.3 million tonnes @ 1.44 gpt gold (613,000 contained ounces) which is accessible by open pit with a stripping ratio of 1.5:1.

REGIONAL GEOLOGY

The Brewery Creek property is located in the foothills of the Ogilvie Mountains along the northeastern boundary of the Tintina Trench. This major topographic feature, the northwestern extension of the Rocky Mountain Trench, marks the trace of a dextral strike-slip fault system with an apparent offset of as much as 450 km (Gabrielse and Yorath, 1991). At this latitude, the Tintina Fault juxtaposes late Proterozoic and Paleozoic rocks of the Selwyn Basin to the northeast, against sheared, metamorphosed rocks of the Yukon-Tanana Terrane, to the southwest.

The property covers an area of clastic sedimentary rocks of the Cambrian to Lower Devonian Road River Group and the Devono-Mississippian Earn Group. Due to poor exposure, Earn Group rocks were not previously recognized in this area. Quartzite and argillite of the Late Proterozoic-Early Cambrian Hyland Group are exposed several kilometres west and north of the property. All of these rocks lie in the hanging wall of the south-dipping Robert Service Thrust, and are cut by stocks, dykes and sills ranging in composition from diorite to quartz

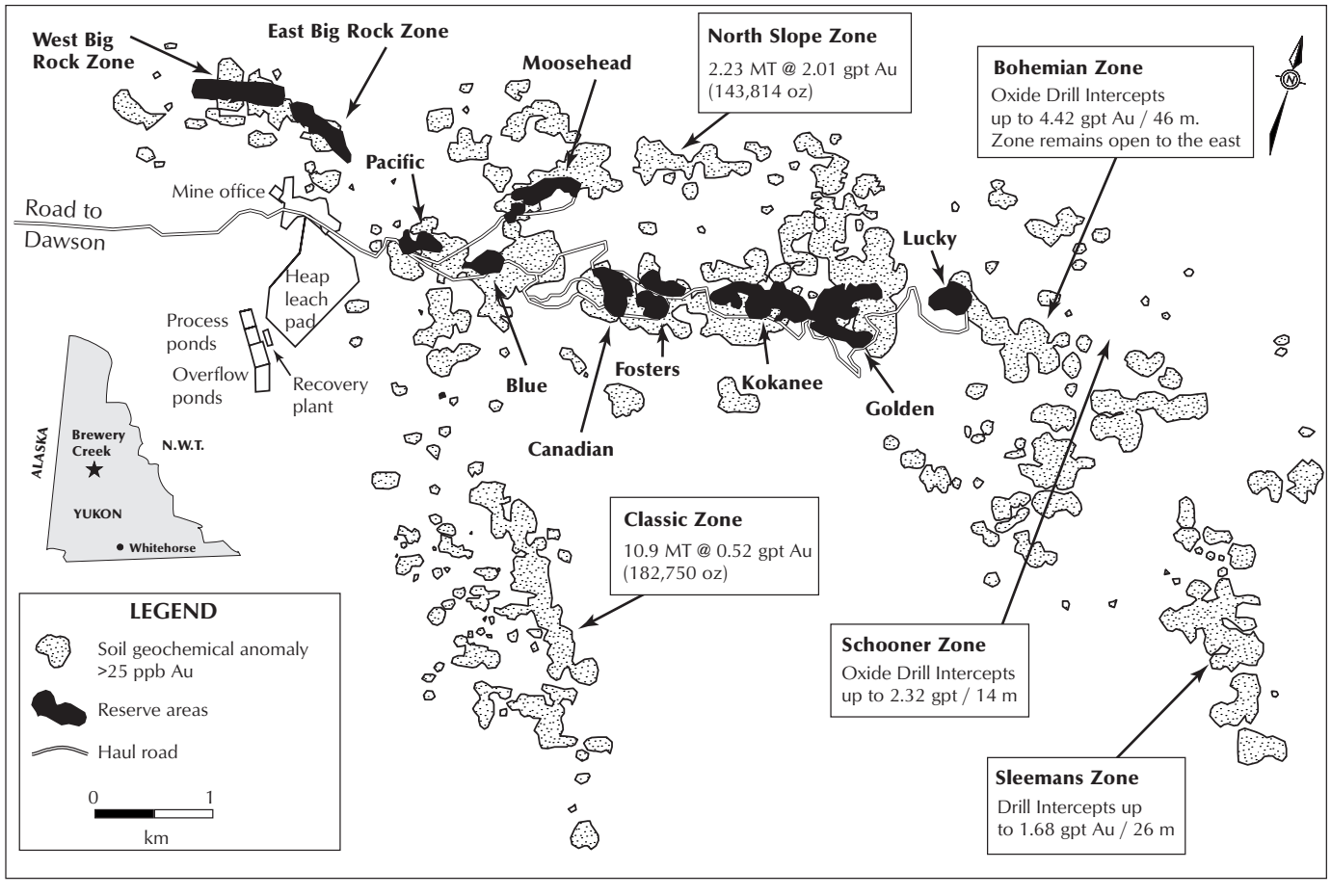

Figure 1. *Exploration potential and current reserves for the Brewery Creek mine.*

monzonite and syenite. The intrusive rocks belong to the Tombstone Plutonic Suite of mid-Cretaceous age.

This part of northern Yukon escaped continental glaciation during the most recent (McConnell) ice advance, allowing a zone of deep weathering and oxidation to be preserved. The oxidation zone extends locally to depths of more than 100 m. Another consequence of the lack of glaciation is that there are no till sheets to mask the geochemical response, and transport of geochemical anomalies is generally restricted to down-slope creep. Some areas of the property have a cover of "loess" (windblown glacial silt or rock flour admixed with coarser material of local derivation) which may reach thicknesses of almost 20 m locally (J.R. Allan, pers. comm., October, 1995). This has the effect of masking portions of geochemical patterns.

PROPERTY GEOLOGY

The following description of the geology of the Brewery Creek property is derived largely from Diment (1995) and from an unpublished map prepared by Loki, based on the work of Bremner (1993-1995). Other information sources are cited as appropriate.

STRATIGRAPHY

Two major packages of dominantly clastic sedimentary rocks are recognized at Brewery Creek (Bremner, 1993-1994, Diment, 1995). These rocks have been correlated with major packages within the Selwyn Basin stratigraphy, the Road River and Earn groups.

The older strata, exposed on the northern portion of the property and generally lying north and south of the known mineralized zones, are correlated with the Road River Group. In the Nahanni map area to the southeast, this group was subdivided by Gordey and Anderson (1993) into the lower Duo Lake Formation of black siliceous graptolitic shale and chert overlain by the Steel Formation of orange-weathering mudstone. At Brewery Creek, the Steel Formation consists of tan-weathering, wispy-laminated, "burrowed" siltstones, with beds up to 10 m thick of graphitic shale and chert. These rocks overlie massive black chert of the Duo Lake Formation and calcareous andesitic flows, tuffs and breccias which are probably Late Cambrian or Early Ordovician in age, similar to the Menzie Creek volcanic rocks at Faro. A conglomerate unit deposited at the top of the volcanic sequence consists of rounded fragments of volcanic rock in a tuffaceous or calcareous matrix. The top of the Road River succession was defined by Gordey and Anderson (1993) in the Nahanni map-area as the highest occurrence of wispy-laminated siltstone; the same criterion has been used at Brewery Creek.

The contact between the Road River and Earn groups is marked by a regional unconformity (Murphy and Héon, 1994). At Brewery Creek, the Earn Group strata make up a heterogeneous package of siliciclastic rocks including argillite, silty shale, sandstone, greywacke and debris flow conglomerate overlain by a distinctive sequence of tuffaceous sandstone and shale. Volumetrically minor units include limestone, bedded barite and black graphitic argillite.

STRUCTURE

The stratified rocks generally strike northwest and dip moderately southeast. A few northerly dips show the presence of open south-vergent, upright folds in the higher units of the Earn Group stratigraphy. Fold axes trend about 100° and plunge gently (about 10°) to the east. A well-developed slaty cleavage occurs in finer-grained clastic rocks. Local tight folds in Earn Group rocks probably reflect deformation related to thrust faulting and drag on normal faults.

The most important structures at Brewery Creek are imbricate low angle faults which strike generally west-northwest and dip to the south. Based on the stratigraphic relationships, these are inferred to be thrust faults. They appear to have controlled the emplacement of Cretaceous quartz monzonite sills which host most of the gold mineralization. Later dip-slip movement of the faults is recorded by slickensides and rotation of some of the sills and adjacent sedimentary rocks on curved fault surfaces, as well as the development of downward-stepping contacts and extensional fault wedges.

Shear zones with a prominent north-northeast (20° to 40°) vertical fracture cleavage cut the sills and sedimentary rocks overlying the thrust faults. Intense brecciation and silicification is associated with these shear zones, and in places they have been invaded by quartz monzonite dykes. The shear zones appear to terminate downward at the thrust surface, and may result from tear faulting contemporaneous with the thrusts. The relationship between the low angle faults, shear zones and quartz monzonite sills suggests that the intrusions are probably syntectonic, formed during an episode of Cretaceous deformation.

Other sets of subvertical fracture cleavages strike about 100° and 340° and are also mineralized. Both the 40° and 100° fracture sets show evidence of normal displacement in the form of steeply plunging slickensides, and offsets up to 3 m. However, numerous subhorizontal slickensides suggest a significant component of strike slip motion.

The latest stage of faulting on the property involves unhealed structures. A north-northwest set consists of faults interpreted as steeply dipping reverse or normal faults, which may have displaced stratigraphic units by as much as 50 m. A second set

strikes east-northeast and appears to have accommodated left-lateral displacement up to 200 m. Both sets of faults truncate sulphide mineralization and all previously described structures.

INTRUSIVE ROCKS

Several distinct intrusive rock types are present at Brewery Creek. The most important bodies from an economic point of view are semi-conformable sills of quartz monzonite, intrusive into the upper Road River and lower Earn Group strata. These sills, which yielded a zircon age of 91.4 +/- 0.2 Ma (Diment, 1995), have been exposed over a strike length of at least 12 km. Where cut by faults or shear zones, they show evidence of gold mineralization over most of this distance. They appear to have been emplaced along Cretaceous thrust faults, mostly marked by zones of graphitic argillite; hornfels development is minimal, suggesting emplacement at a shallow depth. The sills range in thickness from 5 to 10 m or less in the western portion of the property, to greater than 100 m in the east.

In the south-central portion of the property, stocks of syenite and biotite monzonite, as well as sills of the latter rock, have intruded tuffaceous shale, sandstone and chert of the Earn Group. These intrusive rocks tend to be relatively coarse-grained and equigranular, with well-developed hornfels aureoles. With the exception of the Classic Zone, they appear to be unmineralized.

MINERALIZED ZONES

There are at present nine ore zones (or groups of zones) in the mineable reserve category, one zone presently being taken from resource to mineable reserve, two zones with geological resources and an additional two zones which remain exploration targets (Fig. 1). Seven of the ore zones are distributed along a general easterly (mine grid) trend; the eight and ninth lie to the north of this trend. From west to east along the trend, the zones are: Pacific, Blue, Canadian (and west Canadian), Fosters (upper and lower), Kokanee, Golden (upper and lower) and Lucky. The Moosehead Zone lies grid northeast of the Blue Zone, while the Big Rock Zone lies northwest of the Pacific Zone. Southeastward along the main trend is the Bohemian Zone, with a geological resource currently being brought into reserve. The structurally unique Classic and North Slope zones, with defined geological resources, lie just over 3 km south of the Blue and one kilometre north of the Kokanee, respectively. The Schooner and Sleemans zones, along strike to the southeast from the Bohemian Zone, remain priority exploration targets. The total distance between the occurrences at either end of the main trend is almost 12 km.

MINERALIZATION AND ALTERATION

ALTERATION

Alteration associated with the mineralized zones at Brewery Creek follows the major structures. Pervasive phyllic alteration predominates, and is best developed in the intrusive rocks. Altered rocks are characterized by destruction of mafic phenocrysts, alteration of feldspars to sericite (illite) and kaolinite, and introduction of secondary quartz with fine-grained pyrite and arsenopyrite. Intense kaolinization and silicification is localized in narrow vertical shear zones and is associated with high gold grades. A weak propylitic halo, characterized by chloritization of mafic phenocrysts and strong carbonatization, commonly occurs peripheral to mineralized zones.

Alteration, sulphide distribution and gold mineralization all appear to be lithologically controlled. Those units which deformed in a brittle fashion, such as intrusive rocks, sandstone and siltstone, tend to be more strongly altered, due to fault-induced permeability. Shale and argillite tended to deform plastically and are much less altered and mineralized.

MINERALOGY

Mineralogy at Brewery Creek appears to be very simple. Below the zone of weathering, fine-grained pyrite, arsenopyrite and some marcasite are disseminated within quartz veinlets and areas of pervasive silicification. Ion microprobe studies at the University of Western Ontario (Chryssoulis and Agha, 1990) on selected samples showed that gold occurs primarily as extremely fine (micron-sized) particles or as “solid solutions” in arsenopyrite and pyrite growth bands around larger sulphide grains. The sulphide grains themselves are generally less than 250 microns in diameter. Other sulphide minerals noted by Chryssoulis and Agha (1990) included trace amounts of chalcopyrite, sphalerite and pyrrhotite.

Within the zone of weathering, which is extensive and reaches an average depth of 50 m, sulphides have in general been converted to goethite ($Fe_2O_3 \cdot H_2O$) and scorodite. Coarse-grained stibnite veins are commonly preserved. The stibnite veins appear to post-date the main period of mineralization, and rarely contain significant gold values.

STRUCTURAL CONTROLS

The primary control of sill emplacement and gold mineralization seems to be a series of imbricate east to east-southeast trending thrust faults, which have been traced for more than 12 km and probably extend further in each direction. In a few cases, the faults crosscut stratigraphy. The faults juxtapose brittle coarse clastic intrusive rocks against underlying graphitic argillite. They are associated with parallel zones of mineralization which dip 5° to 60° south in the fractured and altered hanging wall rocks. Mineralized zones are contained within altered and fractured rocks lying above the faults and the footwall argillite is generally barren.

A further control on gold mineralization appears to have been exerted by subvertical west-northwest and north-northeast shears in the hanging wall rocks. These fractures are generally filled by narrow (less than 1 centimetre) en echelon quartz veinlets containing fine disseminated sulphides. Locally, as in the Golden Zone bulk sample trench, such fractures coalesce into quartz breccia zones up to several metres wide. These mineralized structures are not generally traceable into the footwall rocks.

In the case of the Classic Zone, low-grade gold mineralization is hosted by a small hornblende monzonite stock 3 km south of the main trend of ore bodies along a northwest-trending normal fault. A strong arsenic soil anomaly follows the trend of this structure for about 3 km northwest to the Pacific Zone. The significance of this structure and its mineralization are as yet unknown and require further exploration.

LITHOLOGIC CONTROLS

Eighty-five percent of the known gold mineralization at Brewery Creek is contained within altered quartz monzonite. Biotite monzonite and syenite are hosts for gold mineralization at the presently under-explored Classic Zone, where the intrusive rocks form stocks rather than sills or dykes. Whole-rock analyses of intrusive rocks suggest a positive correlation between gold content and alteration, characterized by consistent sodium and potassium depletions and silica enrichment in the mineralized zones, except in the case of the Classic Zone, where high potassium levels are reported.

Only the Pacific, Blue and Moosehead zones contain significant amounts of gold mineralization in sedimentary rocks. Here, sandstone and shale have been pervasively flooded by silica, and en echelon hairline quartz veinlets, commonly with envelopes of montmorillonite, occur along bedding planes. Sulphides, especially arsenopyrite, are finely disseminated in unweathered rocks, up to as much as 15% in places.

In the North Slope Zone, calcareous, Steel Formation siltstone of the Upper Road River Group has been altered and cut by a fine quartz stockwork. Bleached sericite haloes have formed around the more siliceous zones; pyrite occurs on fracture surfaces and along bedding planes. The Steel Formation has striking similarities to the highly productive Roberts Mountain formation in the Carlin Trend and may represent a favourable host for replacement-style mineralization.

Argillite, the most common rock type in most of the zones, is generally unmineralized. Elevated gold contents are in most cases confined to highly sheared graphitic contacts between argillite and overlying mineralized intrusive rock or coarser clastic lithologies.

"PREG-ROBBING" ROCKS

Some of the shales and argillites at Brewery Creek have the tendency to remove gold from the pregnant solutions in a heap leach environment and fix it so that it cannot be dissolved and recovered. Numerous tests have been performed on samples of both argillite and graphitic argillite, from surface exposures and drill holes, in order to investigate this problem.

Lenses of potentially "preg-robbing" argillite occur either below or within mineralized zones. The purpose of the testing was to examine the magnitude of the potential problem, and to estimate how much, if any, selective mining might be required. The results of the tests showed that there is a strong correlation between "preg-robbing" tendencies and both the oxide/sulphide interface and the position of the paleo-water table boundary, leading to the following conclusions.

1. Within the oxide zones of the deposits (i.e., areas with significant limonite content and an absence of visible sulphides) above the paleo-water table, argillite (whether obviously graphitic or not) does not have "preg-robbing" characteristics. Neither the percentage of visible graphite nor its morphology (even where described as massive, "sooty" graphite) appears to have any effect on leach rate or gold recovery.
2. Within the oxidized portions of the deposit lying below the paleo-water table, argillites may be weakly to moderately "preg-robbing."
3. Within the "transition zone," where both limonite and sulphides are noted, argillite is commonly weakly "preg-robbing" if lying above the paleo-water table and is moderately to strongly "preg-robbing" if lying below.
4. Within the sulphide zones of the deposits (i.e., in areas with > 1% sulphides and an absence of visible limonite), argillites are strongly "preg-robbing."

Surprisingly, there appears to be no recognizable correlation between graphite content of argillite and the degree of "preg-robbing" characteristics.

AGE AND CLASSIFICATION OF DEPOSITS

Diment (1995) described the Brewery Creek deposit as a member of the "adularia-sericite" class of epithermal precious metal deposits, as described by Heald et al. (1987). This classification of Brewery Creek appears to have been based on several factors, perhaps the most important being the generally low concentrations of sulphides and the typical chemical signature of gold, silver, arsenic, antimony, mercury and barium. As with other adularia-sericite type deposits, gold mineralization does not appear to be confined to one rock host rock type.

The mineralization must be mid-Cretaceous or younger, based on its spatial relationship to brittle faults cutting the Cretaceous intrusions. Several quartz monzonite dykes have invaded steep shear zones which cut quartz monzonite sills in the same area, providing evidence of late magmatic activity which could be related to the gold mineralization.

RECENT DEVELOPMENTS IN EXPLORATION

Recent exploration in the North Slope Zone has discovered the presence of decalcification and silica replacement in stratigraphically lower Silurian Road River Group sediments suggesting that a Carlin-type model may be appropriate at Brewery Creek. A resource of 2.2 million tonnes of 2.01 gpt gold (142,000 oz) has been defined in this zone. The narrow-erratic sediment-hosted mineralization remains open along strike.

A north-northwest striking subvertical extensional fault hosts low-grade gold mineralization (0.3 to 0.6 gpt) gold along a 500 metre strike length in the Classic Zone. Gold is confined to centimetre scale en echelon quartz veinlets which parallel this structural trend cutting biotite monzonite and syenite stocks. An oxide resource of 10.9 million tonnes of 0.52 gpt gold (182,000 oz) using a cut-off of 0.25 gpt gold has been defined. Bottle roll results have returned up to 67% recovery at depths greater than 150 m.

The Bohemian Zone is open along strike to the east and southwest along high angle east southeast and north northeast structures. An oxide resource of 1.3 million tonnes of 1.6 gpt gold (65,733 oz) based upon drilling up to July, 1998, has been defined. This resource includes drill intercepts up to 4.42 gpt gold over 46 m in oxidized quartz monzonite. The resource is being updated to incorporate 3 additional phases of infill and step-out drilling at the time this paper went to press.

MINE OPERATIONS

The Brewery Creek mine achieved commercial production in May, 1997. During 1997, a total of 72,387 ounces were produced from the Kokanee and Golden zones, at a cash cost of US$184 per ounce. A total of 2.1 million tonnes of ore were mined and 2 million tonnes of ore with an average grade of 1.87 gpt gold were delivered to the leach pad.

For the nine months ending September 30, 1998, a total of 52,638 ounces of gold were produced at a cash operating cost of US$197 per ounce. A total of 2.3 million tonnes of ore grading 1.46 gpt gold were mined and 2.2 million tonnes of ore grading 1.46 gpt gold were delivered to the leach pad. Ore was mined from the Kokanee and Golden pits. An intermediate leaching circuit was commissioned at the Brewery Creek mine which effectively doubles the amount of ore under leach. Production forecast for 1998 for Brewery Creek is 80,000 ounces.

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