Geology and geochemistry of the Clear Creek gold occurrences, Tombstone gold belt, central Yukon Territory

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Marsh, E.E., Hart, C.J.R., Goldfarb, R.J. and Allen, T.L., 1999. Geology and geochemistry of the Clear Creek gold occurrences, Tombstone gold belt, central Yukon Territory. *In:* Yukon Exploration and Geology 1998, C.F. Roots and D.S. Emond (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 185-196.

ABSTRACT

Auriferous sheeted quartz veins and silicified shear zones occur along the margins and within adjacent hornfels zones of mid-Cretaceous Tombstone intrusions near the head of Clear Creek in the central Yukon. The lodes are the source for more than 120,000 ounces of downstream placer gold production. These lodes contain variable amounts pyrrhotite, pyrite, and arsenopyrite, with less abundant scheelite – alkali-feldspar, muscovite, biotite and tourmaline are common gangue phases. Grab samples of mineralization often contain gold grades in excess of 1 ounce per ton. Gold-to-silver ratios vary most commonly from 1:1 to 5:1. Gold-rich quartz veins cut all stocks, adjacent hornfels and associated lamprophyre dykes commonly contain greater than 1% arsenic. Bismuth, and less consistently tungsten and stibnite, characterize many of the most highly mineralized veins within and surrounding the stocks. Quartz veins along the intrusive-metasedimentary rock contact around the Pukelman stock are also enriched in lead and silver.

R-mode factor analysis of multi-element geochemical data for 111 gold- and sulphide-bearing rock samples indicates that there are two geochemically distinct metal suites in the Clear Creek occurrences. The first is characterized by As-Au-Bi ± Sb, Te ore-related mineral association, which is typical of many intrusion-related deposits in the Tombstone gold belt. Less consistently, anomalous concentrations of Ag, Co, Cu, Fe, and Mo occur within these auriferous rocks. The second metal factor is defined by Ag-Bi-Pb ± As, Au and Te. It characterizes metalliferous vein samples that have uncommonly low Au:Ag ratios and may represent a second hydrothermal episode. Tungsten shows little consistent correlation with the metalliferous veins in either element suite.

RÉSUMÉ

Des filons de quartz aurifère stratifiés et des zones de cisaillement silicifiées sont présents le long des bordures et dans les zones à cornéennes adjacentes de six amas intrusifs situés à proximité de la source du ruisseau Clear (115P/14). Ces amas font partie de la ceinture de Tombstone de 91Å0,5 Ma et leur composition va de la monzonite quartzifère à la diorite. Ils sont recoupés par des dykes d'aplite et de lamprophyre tardifs et pénètrent des roches clastiques du faciès des schistes verts inférieur à granulométrie fine du Groupe de Hyland d'âge s'échelonnant du Néo-protérozoïque au Cambrien précoce. Les plutons et les dykes se rencontrent de façon constante le long de structures d'extension orientées est-ouest.

Les filons et les zones de cisaillement minéralisées ont produit 120 000 oz d'or alluvionnaire en aval. Ces filons contiennent généralement de la pyrrhotite, de la pyrite, de la scheelite et de l'arsenopyrite en abondance. Les minéraux de gangue fréquents sont le feldspath potassique, la muscovite et la tourmaline. De nombreux indices minéralisés à forte teneur en or sont associés dans l'espace avec des cornéennes à forte teneur en biotite dans des roches clastiques, avec des zones de greisen dans des granitoïdes et avec de petites zones de skarn à tungstène dans des roches calcaires.

Les échantillons prélevés au hasard dans les filons et les zones silicifiées contiennent fréquemment des teneurs en or de plus d'un once la tonne (28 g/t). Les rapports or/argent de 1:1 à 5:1 sont typiques. Les résultats obtenus des analyses factorielles à mode R de données géochimiques montrent un cortège d'éléments Ag-As-Au-Bi-W cohérent apparenté au minerai et des anomalies d'antimoine et de plombe moins consistantes. Des filons de quartz aurifère recoupant tous les amas, les cornéennes limitrophes et les dykes de lamprophyre associés sont susceptibles de contenir plus de 1 % As. Les valeurs de bismuth et de tungstène de 100 à 1 000 ppm caractérisent les filons les plus fortement minéralisés situés à l'intérieur et à la périphérie des amas de Saddle, d'Eiger, de Josephine, de Pukelman et de Rhosgobel. Dans de nombreux échantillons, les enrichissements en antimoine varient entre 10 et 100 ppm. Les filons de quartz présents le long d'un contact de roches intrusives et métasédimentaires, sur le pourtour de l'amas de Pukelman, sont également enrichis en plomb; les échantillons titrent de 100 à 200 ppm Pb. La signature géochimique des filons du ruisseau Clear est cohérente avec celle du gisement de Fort Knox en Alaska et avec d'autres indices d'or situés dans la ceinture de Tombstone du Crétacé moyen.

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INTRODUCTION

A concentration of auriferous sheeted quartz veins and quartz stockworks are found in the Clear Creek area, about 120 km southeast of Dawson in west-central Yukon (Fig. 1). Except for a few small adits driven in the early 1900s, these lodes have not been mined but have been the focus of exploration activity for the past 20 years. These occurrences are the likely source for the more than 129,000 ounces (~ 4 million g) of gold that have been placer mined along Clear Creek since the turn of the century (Allen et al., this volume). Similarities in structural style, ore mineralogy, and spatial associations of the mineralization with several stocks of the Tombstone plutonic suite (~92 Ma) has led to their inclusion in the "Tombstone gold belt." This easterly-trending belt of intrusion-related gold deposits includes active gold mines at Fort Knox, Alaska (Bakke, 1995) and Brewery Creek (Diment, 1996), as well as the deposit at Dublin Gulch (Hitchins and Orssich, 1995; Smit et al., 1996; Maloof et al., 1997), 70 km northeast of Clear Creek.

Although there are regional studies of mineral occurrences (Emond and Lynch, 1990; Murphy, 1997), detailed studies of the geology and geochemistry of gold lodes in the Clear Creek area are unavailable. We initiated this study during the summer of 1998 to better understand the nature of mineralization and ore-forming fluids in the Tombstone gold belt. The portion of the study reported here is based upon detailed geochemical sampling of all the reported gold-bearing occurrences. We present results of multi-element metals analyses of mineralized samples from the numerous lode occurrences in the headwaters of Clear Creek. Data are subsequently interpreted statistically using R-mode factor analyses to better understand the correlation between elements and to define the geochemical signatures of the Clear Creek occurrences. Associated studies, including fluid inclusion geochemistry and stable isotope chemistry of the occurrences, and the radiogenic isotope character of the associated granitoids, are in progress.

SUMMARY OF GEOLOGICAL CHARACTERISTICS

The Clear Creek area is underlain by phyllite, quartzite, psammite, calc-phyllite, calc-silicate, grit and marble of the Yusezyu Formation of the Neoproterozoic to Early Cambrian Hyland Group (Murphy, 1997). The strata along the northern Selwyn Basin margin are imbricated by thrust faults of Jurassic and Early Cretaceous age. The Clear Creek area is in the hanging wall of the Robert Service Thrust within an east-trending, moderately north-dipping, transposed assemblage of lower greenschist facies rocks of the Tombstone Strain Zone (Murphy, 1997).

At the headwaters of Clear Creek, six Tombstone intrusions, the Saddle, Eiger, Pukelman, Rhosgobel, Josephine and Big Creek stocks, have surface exposures ranging from 0.2 to 3.5 km (Fig. 2). They yield U-Pb dates of ~92 Ma and are part of the Tombstone plutonic suite (Murphy, 1997). Notable gold occurs within and surrounding all except the Big Creek stock. The Saddle, Pukelman and Rhosgobel stocks are composed of medium- to coarse-grained quartz monzonite characterized by large (1cm) alkali feldspar phenocrysts. Local zones are granitic and aplitic, particularly in the southern Rhosgobel stock. Biotite is the dominant mafic mineral, but hornblende is not uncommon. The Josephine and Big Creek stocks are composed of fine- to medium-grained, equigranular granodiorite. The Eiger stock is composed of fine- to medium-grained, equigranular diorite with rare mafic phenocrysts. The intrusions have good exposure above treeline.

Contact metamorphism of the Hyland Group country rocks extends for as much as 0.5 km around the stocks and is dominated by a resistant, rusty weathering biotite hornfels. Calcareous rocks are altered to calc-silicate and thin carbonate beds locally form small skarns.

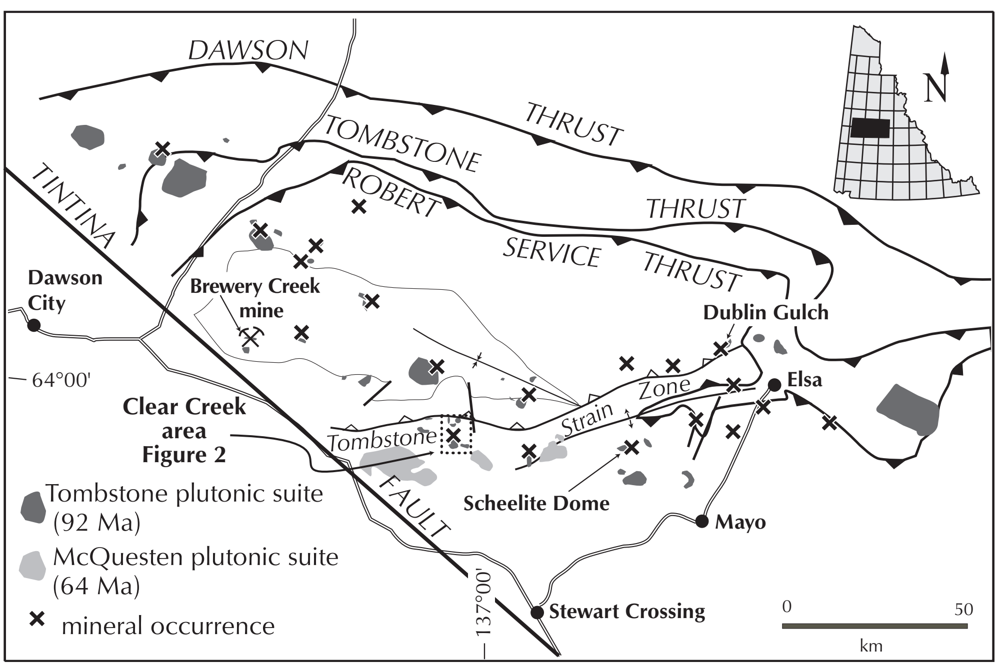

***Figure 1**. Geological framework of northern Selwyn Basin in west-central Yukon (modified from Murphy, 1997). The Clear Creek area (Fig. 2) is in the hanging wall of the Robert Service Thrust immediately south of the Tombstone Strain Zone.*

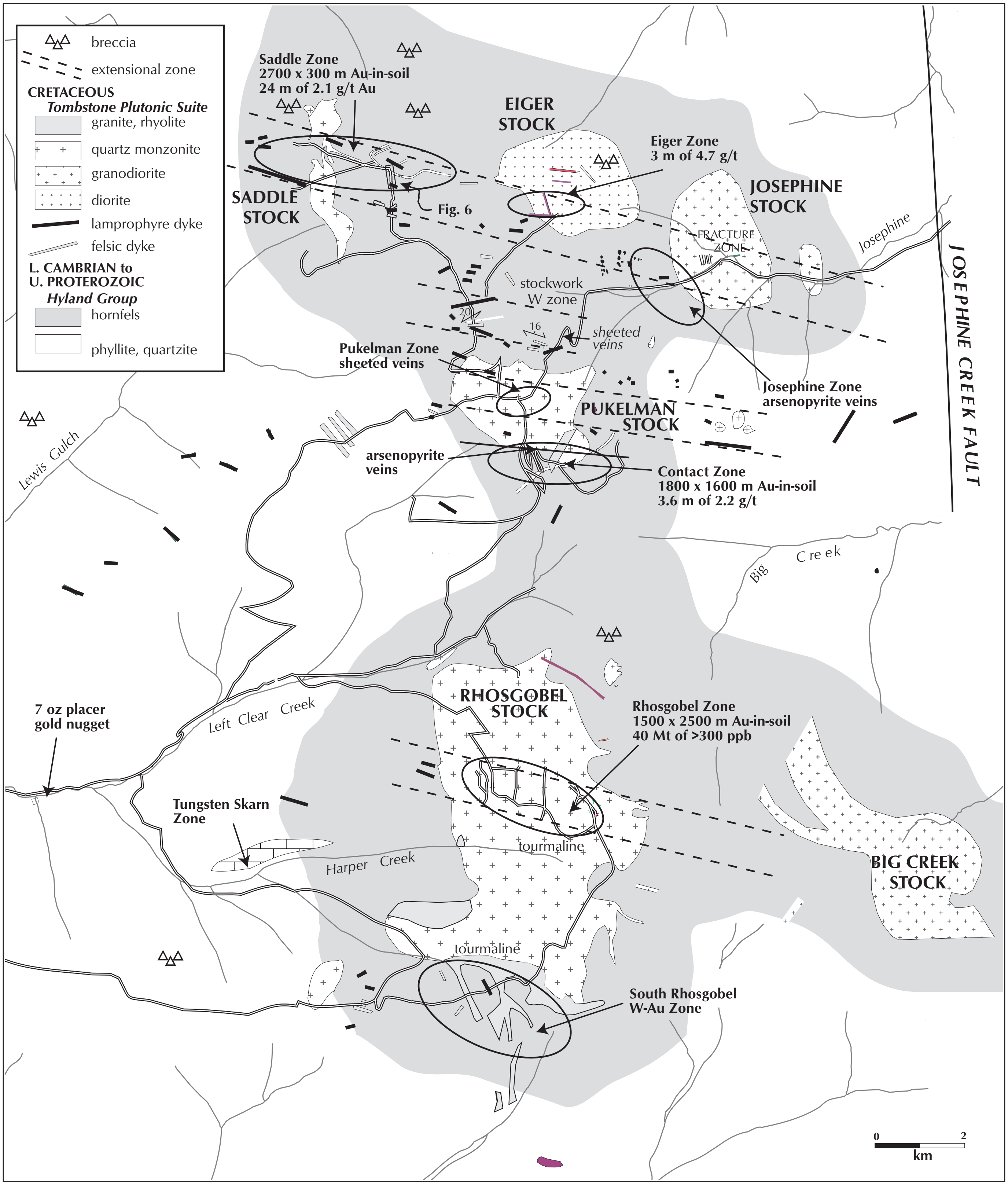

***Figure 2**. General geology of the upper Clear Creek drainage. Six stocks intrude Hyland Group metasedimentary rocks, each with a surrounding hornfels. All except the Big Creek stock are well mineralized. Linear regions, characterized by numerous parallel felsic and lamprophyre dykes, quartz and arsenopyrite veining, and alteration, are interpreted to represent zones of extension, delineated on this map by the dashed lines.*

Dykes, a common feature of the Clear Creek area, are dominantly ESE-trending and dip steeply (Fig. 3). Compositionally they are dominantly felsic, mostly composed of the porphyritic quartz monzonite. Also common are granite, quartz-feldspar porphyry, and rhyolite dykes. The felsic dykes are generally 0.5 to 2 m wide. Pegmatite and aplite dykes are thinner and are sparse outside of the intrusions. Lamprophyre dykes are up to 12 m wide, contain sparse biotite phenocrysts and biotite-diopside nodules, and cut all intrusive phases.

GOLD-BEARING MINERAL OCCURRENCES

Various styles of auriferous mineralization occur in the Clear Creek area, but intrusion-hosted sheeted arrays of low-sulphide quartz veins are predominant and characterize the Tombstone gold belt (Fig. 4). Irregularly spaced auriferous quartz veins are found in the adjacent hornfels. The sheeted and stockwork-style quartz veins, within the granitoids and hornfels, show traces to a few percent sulphide minerals, mainly arsenopyrite, pyrite, and less commonly, pyrrhotite. Scheelite is common in a minority of the veins and in local skarn zones. Molybdenite, galena, chalcopyrite, and bismuthinite have been also been reported (Coombes, 1997). K-feldspar, muscovite, biotite and carbonate are common gangue minerals, with less abundant tourmaline, albite and sericite.

Sheeted veins cut all intrusive rock types including felsic and lamprophyre dykes. Their localized coincidence with aplite and pegmatite dykes, and the presence of high-salinity fluid inclusions in metal-rich veins (Marsh, unpub. data), suggests a genetic link between mineralizing fluids and the latter phases of magma crystallization.

Arsenopyrite-rich veins are rare within the stocks but are normally in the margins or hosted by the hornfelsed country rocks. Notable occurrences occur on the margin of Josephine Creek stock in the Josephine Creek valley, and within the Contact zone at the southern margin of the Pukelman stock in the adjacent hornfels. Disseminated arsenopyrite is visible outside of some veins and within the most highly altered wall rocks.

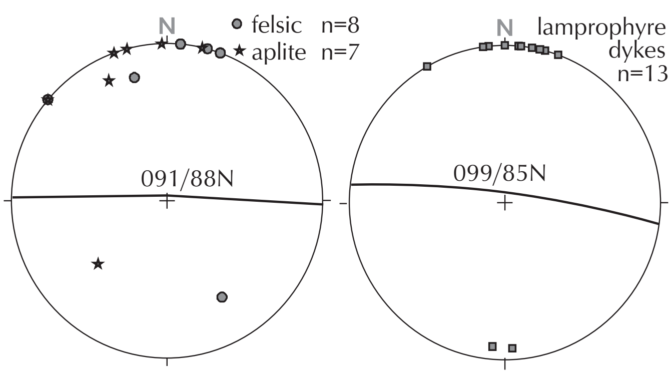

Figure 3. Equal-area, lower hemisphere projections of poles to planes of dykes measured in the Clear Creek area. Planes plotted are averages and may be shown steeper than actual since accurate dips were difficult to acquire.

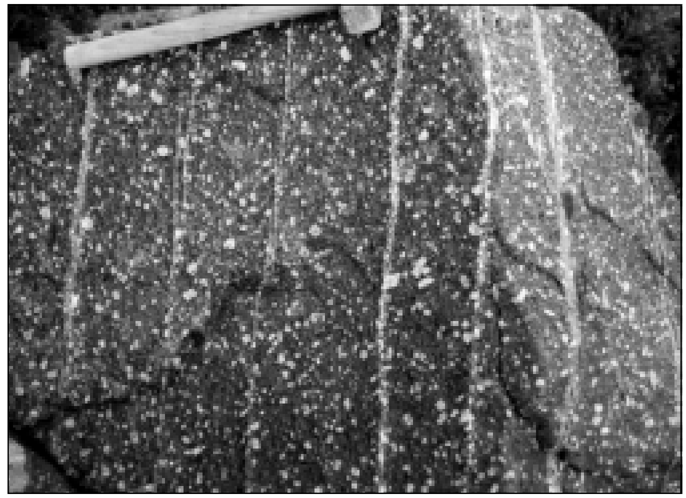

Figure 4*. Sheeted quartz-muscovite-pyrite veins are characteristic of Tombstone Gold Belt mineralization. This example, from the central Pukelman stock, displays a particularly high density of veins. The porphyritic texture of the host quartz monzonite is also characteristic of the Saddle and Rhosgobel stocks. Hammer handle is 38 cm long.*

Sheeted veins are in joints that are preferentially east-trending, within all of the stocks measured (Fig. 5). Other joint sets are rarely mineralized and cut the veins, thus indicating that the mineralized set represented the first set of dilational features. Veins not hosted in joints, sulphide-rich veins hosted in country rocks and felsic and lamprophyre dykes are also east-trending. Several east-trending zones that host numerous dykes and mineralized zones (i.e., Fig. 6) are continuous for several kilometres and likely represent extensional zones that evolved during waning magmatism.

GEOCHEMICAL METHODS

We collected 111 grab samples of quartz veins and stockworks, and of highly altered granitoid and hornfels throughout the headwaters of the Clear Creek. All analyses were performed by Chemex Labs Ltd. of North Vancouver, B.C. Samples were crushed in a ring-crusher to approximately minus-150 mesh. Gold was determined by standard fire assay on 30 g sample with atomic absorption (AA) finish; the lower determination limit was 5 ppb. Concentrations of 32 other major, minor, and trace elements in the 111 samples were determined by inductively-coupled plasma atomic emission spectroscopy

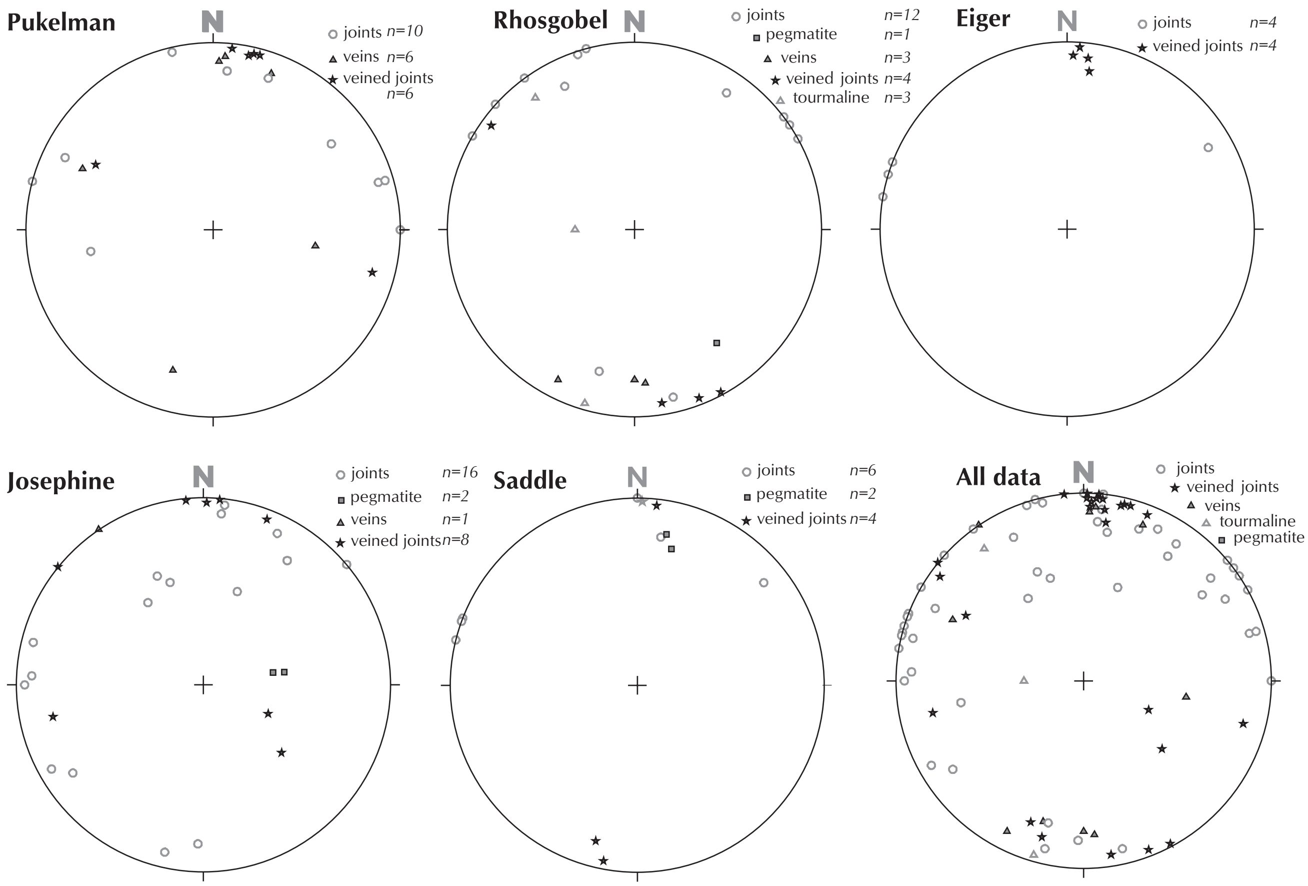

***Figure 5**. Equal-area, lower hemisphere projection of joints and mineralized veins and pegmatites throughout the Clear Creek area. Data are plotted as poles to planes. Note the dominance of data from veins in joints near the North and South poles that indicate the east-trend of steeply dipping veins.*

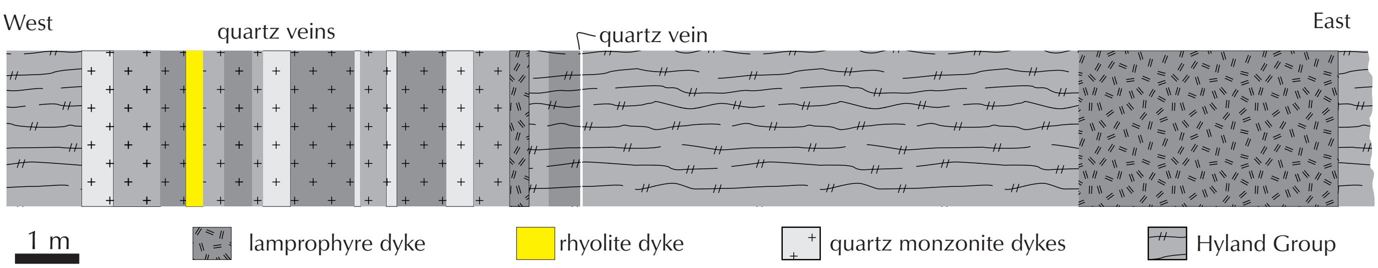

***Figure 6**. Schematic section across the mineralized zone southeast of Saddle zone. Several felsic and two lamprophyre dykes, and numerous quartz ± arsenopyrite veins have infiltrated and altered the adjacent rocks. Alteration is denoted by shading with most altered rocks being darker.*

(ICP-AES) analysis using nitric-aqua regia digestion. Digestion was possibly incomplete for Al, Ba, Be, Ca, Cr, Ga, K, La, Mg, Sr, Ti, Tl, and W.

A few dozen samples with the highest gold concentrations were subsequently analyzed by AA methods for tellurium and selenium, subsequent to HBr-Br_2 digestion and HCl-$KClO_3$ digestion with organic extraction, respectively. Ten samples with notably high metal values were also analysed for tin using NH_4I sublimation and extraction with AA finish. None of these samples contained more than the lower determination limit of 2 ppm. Ten samples with anomalous tungsten values were reanalyzed by colorimetric analysis after potassium pyrosulfate fusion because of the possibility of incomplete digestion by the aqua regia leaching procedure used in the ICP-AS analysis. Tungsten values less than about 300 ppm were consistent between the two analytical methods. Differences at higher concentrations indicate that ICP-AS data for tungsten in Tables 1-5 must be viewed as only minimum approximations.

Resulting data for the Saddle area are presented in Table 1, Eiger stock areas in Table 2, Pukelman stock area in Table 3, Rhosgobel stock area in Table 4, and Josephine stock area and Josephine Creek in Table 5.

METALS GEOCHEMISTRY OF THE CLEAR CREEK GOLD OCCURRENCES

SADDLE AREA

The several constituents that make up the intrusions of the Saddle area include the Saddle stock, a range of dykes, and a monzonitic-granitic sill. The main porphyritic Saddle stock ranges in composition from monzonite to granite. The monzonite is a medium- to coarse-grained rock consisting of quartz, feldspar, biotite and minor hornblende with K-feldspar phenocrysts that can reach one centimetre in diameter (Coombes, 1996). The medium-grained equigranular granite consists of quartz, feldspar, biotite, and minor hornblende.

Quartz veins cutting the intrusion contain as much as 3.9 ppm Au, 700 ppm As, 32 ppm Bi, 1.4 ppm Te, and 520 ppm W (sample 37). Altered monzonite and granite, with an abundance of secondary biotite, disseminated sulphides, and minor feldspar that is altered to sericite, occur adjacent to such veins. They contain as much as 2.8 ppm Au, 3.4 ppm Ag, 1965 ppm As, 46 ppm Bi, 1.4 ppm Te, and 170 ppm W (sample 36).

The stock is cut by several fine-grained lamprophyre dykes consisting mainly of fine-grained biotite and feldspar. A high density of arsenopyrite-rich quartz veins fill fractures in some of these lamprophyre dykes (Fig. 7). Alteration of the dykes within about 10 cm of the veins includes development of secondary biotite and arsenopyrite. Veins hosted by lamprophyre dykes (samples 7 and 9; Table 1) contain extremely high levels of Au (3.7-32 ppm), Ag (30-32 ppm), Bi (910-1455 ppm), and Sb (24-34 ppm); sample 9 also contained 875 ppm Cr, which is suggestive of inclusion of a chromite-bearing fragment from the dyke material. The Au:Ag ratios of ≤ 1, a relatively low arsenic content of sample 7, and concentrations of < 10 ppm W, contrast with the analyses of many other auriferous mineralized occurrences in the Clear Creek area, indicating probable local country rock control of elemental abundances of Ag, Bi, Sb, and W, for example. The vein cutting the dyke in sample 11 gives a

Table 1. *Mineralized samples from near the Saddle stock. (not/ss indicates insufficient sample for analysis)*

Sample and description

1 aplitic dyke with recrystallized biotite
2 quartz vein cut from sample 1
3 quartz vein with sulphide cut from aplite dyke
4 aplite dyke associated with vein of sample 3
5 biotite-rich recrystalized monzonite
6 monzonite with disseminated sulphides
7 quartz vein cut from lamprophyre dyke
8 lamprphyre dyke cut by quartz vein of sample 8
9 quartz vein with sulphide in lamprophyre dyke
10 porphyritic quartz monzonite
11 quartz vein from lamprophyre dyke
13 lamprophyre dyke
15 hydrothermally altered porphyry quartz monzonite
16 hydrothermally altered porphyry quartz monzonite
17 quartz vein cut from sample 17
18 hydrothermally altered porphyry quartz monzonite
19 quartz vein cut from sample 18
20 mafic intrusion rich in biotite, hornblende and quartz
21 biotite-rich vein in altered Hyland
22 porphyritic quartz monzonite
36 quartz monzonite with disseminated sulphides
37 quartz vein cut from 36
38 lamprophyre dyke
72 aplitic dyke with disseminated sulphides

Sample	1	2	3	4	5	6	7	8	9	10	11	13	15	16	17	18	19	20	21	22	36	37	38	72
Au ppb	<5	<5	>10,.000	4530	505	120	>10,000	85	not/ss	35	3230	20	1355	95	470	110	60	25	70	50	2850	3920	155	510
Ag ppm	<0.2	<0.2	3.2	0.8	<0.2	<0.2	32.2	0.2	30.4	<0.2	1.4	0.2	0.2	0.2	0.2	<0.2	<0.2	0.2	0.2	<0.2	3.4	0.2	<0.2	0.2
As ppm	99	50	630	1195	52	22	112	20	2310	68	>10,000	36	754	462	58	234	232	10	12	34	1965	704	60	8240
Ba ppm	70	30	160	130	170	560	40	360	10	290	10	1480	40	50	20	60	60	70	220	280	110	50	570	90
Bi ppm	<2	<2	226	50	2	6	910	6	1455	6	34	4	22	2	12	2	<2	<2	2	<2	46	32	<2	24
Co ppm	1	<1	4	6	14	15	3	8	6	3	30	22	1	<1	1	<1	<1	6	6	5	5	3	5	5
Cr ppm	56	197	136	89	100	102	356	57	875	67	288	244	82	63	220	103	147	95	193	74	148	211	32	63
Cu ppm	56	22	6	4	11	116	20	45	67	8	23	51	31	42	10	19	16	52	93	76	5	3	11	54
Fe %	1.28	0.47	0.89	2.14	4.34	5.38	0.9	3.08	1.86	1.52	2.77	3.55	1.1	0.64	0.36	0.47	0.56	1.2	3.59	2.59	1.23	0.75	4.18	2.34
La ppm	10	<10	10	30	40	130	<10	30	<10	50	<10	10	60	40	<10	60	30	20	40	50	40	30	40	10
Mg %	0.13	0.04	0.25	1.09	1.35	1.59	0.07	0.85	0.13	0.43	0.05	2.49	0.03	>0.01	0.01	0.01	0.02	0.32	0.71	0.69	0.46	0.24	1.06	0.14
Mn ppm	55	35	195	220	320	490	125	550	135	235	65	525	35	5	15	15	15	125	230	150	130	135	585	80
Mo ppm	1	4	1	1	<1	4	2	1	1	1	7	1	2	3	1	3	2	1	3	4	1	4	<1	2
Ni ppm	1	3	5	10	33	16	10	8	32	4	6	42	3	1	5	1	3	16	11	5	7	5	1	1
Pb ppm	14	14	8	10	6	8	24	8	42	8	12	10	12	16	6	16	10	12	8	6	26	6	12	10
Sb ppm	<2	<2	4	<2	<2	<2	34	<2	24	<2	30	<2	2	10	4	2	<2	<2	<2	<2	2	2	2	6
Te ppm			7.2	2.2	0.07						4.7		1		0.5	0.1					1.4	1.4		0.4
W (ICP) ppm	<10	<10	900	240	<10	20	<10	<10	<10	<10	100	<10	<10	<10	<10	<10	<10	90	10	10	170	520	20	<10
W (special)				160																	180	900		
Zn ppm	20	12	20	34	36	78	6	46	<2	42	20	88	10	2	2	2	<2	24	38	24	18	10	64	14

more typical geochemical signature (> 10,000 ppm As, 34 ppm Bi, 4.7 ppm Te, 100 ppm W) and a Au:Ag ratio > 1. Although containing visible disseminated arsenopyrite, the highly altered lamprophyre dyke samples were not notably enriched in gold (≤ 155 ppb Au) and other metals (samples 8, 13, and 38).

East of the Saddle Stock are several dykes that range in composition from aplite to lamprophyre. The aplite dykes are cut by several series of quartz veins. A vein with abundant scheelite, and the highest tungsten value from all the samples collected during this study (900 ppm; sample 3), contained > 10 ppm Au, 630 ppm As, 226 ppb Bi, and 7.2 ppm Te. The adjacent altered dyke, containing secondary biotite and abundant phenocrysts of arsenopyrite, has a similar signature although it contains lower concentrations for gold and all related pathfinder elements except arsenic. Another aplite dyke with a much higher concentration of disseminated arsenopyrite (sample 72), actually contained significantly lower concentrations of Au, Ag, Bi, Te, and W, despite a concentration of 8240 ppm As. This indicates that arsenic alone is not a consistently reliable pathfinder element for precious metal mineralization in the Clear Creek area.

A monzonitic to granitic sill, similar in composition and texture to the Saddle stock, outcrops ~200 m east of the stock. A series of quartz veins and a lamprophyre dyke cut the sill, with a selvage of secondary biotite and disseminated arsenopyrite around the veins for as much as 10 cm. Samples taken from the altered wall rock and a quartz vein contain as much as 3.9 ppm Au, 3.4 ppm Ag, 1,965 ppm As, 46 ppm Bi, 1.4 ppm Te, and 520 ppm W (samples 36 and 37, Table 1).

EIGER

The Eiger stock is an equigranular, fine- to medium-grained diorite with rare mafic phenocrysts. Gold mineralization occurs on the southern margin of the intrusion, within a zone along the contact with the Hyland Group country rocks. Several aplitic dykes, up to 2 metres in width, cut through this area. The adjacent diorite is often altered to flaky secondary biotite, irregularly silicified, and cut by sulphide-poor and arsenopyrite-

***Figure 7**. Sheeted arsenopyrite-rich quartz veins (white) cutting a lamprophyre dyke (dark) in the Saddle area. Chisel near top is 21 cm long.*

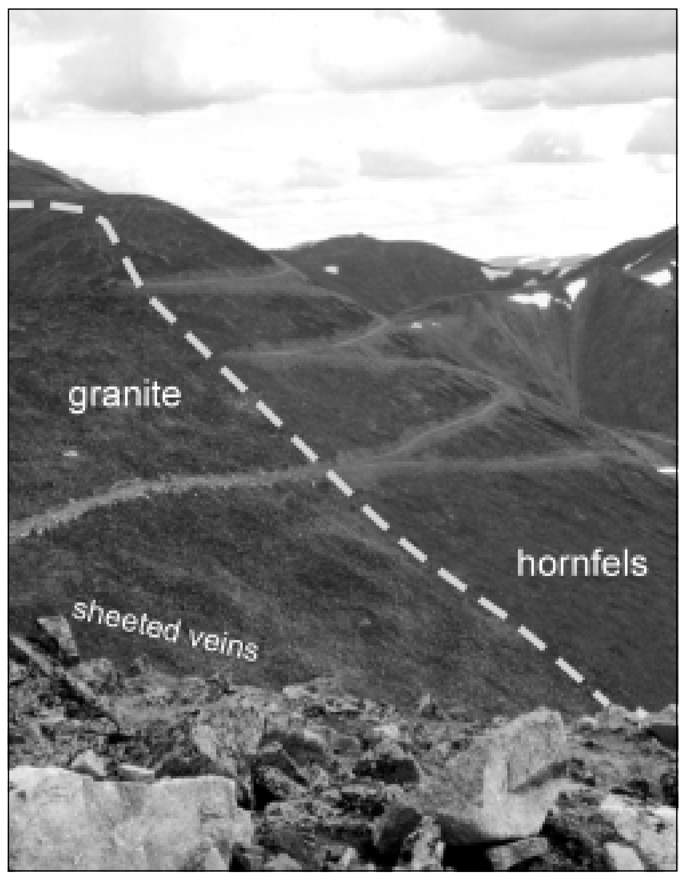

***Figure 8**. View southeast towards the bulldozer roads workings and drill pads near the southern margin of the Pukelman stock (Contact zone). The top of the stock is exposed at left, with sheeted veins exposed in the felsemeer.*

rich quartz veins. Samples from the sulphide-rich veins contain about 3 ppm Au, and As, Bi and W contents of as much as > 10,000 ppm, 600 ppm, and 370 ppm, respectively (Table 2). Sulphide-poor veins are low in gold.

PUKELMAN

The Pukelman stock is a porphyritic monzonite that is similar to the Saddle stock. Mineralization occurs along the Contact zone at the margin of the intrusion and extends into the hornfels aureole (Fig. 8). This zone was the focus of previous exploration efforts that included diamond drilling. Medium- to fine-grained masses of biotite are abundant and may be part of a late-stage magmatic fluid event. Samples of these biotite-rich zones in the monzonite contain as much as 1.8 ppm Au, 5% Fe, 130 ppm W, and > 10,000 ppm respectively (sample 90). Many of the veins in Hyland Group rocks in the Contact zone are notable by their relatively high silver and lead contents. Talus fragments of milky white, arsenopyrite-bearing quartz veins in hornfels, contain 46 ppm Au, as well as 18 ppm Ag, 3840 ppm As, 16 ppm Bi, 300 ppm W and 38 ppm Pb (sample 91, Table 3). Sheeted quartz veins in the hornfels contain as much 116 ppm Au, 37 ppm Ag, > 10,000 ppm As, 546 ppm Bi, 206 ppm Pb, 54 ppm Sb, and 14 ppm Te (samples 99, 101, 103, and 104).

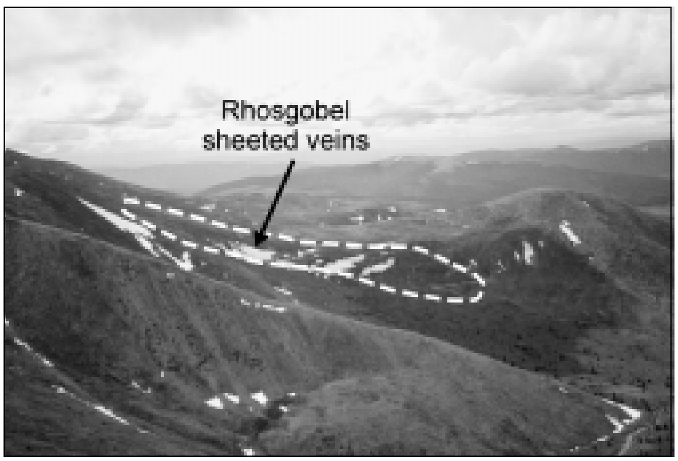

***Figure 9**. View south towards the Rhosgobel Stock with the 1200 by 250 m region of >300 ppb Au in sheeted veins as outlined by drilling by Kennecott in 1995.*

RHOSGOBEL

The Rhosgobel stock is also a porphyritic monzonite comprising quartz, feldspar, biotite, and minor hornblende. Mineralization occurs as a series of sheeted quartz veins in the Rhosgobel stock within a 1.2 km-long ESE-trending zone (Fig. 9), and along its eastern contact. The veins consist of the quartz, stringers of tourmaline, and rare visible arsenopyrite crystals. Greatest precious metal concentrations in the veins cutting the intrusion are about 3.5 ppm Au, with gold-to-silver ratios of < 1. These veins also have low arsenic concentrations (< 40 ppm), 240-380 ppm W, and elevated lead values of as much as 84 ppm (samples 44 and 53; Table 4).

JOSEPHINE

The Josephine stock is a fine- to medium-grained granodiorite. Gold mineralization occurs as a series of transparent to milky, arsenopyrite-rich quartz veins that range from less than a millimetre to 13 cm wide. The veins intrude and alter granodiorite at the southeastern margin of the stock. Biotite is abundant, quartz and feldspar appear recrystallized, and minor garnet is present in altered areas. A sample of a quartz vein with abundant

***Table 2**. Mineralized samples from near the Eiger stock. (not/ss indicates insufficient sample for analysis)*

Sample and description

- **58** aplitic dyke with disseminated sulphides
- **59** quartz vein cut from sample 58
- **60** quartz-enriched altered diorite
- **61** quartz vein cut from sample 60
- **62** diorite with disseminated sulphides
- **63** quartz vein cut from sample 62
- **64** altered diorite with recrystallized biotite
- **65** diorite with quartz enrichment
- **66** diorite
- **67** quartz bleb cut out of sample 66
- **68** arsenopyrite vein in diorite
- **69** quartz
- **70** arsenopyrite vein in diorite

Sample	58	59	60	61	62	63	64	65	66	67	68	69	70
Au ppb	20	145	90	95	25	95	<5	<5	<5	20	3290	135	not/ss
Ag ppm	0.2	0.2	<0.2	<0.2	<0.2	0.2	<0.2	<0.2	0.2	<0.2	1	<0.2	2.4
As ppm	102	92	44	212	50	66	72	66	32	56	>10,000	338	>10,000
Ba ppm	140	160	350	380	380	250	1140	700	470	60	150	30	10
Bi ppm	14	6	2	2	2	6	<2	<2	<2	<2	80	8	600
Co ppm	4	4	13	21	12	7	19	8	11	6	28	1	50
Cr ppm	112	380	97	268	162	229	114	60	205	408	89	347	22
Cu ppm	76	27	26	78	19	31	35	13	21	20	63	15	37
Fe %	1.7	0.97	3.48	3.99	2.86	2.4	4.8	2.78	3.08	1.04	5.16	0.49	>15.00
La ppm	40	20	30	30	10	30	50	30	10	<10	30	<10	<10
Mg %	0.49	0.24	1.49	1.59	1.65	1.42	2.59	0.76	1.59	0.28	1.32	0.01	0.02
Mn ppm	135	70	365	370	285	255	950	465	320	105	190	25	25
Mo ppm	<1	1	<1	7	<1	1	<1	<1	<1	1	1	1	5
Ni ppm	3	6	9	14	33	23	26	5	12	10	5	6	7
Pb ppm	12	6	12	12	10	8	8	6	12	2	10	6	50
Sb ppm	2	<2	<2	<2	<2	<2	<2	<2	2	<2	18	<2	274
Te ppm				0.1							1.1		
W (ICP) ppm	<10	<10	<10	190	<10	30	<10	<10	<10	<10	370	<10	20
W (special)					200						340		
Zn ppm	4	8	68	46	58	30	78	46	62	8	22	10	42

***Table 3**. Mineralized samples from near the Pukelman stock. (not/ss indicates insufficient sample for analysis)*

Sample and description

88 biotite-rich altered quartz monzonite
89 biotite-rich altered quartz monzonite
90 biotite-rich altered quartz monzonite
91 quartz with arsenopyrite
92 quartz with arsenopyrite
93 biotite-rich seam through Hyland Group
94 quartz vein in altered Hyland Group with sulphides
95 biotite-rich quartz monzonite
96 quartzite with sulphides
97 Hyland quartzite
98 quartz vein from sample 97
99 quartz vein and sulphides in felsic Hyland
100 quartz vein and sulphides in felsic Hyland
101 quartz vein with tourmaline and sulphides
102 biotite-rich aplite
103 sulphide-rich quartz veins in Hyland quartzite
104 sulphide-rich quartz veins cut from 106
105 quartz and biotite veining in Hyland
106 Hyland quartzite
107 apalite with disseminated sulphides
108 quartz with sulphide
109 quartz with some Hyland
110 porphyritic quartz monzonite
111 quartz vein through felsic Hyland
112 quartz vein through felsic Hyland

Sample	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
Au ppb	<5	<5	1845	>10,000	280	1805	210	255	965	225	625	8370	8310	>10,000	1015	not/ss	2850	340	50	80	1975	135	>5	40	65
Ag ppm	0.2	0.2	<0.2	18	<0.2	0.3	1.2	<0.2	<0.2	<0.2	<0.2	50.4	3.8	37.4	0.4	3.4	2.2	<0.2	<0.2	0.2	10.4	0.6	<0.2	<0.2	<0.2
As ppm	48	24	>10,000	3840	114	36	1740	212	6850	66	62	2440	368	>10,000	3690	6660	456	110	80	424	5010	388	38	18	46
Ba ppm	410	620	500	10	<10	140	<10	320	30	80	10	120	10	30	220	230	60	180	100	200	<10	40	260	<10	10
Bi ppm	<2	<2	6	16	<2	<2	8	2	<2	4	30	546	8	70	34	12	132	<2	2	<2	68	2	<2	2	<2
Co ppm	23	28	14	1	<1	9	1	13	4	1	1	5	1	13	13	4	1	9	1	<1	2	1	5	6	3
Cr ppm	194	279	93	263	354	248	511	79	227	301	285	279	416	375	136	503	375	250	313	112	247	309	123	226	350
Cu ppm	11	25	12	10	3	39	4	15	59	21	8	8	13	9	12	44	6	4	6	7	10	3	<1	4	4
Fe %	5.1	5.88	5.14	0.7	0.43	4.47	0.73	2.65	1.89	0.74	0.65	0.73	1.22	1.71	1.47	2.47	0.93	3.76	1.91	0.85	0.84	0.7	2.33	0.3	0.75
La ppm	20	20	50	<10	<10	30	<10	40	10	<10	<10	<10	30	<10	10	<10	10	40	10	10	<10	<10	30	<10	<10
Mg %	1.46	1.78	1.1	0.01	<0.01	1.21	<0.01	0.61	0.01	0.09	0.1	0.07	0.03	<0.01	0.45	0.03	0.16	1	0.53	0.06	<0.01	<0.01	0.6	0.01	0.2
Mn ppm	455	565	340	15	20	410	30	345	15	35	35	80	30	25	120	25	50	200	130	20	15	15	470	55	50
Mo ppm	<1	<1	2	1	1	<1	1	<1	<1	<1	1	7	1	2	3	3	1	6	<1	1	<1	6	1	1	1
Ni ppm	63	124	11	6	5	24	7	22	11	6	7	11	6	13	10	10	7	31	6	4	4	5	6	7	10
Pb ppm	10	10	6	38	<2	8	6	8	2	2	2	102	4	206	8	16	96	8	4	14	174	8	8	<2	<2
Sb ppm	2	<2	8	16	<2	<2	<2	<2	22	<2	<2	40	<2	54	<2	12	<2	<2	<2	<2	92	<2	<2	<2	<2
Te ppm			0.3	0.3		0.1			0.07			14	0.07	1.3	1.2	1.5	2.6				0.7				0.07
W (ICP) ppm	<10	<10	130	300	<10	<10	<10	20	<10	20	140	250	<10	<10	10	<10	<10	140	<10	<10	<10	<10	<10	10	680
W (special)				210																					700
Zn ppm	84	92	40	2	<2	76	<2	36	<2	2	2	6	6	2	16	2	6	44	18	16	2	<2	48	<2	2

***Table 4**. Mineralized samples from near the Rhosgobel stock. (not/ss indicates insufficient sample for analysis)*

Sample and description

39 prophyritic quartz monzonite
40 quartz and tourmaline veins cut from sample 39
41 prophyritic quartz monzonite
42 quartz and tourmaline veins cut from sample 42
43 quartz and tourmaline vein
44 quartz vein with tourmaline veining cut from sample 45
45 prophyritic quartz monzonite with tourmaline and quartz
46 quartz vein with tourmaline and sulphides cut from sample 47
47 porphyritic quartz monzonite
48 quartz tourmaline and sulphide vein cut from sample 49
49 porphyritic quartz monzonite
50 quartz and tourmaline vein cut from sample 51
51 massive tourmaline
52 Hyland Group quartzite with quartz vein
53 sheeted quartz and tourmaline veins
54 clean porphyritic quartz monzonite
55 quartz and tourmaline in porphyritic quartz monzonite
56 pegmatitic muscovite, quartz, feldspar, and tourmaline

Sample	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Au ppb	425	80	10	<5	<5	3720	380	15	<5	<5	5	<5	<5	990	3520	15	<5	<5
Ag ppm	1	1.8	1	0.2	<0.2	32.2	4.4	7.6	1	0.6	0.6	0.2	<0.2	0.2	5.6	<0.2	0.2	0.2
As ppm	48	24	62	12	20	38	32	2	4	8	36	<2	2	2	16	6	40	10
Ba ppm	120	60	350	90	40	40	50	60	120	50	220	<10	<10	30	20	180	50	20
Bi ppm	12	6	<2	<2	<2	158	22	20	<2	8	2	<2	<2	16	146	<2	<2	<2
Co ppm	8	1	9	1	9	2	5	3	4	1	7	<1	<1	<1	1	5	4	1
Cr ppm	153	134	98	326	239	260	135	250	138	406	159	242	81	153	179	85	211	141
Cu ppm	8	3	13	6	10	6	18	5	9	3	8	3	2	4	3	2	3	6
Fe %	2.38	0.97	1.72	0.56	1.04	0.64	2.17	1	1.11	0.74	1.74	0.33	0.29	0.29	0.47	2.22	1.47	0.65
La ppm	40	20	40	<10	<10	<10	30	10	30	<10	40	<10	<10	<10	<10	30	10	<10
Mg %	0.07	0.04	0.06	0.03	<0.01	<0.01	0.03	0.04	0.08	0.06	0.14	0.04	0.09	0.03	0.01	0.59	0.02	<0.01
Mn ppm	210	75	2200	390	460	35	180	165	120	135	260	45	80	30	235	475	490	30
Mo ppm	13	4	1	<1	1	7	9	<1	<1	1	4	<1	<1	1	4	1	<1	1
Ni ppm	7	4	7	5	17	4	7	5	5	5	5	3	1	3	3	5	6	5
Pb ppm	64	38	24	6	2	84	74	72	24	26	48	10	8	12	42	12	30	28
Sb ppm	<2	<2	<2	<2	3	8	4	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Te ppm						4								0.8	5			
W (ICP) ppm	30	<10	20	<10	<10	240	10	<10	<10	<10	<10	<10	<10	10	380	<10	10	<10
W (special)						680									460			
Zn ppm	76	26	44	12	8	4	72	44	48	18	64	16	16	4	6	60	44	<2

***Table 5**. Mineralized samples from near the Josephine stock.*

Sample and description

80 quartz vein with arsenopyrite
81 granodiorite
82 lamprophyre dyke
83 granodiorite with a quartz-feldspar-biotite vein
84 granodiorite with garnet and biotite
85 granodiorite with disseminated sulphide
86 granodiorite
87 quartz vein cut from sample 86

Sample	80	81	82	83	84	85	86	87
Au ppb	2390	25	<5	<5	<5	10	45	<5
Ag ppm	0.6	<0.2	0.2	<0.2	<0.2	<0.2	<0.2	1.4
As ppm	>10000	732	294	658	60	22	4240	88
Ba ppm	10	610	1190	630	880	770	800	460
Bi ppm	240	4	4	<2	<2	<2	20	<2
Co ppm	23	5	18	8	9	4	22	3
Cr ppm	249	158	321	132	164	93	156	264
Cu ppm	4	1	24	4	16	2	56	8
Fe %	7.08	2.68	4.03	2.73	3.25	2.38	3.78	1.54
La ppm	<10	30	10	40	40	40	30	20
Mg %	0.01	0.84	2.76	1.17	1.45	0.7	1.24	0.42
Mn ppm	25	325	540	310	395	265	280	135
Mo ppm	2	1	<1	<1	<1	<1	1	1
Ni ppm	4	5	20	11	15	4	11	7
Pb ppm	10	10	14	8	8	8	8	10
Sb ppm	52	<2	<2	<2	<2	<2	2	<2
Te ppm	0.9			0.07			0.07	
W (ICP) ppm	510	<10	<10	10	<10	<10	<10	<10
Zn ppm	12	48	70	66	94	46	38	20

arsenopyrite contains 2.4 ppm Au, > 10,000 ppm As, 240 ppm Bi, 7% Fe, 510 ppm W, and 52 ppm Sb (sample 80; Table 5).

FACTOR ANALYSIS OF LITHOGEOCHEMICAL DATA

R-mode factor analysis with Varimax rotation was used to identify the main element associations within the geochemical data. In factor analysis, similarly behaving variables (elements) are placed into groups termed factors. Specific rock types or ore deposit types are commonly represented by a distinct suite of trace elements, and therefore certain factors may indicate these common geochemical signatures. Factor loadings, which depict the influence of each variable on a factor, may be interpreted similarly to correlation coefficients.

Since some data range beyond the limits of the analytical techniques, several corrections are necessary for their incorporation into the statistical method. All data qualified with a "less than" value were replaced with 0.7 times the lower determination limit prior to calculations. Data qualified by "greater than" were replaced with 1.3 times the upper determination limit. Four samples that had insufficient material for gold analysis, were given gold values of three times the silver concentration (an approximate average Au:Ag ratio for the mineralized veins in the Clear Creek area). The highly censored (data qualified with > or <) elements consisting of Cd (all values ≤ 0.5 ppm), Ga (all values ≤ 10 ppm), Hg (all values < 1 ppm), Sb (most values < 2 ppm), Tl (all values < 10 ppm), U (all values ≤ 10 ppm), and W (most values ≤ 10 ppm) were eliminated from analysis. Data for Te and Se were not included because these elements were only determined for a select suite. All raw data for the remaining 24 elements were converted to logs and then run through factor analysis using Statistica 5.0 (StatSoft Inc., 1995). A five-factor model that explains about 79% of the total variance was selected as the most appropriate for summarizing the geochemical associations in the data from the Clear Creek area (Table 6). The factors are discussed below.

The first factor contains high loadings for Al, Ba, Ca, Fe, K, Mg, Mn, Na, P, Sc, V, and Zn. This signature represents relatively unmineralized intrusive and country rocks. These samples were analysed as they represented variably altered wall rock adjacent to sulphide-bearing veins. These elements are typical of common rock-forming silicate and carbonate minerals in both the hornfels zones and granitoid stocks. If a sample of country rock was significantly mineralized by the gold-forming event, then it would not have a high score in factor one; but would be better defined by factors 2 or 4 (see below).

***Table 6**. Five-factor model of R-factor analysis of geochemical associations in the Clear Creek area. Factors 1 and 2 describe metallogenic associations, whereas factors 3, 4 and 5 describe lithologic associations. Additional characterizations are explained in text. Positive numbers indicate the degree of positive correlation.*

Element	1	2	3	4	5
Au		0.80		0.36	
Ag	-0.26	0.31		0.84	
Al	0.88				
As		0.87			
Ba	0.88				
Be	0.34	-0.30			0.65
Bi		0.57		0.69	
Ca	0.85				
Co	0.64	0.26	0.53		
Cr	-0.48		0.63		-0.29
Cu	0.27	0.42	0.30		0.29
Fe	0.71	0.30	0.36		0.25
K	0.85				
La	0.63				0.52
Mg	0.93				
Mn	0.76	-0.39	0.25		
Mo		0.27			0.54
Na	0.85				
Ni	0.32		0.88		
P	0.82				0.33
Pb				0.84	
Sc	0.88				
Sr	0.90				
Ti	0.89			-0.25	
V	0.91				
Zn	0.80				0.27
Cumulative %	**47.63**	**60.84**	**68.67**	**74.23**	**78.52**

Factors 3 and 5 represent lithologic associations within the rock data. Samples with highest scores onto factor 3, a factor with highest loadings for Ni, Co, Cr, Fe ± Cu and Mn; these samples were collected from mafic rocks in the Clear Creek area. Most of these samples are lamprophyre dykes from the Saddle area, Eiger stock, and Josephine stock. Factor 5 is characterized by an element association of Be, La, Mo and P; highest scores were samples collected from the Rhosgobel and Pukelman stocks. These granitoids may be slightly more evolved than the other three stocks in the study area.

Factors 2 and 4 represent the precious metal mineralization assemblage in the Clear Creek area. Factor 2 (13% of the overall data variance), is defined by very high loadings for Au, As, and Bi, with less significant values for Ag, Co, Cu, Fe, and Mo. The samples with high scores were collected from quartz veins in the lamprophyre dykes cutting the Saddle stock and surrounding Hyland Group hornfels; quartz veins in the Saddle area trench; quartz veins and alteration zones in the Saddle area sill; biotite-rich, highly-altered rocks in the Pukelman contact zone; and sheeted quartz veins cutting the Josephine stock. This suggests that arsenopyrite- and Bi-bearing mineral phases are most closely associated with gold in the Clear Creek area. In addition, many of the samples with the highest scores also had high Sb and Te concentrations. It is therefore likely that Bi- and Au-bearing tellurides are common in many veins; the anomalous antimony, typically < 100 ppm, is probably present in arsenopyrite. Tungsten, not included in the factor analysis, is enriched in some samples with high factor 2 scores (e.g., samples 4, 11, 68, 90, 91), but typically shows little association with the gold-bearing suite (e.g., samples 33, 37, 61, 98, 105, 112).

Factor 4, in contrast to factor 2, is dominated by silver and lead, with bismuth and irregular As loadings. Gold has a weaker positive loading than in factor 2. High scores for this factor (samples 3, 9, 44-46, 53, 77, 78, 99, 101, 108) were collected from arsenopyrite-rich veins in the Eiger stock; some quartz veins in the lamprophyre dykes of the Saddle area; quartz in talus with arsenopyrite from the Pukelman Contact zone; sheeted quartz veins cutting the hornfels and quartzite of the Hyland Group surrounding the Pukelman stock; and sheeted veins hosted by the Rhosgobel stock. This factor indicates metalliferous locations characterized by Ag>Au and lead values typically 40-200 ppm, suggesting local argentiferous galena. Critical factor 2 elements such as gold (e.g., samples 45, 46, 77, 78) and arsenic (e.g., samples 44-46, 53, 77-78), are often at background levels in Factor 4. Bismuth and tellurium are consistently elevated in samples with the highest silver and lead concentrations, suggesting a complex, but not necessarily gold-rich, metal assemblage.

DISCUSSION

Gold-bearing veins are most apparent in Hyland Group rocks surrounding the Pukelman stock; in lamprophyre dykes and, less commonly, in aplitic dykes, of the Saddle area; and in arsenopyrite-rich zones along the margin of the Eiger stock. Less extensive and lower grade occurrences are located near the margins of the Josephine, Rhosgobel, and Pukelman stocks. The spatial distribution of the lodes indicates that the more favourable occurrences may be coincident with late-stage dykes and sills, and in the hornfels.

Results from factor analysis indicate that the gold-rich zones are characterized by a consistent As-Au-Bi signature. Emond and Lynch (1990) indicated that many of the veins in this part of the Yukon contained anomalous bismuth, but that a correlation between bismuth and gold was not apparent. Our detailed sampling in the Clear Creek area indicates a strong positive correlation between gold and bismuth and supports similar assertions by Murphy et al. (1993). Gold-bismuth correlations in other deposits of the Tombstone gold belt have also been documented by Bakke, (1995); Hitchins and Orssich, (1995); and McCoy et al., (1997).

Tellurium and antimony locally occur at elevated values in gold- and bismuth-enriched samples containing visible pyrite and arsenopyrite. Although these elements are too highly censored for inclusion in the factor analysis, they appear to be additional important pathfinder elements for the gold occurrences in the Clear Creek area.

Therefore, any soil or rock geochemical exploration program for gold ores in the Clear Creek area should consider As, Au, Bi, Sb, and Te as the elements that would be most useful for the identification of localities proximal to significant gold-bearing lode occurrences.

CONCLUSIONS

Auriferous sheeted quartz veins and silicified shear zones occur along the margins and within adjacent hornfels zones of five stocks of the Tombstone plutonic suite near the head of Clear Creek. Sheeted veins cut all intrusive rock types including felsic and lamprophyre dykes. Sheeted and solitary veins in the intrusions and hornfels, as well as felsic and lamprophyre dykes are all dominantly east-trending. Zones with high vein and dyke densities are interpreted as localities of extension.

The lodes typically contain variable amounts pyrrhotite, pyrite, and arsenopyrite, with scheelite sporadically abundant. Alkali-feldspar, muscovite, biotite and tourmaline are common gangue phases. Many of the gold-rich mineral occurrences are in biotite-rich hornfels.

Grab samples of mineralized rock locally contain gold grades in excess of 1 ounce per ton. The gold-rich samples typically contain greater than 1% arsenic. Bismuth, and less consistently tungsten values of 100-1000 ppm characterize many of the most highly mineralized veins within and surrounding the stocks.

Quartz veins along the intrusive-metasedimentary rock contact around the Pukelman stock are also enriched in lead and silver, with samples containing 100-200 ppm Pb and 18-37 ppm Ag.

In many of these samples, antimony enrichments range between 10-100 ppm.

R-mode factor analysis of multi-element geochemical data discern a five-factor model that explains 79% of the total variance. Three factors define the geochemical signatures of the main lithologies. The suites reflect (1) common rock-forming silicate and carbonate minerals of the Hyland Group and typical granitoids, (2) mafic silicate phases in the lamprophyre dykes and (3) incompatible elemental enrichments in the most evolved granitoid phases. Sulphide-bearing quartz veins and hydrothermally altered wall rocks are represented by the two other factors. The first of these is the As-Au-Bi ± Sb, Te ore-related mineral association characteristic of intrusion-related gold deposits throughout the Tombstone gold belt. Less consistently, anomalous concentrations of Ag, Co, Cu, Fe, and Mo occur within these auriferous rocks. The second metal suite noted from the factor analysis is defined by Ag-Bi-Pb ± As, Au, Te and characterizes metalliferous vein samples that have uncommonly low Au:Ag ratios. The geochemical signature particularly characterizes many samples from in and around the Pukelman stock. It may identify a second metalliferous hydrothermal event in the Clear Creek area. Tungsten shows little consistent correlation with the metalliferous rocks in either element suite.

ACKNOWLEDGEMENTS

Thanks to Nels and Madeline Harper of Blackstone Placer Mines, Hans Smit of New Millenium Mining, Steve Coombes of Kennecott Canada Inc. and Don Murphy of the Yukon Geology Program for generously supplying geological information about the Clear Creek area. Field assistance by Alana Rawlings and Melanie Reinecke is appreciated. Cynthia Parnow, Don Keedicks, Lang Farmer, and Bill Atkinson of the University of Colorado at Boulder are also acknowledged for support and advice. Reviews by Charlie Roots are appreciated.

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