THE TILLICUM MOUNTAIN GOLD PROPERTY
A PETROLOGIC UPDATE
(82F/13)

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INTRODUCTION

The Tillicum Mountain gold property (latitude 49 degrees 59 minutes north, longitude 117 degrees 43 minutes west) is located approximately 13 kilometres east of Burton in the Arrow Lakes region of southeastern British Columbia. Shortly after the initial discovery of high-grade surface gold in 1980 by local prospectors, Arnold and Elaine Gustafson, the property was optioned to the Welcome North-Esperanza Joint Venture. In 1982, Esperanza Explorations Ltd. acquired the 50-per-cent interest of Welcome North Mines Ltd. and concluded a financial agreement with La Teko Resources Ltd. for further exploration. An intensive diamond drilling, prospecting, trenching, and sampling program has been carried out in subsequent field seasons.

The Tillicum Mountain gold prospect is a significant, relatively new find in the Province. Localized high-grade zones occur; the Money Pit, the original discovery, has already yielded a 64-ton bulk sample with 2.3 ounces gold per ton. In addition, several low-grade but large tonnage, roughly northerly trending zones of gold mineralization have been delineated. Moreover, recent exploration is also assessing two silver-dominated zones toward the southern boundary of the property.

The overlapping record of successive geological events, together with the fine grain size of many host rocks, have led to contrasting models of mineralization. Ideas put forward to explain the gold prospect range from skarn (Godwin, personal communication, 1983), to volcanogenic (Smith, 1983), to epigenetic and mesothermal (Kwong and Addie, 1982). To attempt to determine the genesis, a well-explored portion of the property was studied in detail. This communication presents findings on the petrology of the property and discusses their implications toward further exploration in the area. A model for the gold mineralization compatible with the new data is also proposed.

GEOLOGICAL SETTING

Tillicum Mountain lies in the southern extremity of the Nakusp area which was studied and mapped by Hyndman (1968). An extensive strip of rocks of the Milford (?) Group (Pennsylvanian (?) to Triassic) is intruded to the northwest by Cretaceous and/or Jurassic plutonic rocks of the Goatcanyon-Halifax Creeks stock (Fig. 2). The Milford Group consists of fine-grained pelitic schists with widespread occurrences of calc-silicate-rich rocks. The stock largely consists of hornblende-biotite quartz monzonite with localized quartz diorite and granodiorite at the margins of the intrusion. Occupying the northwest side of Tillicum Mountain and separating the pelitic schists from the intrusive rocks is a small area of amphibole-rich metavolcanic rocks, presumably belonging to the Triassic Kaslo Group (Hyndman, 1968). Correlation of rock groups in the region by Hyndman (1968) was based mainly on lithology. The same metasedimentary and metavolcanic rocks were mapped earlier by Little (1960) as belonging to the Slocan Group [Triassic and Lower Jurassic (?)] and Rossland Group (Lower Jurassic), respectively.

According to Hyndman (1968), three episodes of folding affected the metasedimentary and metavolcanic package prior to the consolidation of the intrusive stocks. Based on a detailed study at the Nemo Lakes belt to the south, Parrish (1981), recognized only two, possibly related periods of major folding. Both authors, agreed that a continuity of regional metamorphism exists throughout the region with metamorphic grade generally decreasing northward. Major periods of folding and regional metamorphism were interpreted to have occurred during Jurassic time.

LOCAL GEOLOGY AND PETROGRAPHY

Figure 3 is a generalized geological map of the area that was studied in detail. Five major rock units as well as late and locally abundant lamprophyre and dacitic dykes, not shown on the map for the sake of clarity, can be recognized. Unit 1 consists of very fine to fine-grained metasedimentary rocks, including argillite, metasiltstone, and a small amount of phyllite that is locally abundant along shear zones. Where carbonaceous material is abundant, bedding, consisting of light and dark bands varying in thickness from less than a centimetre to about half a metre, can frequently be discerned. Metamorphic foliation is defined by subaligned biotite and muscovite and/or chlorite, which rarely exceed 20 per cent by volume. In many thin sections fine-grained mica shows two preferred directions of orientation at less than 30 degrees to each other, suggesting possibly two recrystallization events. Compositional layering is always parallel to one of these preferred orientations. Most of the chlorite, which replaces biotite and/or amphibole, appears to be at an angle to the compositional layering. Hornfelsed argillites in the vicinity of the southeastern quadrant of the Money Pit have randomly oriented micas and more abundant tremolite and pyrrhotite; hornfelsic argillite southwest of the Blue zone has more abundant zoisite.

Unit 2 is mainly semi-pelite with lenses, pockets, and discontinuous bands of calc-silicate rocks. The calc-silicate assemblage is typically fine to medium grained and consists dominantly of tremolite, diopside, and plagioclase with or without minor amounts of garnet, K-feldspar, zoisite, and opaque minerals. In general, the minor phases are more concentrated toward the edges of the calc-silicate bodies. Pyrrhotite is the most prominent opaque mineral observed; less common ones include sphalerite, galena, chalcopyrite, gold, marcasite, pyrite, and tetrahedrite (?).

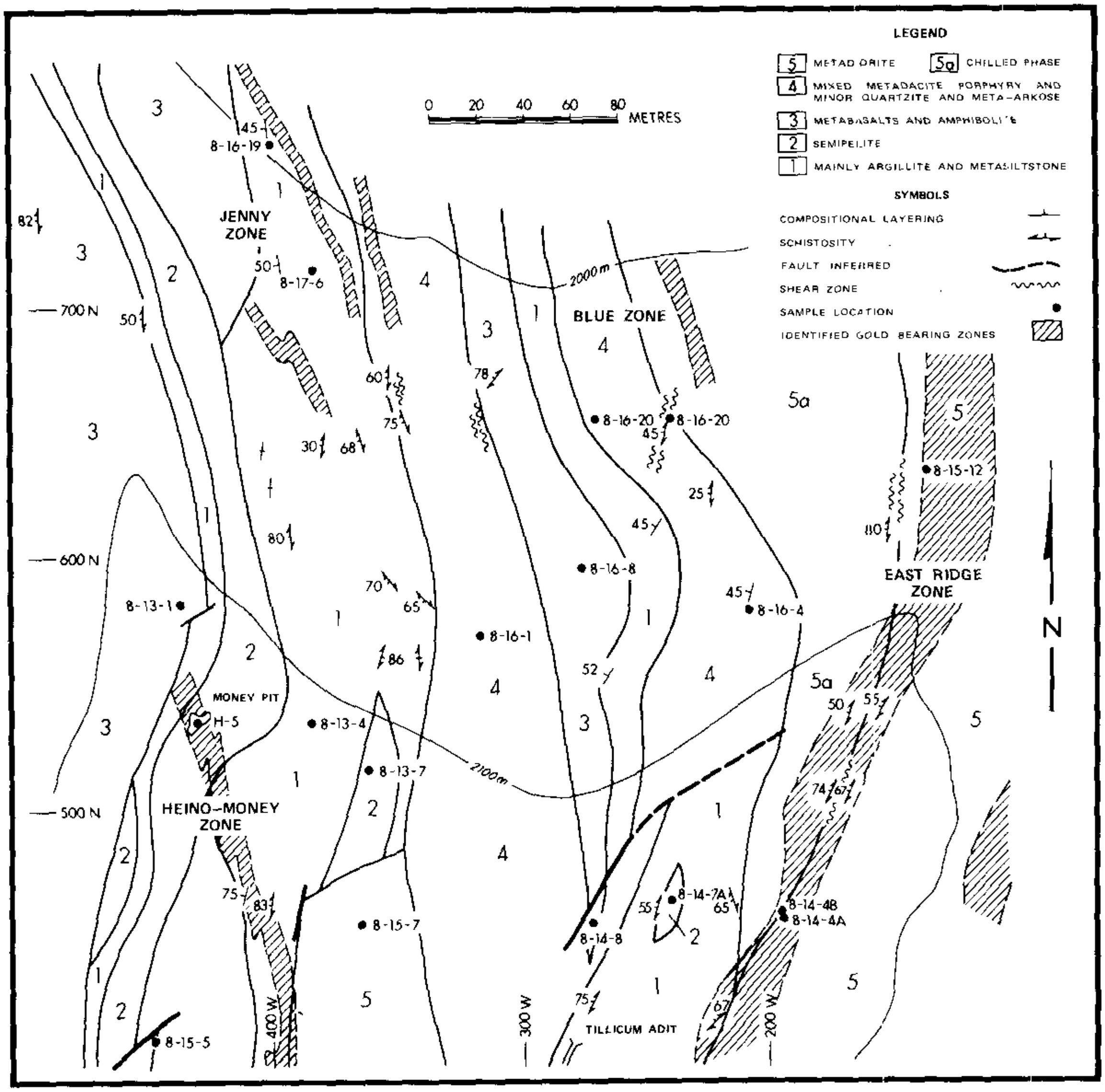

Figure 3. Generalized geology of the area studied in detail.

Minerals identified from the fine-grained, semi-pelite matrix include subaligned biotite, tremolite, plagioclase, microcline, garnet, chlorite with or without zoisite, opaque minerals (pyrite, arsenopyrite, local pyrrhotite), and quartz. Quartz is rare in semi-pelites adjacent to calc-silicate bodies of various sizes but quartz fragments and veinlets and interstitial quartz with or without calcite sometimes occur within the calc-silicate rocks. Quartz breccia carrying gold is locally present in this unit.

Unit 3 is essentially a massive, generally porphyritic, metabasalt that is characterized by an abundance of hornblende and plagioclase with minor amounts of biotite and calcite. Recrystallization of hornblende to tremolite-actinolite, chlorite, and, locally, biotite are quite common; K-feldspar, quartz, and garnet are uncommon. This unit is locally amygdaloidal and some layers are flow brecciated. Adjacent to the metasedimentary rocks, thin interbeds of calc-silicates up to 1 centimetre thick have been observed in the metabasalt unit, indicating a gradual transition from a sedimentary-dominated to a volcanic-dominated regime (or vice versa) with intermittent quiescent periods.

Unit 4 includes fine to medium-grained, light-coloured dacite porphyry as well as localized outcrops of quartzite and meta-arkose. Plagioclase and hornblende partially replaced by chlorite are the most common phenocrysts occurring in the porphyry, whose matrix consists of K-feldspar, plagioclase, quartz, and accessory apatite and pyrite. Due to deformation and alteration, it is not possible to determine whether the dacite porphyry is an intrusive sill or a lava flow. Scattered occurrences of medium-grained, well-bedded quartzite and arkose may be large blocks of unassimilated country rock within the porphyry. Sulphides found along fractures in rocks of unit 4 are dominated by pyrite.

Unit 5 consists of medium to coarse-grained metadiorite with a fine-grained chilled margin varying from 1 to 100 metres wide. Gneissic banding is best exhibited along the finer grained contact margin in which darker hornblende-biotite bands up to 2 centimetres thick alternate with lighter coloured feldspathic bands of similar thickness. The grain size of the metadiorite increases toward the southeast and metamorphic foliation defined by subaligned biotite and poor gneissic banding is well exhibited, even in the coarsest portion of the intrusive body, which is southeast of the study area. In addition to plagioclase, hornblende, biotite, and accessory quartz, chlorite, and opaques, manganese-rich garnet is also common. Arsenopyrite, pyrite, and pyrrhotite are among the more common sulphide minerals in this unit.

Both bedding and schistosity in these units generally trend north-south. In the western half of the study area they are subvertical, whereas in the eastern portion they show gentle, generally westerly dips. The distribution pattern of the rock units suggests cross-folding with initial north-south-trending, tightly folded rocks affected by a later, open east-west-trending fold. A north-south-trending fault is also suspected in the centre of the area (Fig. 3), causing some repetition of the units. The way-up of these units is uncertain, so their relative age is not known. However, based on intrusive relationships, it is evident that units 4 and 5 are younger than units 1 through 3.

GEOCHEMISTRY AND METAMORPHIC PETROLOGY

Table 1 summarizes the major element geochemistry of 18 selected samples collected from the property. Relevant data are also plotted on the ACF

TABLE 1
MAJOR ELEMENT GEOCHEMISTRY OF SELECTED SAMPLES FROM THE TILLICUM GOLD PROPERTY

Field No.	Description	SiO_2	Al_2O_3	K_2O	Na_2O	TiO_2	MgO	Fe_2O_3	CaO	MnO	Total
8-14-4A	metadiorite	59.00	17.66	2.97	4.16	0.81	1.81	5.64	6.43	0.23	98.71
8-14-4B	metadiorite (chilled phase)	59.96	17.58	2.44	4.07	0.84	1.62	5.61	5.56	0.17	97.85
8-15-7	metadiorite	61.43	18.57	3.52	3.72	0.61	1.16	6.09	4.66	0.16	99.92
8-15-12	metadiorite	60.13	17.51	3.26	4.21	0.78	1.54	5.41	6.08	0.14	99.06
8-13-1	metabasalt	47.71	13.63	1.63	2.24	0.82	9.22	11.44	12.34	0.20	99.24
8-14-8	biotite-hornblende schist/metabasalt	52.02	17.74	3.82	1.17	0.92	4.75	10.53	8.11	0.29	99.32
8-15-5	hornfelsed basalt	47.65	16.48	4.31	1.52	0.93	6.50	11.60	7.77	0.64	97.40
8-16-1	hornfelsed basalt	49.69	16.93	3.45	2.80	1.06	6.11	11.64	6.39	0.35	98.42
8-16-8	metabasalt	46.45	14.23	3.71	1.75	0.88	6.44	12.00	10.79	0.24	96.49
8-13-4	argillite	60.64	15.56	3.95	2.64	0.67	3.01	8.62	3.09	0.13	98.30
8-16-19	graphitic argillite	58.47	15.85	1.88	2.36	0.85	1.88	3.72	5.31	0.16	90.48
8-17-6	hornfelsic argillite	55.83	16.55	3.58	2.42	0.79	3.74	9.21	4.98	0.22	97.32
8-16-4	meta-arkose	63.56	16.99	5.00	0.89	0.55	1.33	4.15	4.89	0.13	97.49
8-16-20	meta-greywacke	60.75	17.25	3.48	4.09	0.70	1.81	5.21	3.98	0.15	97.42
8-16-21	muscovite phyllite	65.38	17.35	5.44	0.36	0.56	1.30	5.14	0.83	0.19	96.55
8-13-7	calc-silicate schist	55.29	16.15	4.92	1.31	0.97	3.36	8.85	6.88	0.26	97.99
8-14-7A	calc-silicate schist	50.57	15.87	5.51	0.47	0.85	5.17	10.88	8.49	0.32	98.13
H-5	calc-silicate skarn (massive)	47.14	12.13	3.18	0.52	0.81	8.16	11.43	13.14	0.90	97.41

*Total iron expressed as Fe_2O_3

diagram (Fig. 4) which shows the compositional fields of various volcanic metasedimentary material, as well as the prograde and retrograde mineral assemblages observed in these and other samples collected from the study area. When plotted on an A'FK diagram, most of these rocks fall on or close to the FK joint with a concentration near the composition of biotite. The only exception is a highly sericitized dacite, which lies along the muscovite-biotite joint toward the composition of muscovite. The high potassium content accounts for the absence of pure aluminum-silicate phases, while the stabilization of micas probably hinders the crystallization of staurolite and chloritoid. Nevertheless, the prograde mineral assemblages are compatible with an almandine-staurolite facies of regional metamorphism, whereas the retrograde assemblages indicate the albite-epidote-chlorite-actinolite subfacies of greenschist metamorphism.

The metamorphic history of the area is complex. It was generally assumed that the hornfelsic texture so evident in many argillites, particularly those in the vicinity of the Money Pit, was due to the intrusion of the Goatcanyon-Halifax Creeks stock (for example, Kwong and Addie, 1982). However, with recognition of the metadiorite and more detailed mapping and examination of drill cores during the summer of 1983, a more complex picture is evident. Spatially, hornfelsic argillites, with the exception

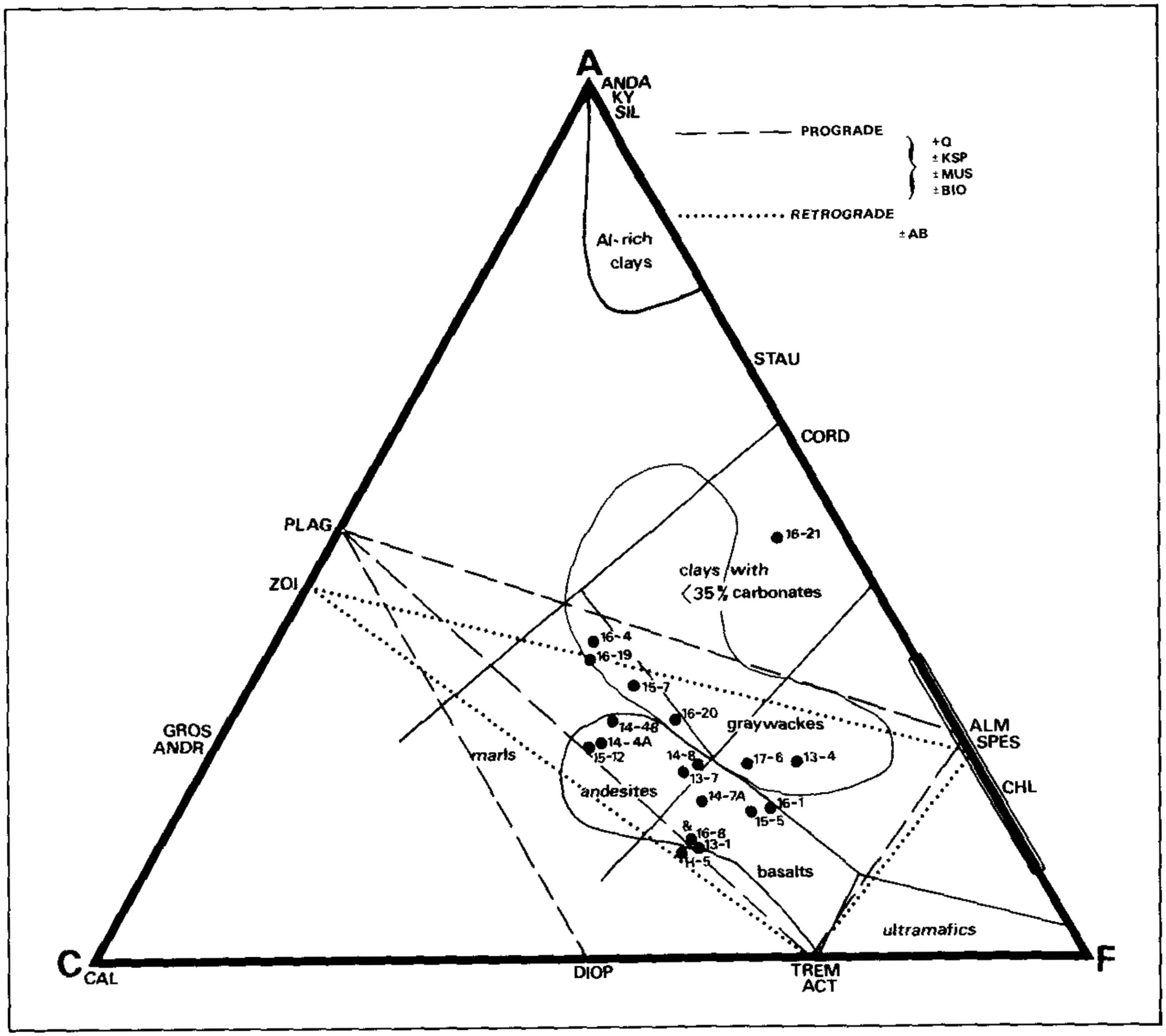

Figure 4. ACF plot for selected samples from the Tillicum gold property showing prograde and retrograde assemblages.

of those characterized by abundant zoisite, correlate more closely with the metadiorite than with the younger stock. As well, textural evidence supports the hypothesis that an early generation of hornfels formed during intrusion of the diorite. Contact metamorphism of carbonate lenses, pockets, and bands produced a diopside-dominated rock, randomly oriented fine-grained biotite grew in the argillaceous sediments, and hornblende in some metabasalt was recrystallized to actinolite. During subsequent regional metamorphism, recrystallization in these partially dehydrated rocks was generally less pervasive than elsewhere and the effects of structural deformation are more obvious. The most prominent effects were development of subaligned micas and growth of accessory manganese-rich garnets in the finer grained rocks, and the development of poor banding in the diorite. The conversion of carbonates to calc-silicates involves a reduction in volume and any incipient porosity produced during the early hornfelsing was probably accentuated by structural deformation during the regional metamorphism. This probably accounts for the brecciated texture of calc-silicate pockets in the Money Pit.

During intrusion of the Goatcanyon-Halifax Creeks stock, a third period of recrystallization was initiated. Diopside in the calc-silicate bodies was replaced by tremolite, calcite, and quartz; a second generation of actinolite grew in the metabasalt; and along microfractures in the metasedimentary rocks, amphibole, biotite, garnet, and plagioclase were replaced by chlorite, a new biotite, and zoisite. Sulphides were also modified; pyrrhotite was replaced by marcasite and arsenopyrite was introduced. If the intrusion of the Goatcanyon-Halifax Creeks stock occurred after the stratigraphic succession was uplifted or partially uplifted, then the effects of this second contact metamorphism would be very difficult, if not impossible, to distinguish from those of retrograde metamorphism except in the immediate vicinity of the intrusion. It is likely that retrogressive reactions were enhanced by this younger intrusion, which provided heat and a ready source for reactive fluid. In short, a three-stage model of modification of the rocks in the study area explains the observed textures and field data better than the two-stage model proposed earlier (Kwong and Addie, 1982).

PRECIOUS METAL AND SULPHIDE MINERALIZATION

Within the mapped area, gold is the main commodity of interest. it occurs essentially in its native state as fracture-filling material. It commonly occurs in veinlets and as discontinuous trains of tiny blebs (less than 0.1 millimetre in diameter) along microfactures in various rock types; rarely it occurs as impregnations and stringers up to 0.5 centimetre in width in brecciated calc-silicate rock and quartzite, and, to a lesser degree, semi-pelite. From polished section studies, it is evident that the deposition of gold covered a rather wide range of temperatures. Plate I shows native gold associated with pyrrhotite,

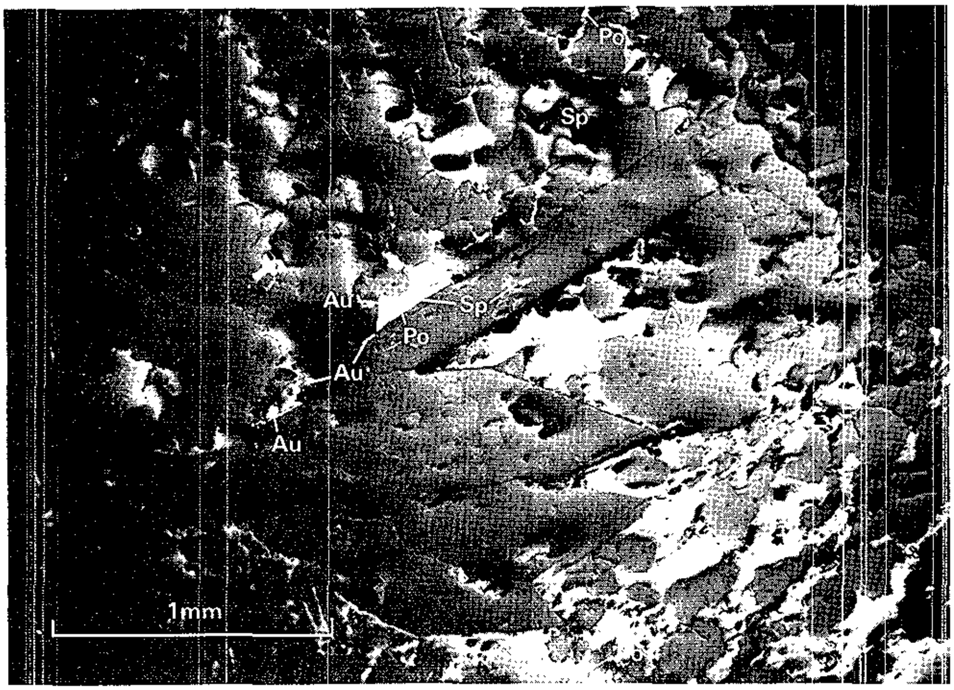

Plate I. Native gold (Au), pyrrhotite (Po), and sphalerite (Sp), with or without tetrahedrite, fill the interstitial spaces between tremolite crystals and partially resorbed, rounded grains of diopside. *(Specimen collected from the Money Pit).*

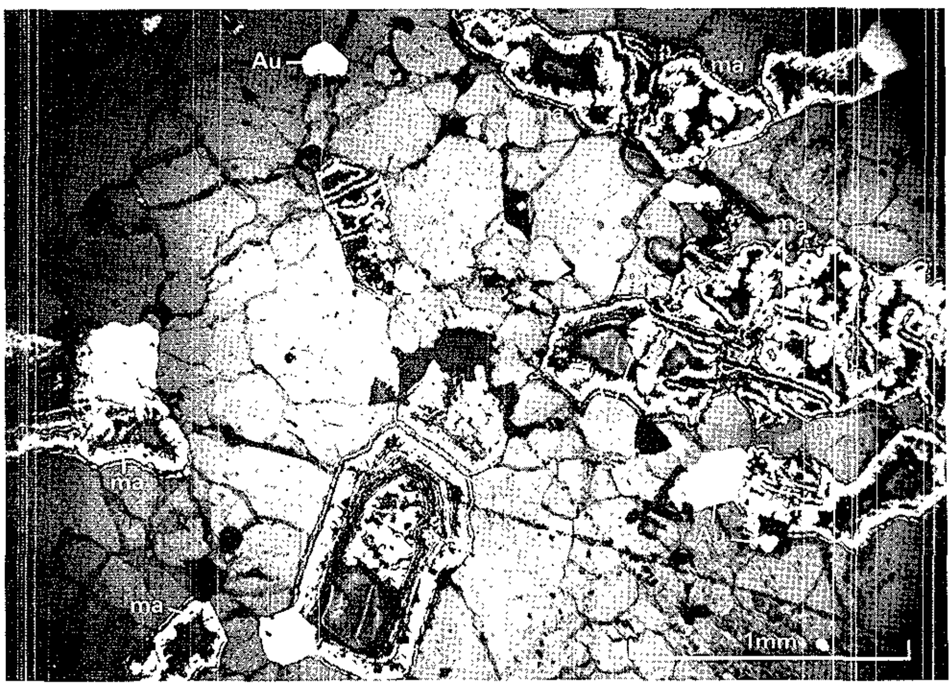

Plate II. Native gold (Au) is associated with marcasite (ma) and locally pyrite (py) that have almost completely replaced pyrrhotite (Po). *(Specimen collected from the Heino Pit by G. G. Addie).*

sphalerite, and possibly tetrahedrite filling the interstitial spaces between tremolite crystals and partly resorbed, rounded diopside grains. More rarely, gold lies along cleavage planes in the amphibole. At higher magnification, sphalerite shows exsolved trains of pyrrhotite and chalcopyrite, suggesting a moderately high temperature of deposition of the original sphalerite solid solution; a temperature of 350 50 degrees Celsius for the precipitation of gold is compatible with the observed mineral associations. Plate II shows blebs of gold associated with marcasite which forms under low temperature (probably <250 degrees Celsius) acidic conditions. Plate III shows a discontinuous train of blebs of native gold crossing pyrrhotite and pyrite. The temperature of deposition of this gold is uncertain but is probably low (<150 degrees Celsius ?) because the gold postdates all other minerals observed in the section. Rarely, gold also occurs as globules up to 1 millimetre in diameter along weathered surfaces of some semi-pelites in the vicinity of Heino Pit. Its shape suggests that this gold is pseudomorphing goethite with which it is closely associated. Apparently, during oxidation of iron sulphides to goethite, gold associated with the sulphides agglomerates and remains fixed *in situ* rather than being removed. Hence, secondary dispersal of the precious metal during weathering is probably minimal in this area.

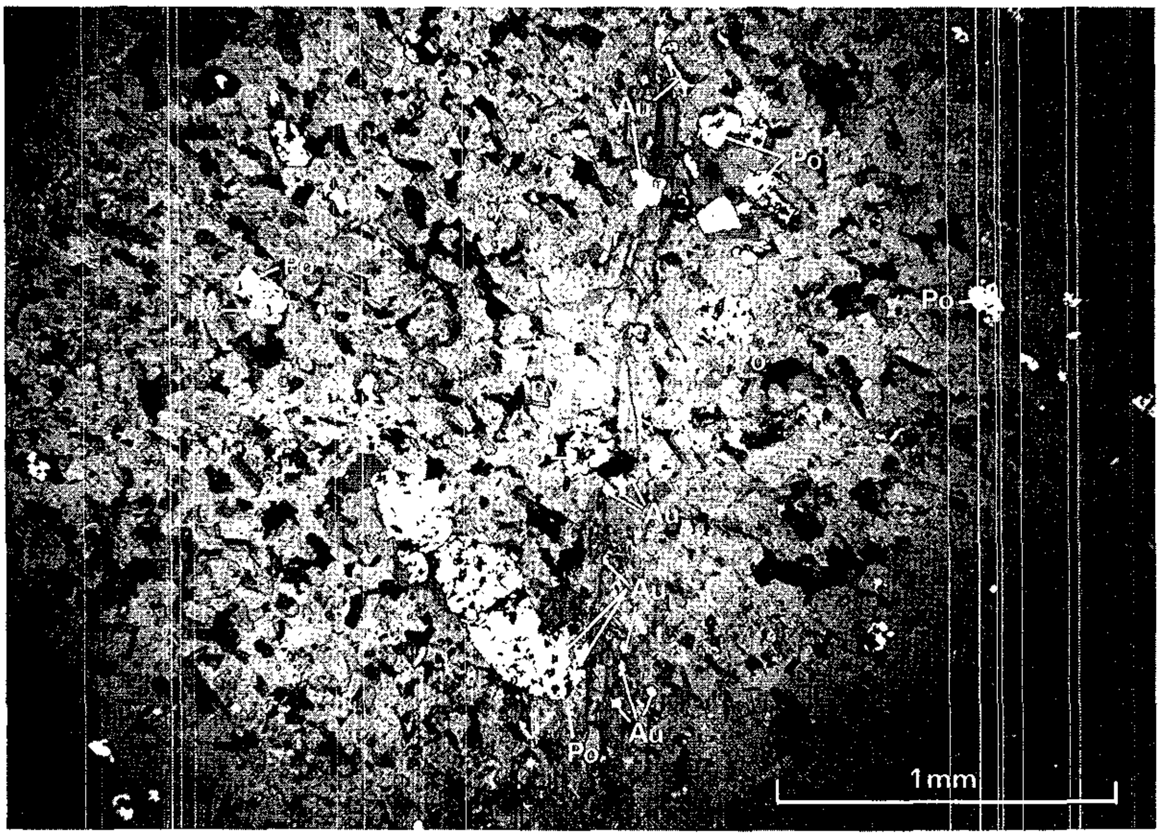

Plate III. Late-stage native gold (au) forms a discontinuous train of blebs along a fracture that cuts pyrrhotite (Po) and pyrite (py). (Specimen collected from the vicinity of the Heino Pit by G. G. Addie).

Mineralization also deposited sphalerite, galena, pyrrhotite, pyrite, marcasite, arsenopyrite, chalcopyrite, and tetrahedrite (?). Pyrrhotite and, to a lesser degree, pyrite are the most common disseminated sulphides in all rock units except the metabasalt. Pyrrhotite also occurs with sphalerite and galena as impregnations in locally brecciated rocks. Tetrahedrite (?) occurs mainly as a minor phase associated with impregnations of sulphides with or without gold. Chalcopyrite, another minor phase, occurs mainly as veinlets and exsolved lamellae in sphalerite. Arsenopyrite occurs rarely in the metadiorite but is locally abundant in the metasedimentary rocks. It postdates pyrrhotite, pyrite (except along late fractures), sphalerite, and galena but does not replace them. In contrast, marcasite is solely a replacement product of pyrrhotite. Upon weathering, arsenopyrite is locally altered to scorodite, while native sulphur is a frequent alteration product of marcasite. Other prominent weathering products observed in shear zones of the gold-rich Money Pit include goethite, hydrozincite, hemimorphite, gypsum, and calcite.

Besides mineralogy and modes of occurrence of the ore minerals, the most important parameter for establishing a genetic model for the gold mineralizaiton is the distribution of identified gold-bearing zones. As is evident from Figure 2, nearly all the proven gold zones are roughly north-south trending, although locally offset by later minor faults. In addition, they are not limited to a particular lithology but transect all rock types. Therefore, notwithstanding the possibility that there might be a lithological control on the primary distribution of the ore elements, their final concentration is more likely structurally controlled.

DISCUSSION AND CONCLUSION

To date, lithological similarity has been the main criterion employed in making regional correlations of rocks in the Tillicum Mountain area with those elsewhere. There is some controversy regarding the assignment of the metasedimentary rocks and the fringing patch of amphibolite (metabasalt). Thus, Little (1960) assigned the metasedimentary rocks to the Slocan Group (Triassic to Lower Jurassic) and the metabasalts to the Rossland Group (Lower Jurassic), whereas Hyndman (1968) assigned them to the Milford Group [Pennsylvanian (?) to Triassic] and the Kaslo Group (Triassic), respectively. The present study confirms a significant igneous component in the country rock assemblage. Moreover, it is shown that the transition between the metasedimentary rocks, which are often tuffaceous in appearance, and the metabasalt is gradual. The author believes that the entire rock assemblage in the area belong to the Kaslo Group since they show remarkable similarity to the rocks described by Cairnes (1934, pp. 43-48).

Any model for the gold mineralization has to account for the following observations: (a) gold occurs mainly as fracture fillings; (b) its distribution appears to be primarily structurally controlled; (c) its deposition covers a wide temperature range; and (d) at some stage of the mineralization, the process involved an acidic solution which also provided a source of sulphur for various sulphidation reactions resulting in the formation of arsenopyrite and marcasite. Furthermore, the location of the gold-rich Money-Heino zone with respect to the silver-gold occurrences in Arnie Flats to the south and the silver-dominated Silver Queen mine to the southeast (Fig. 2) indicate that the gold/silver ratio increases northwestward, roughly in accordance with a decreasing grade of regional metamorphism. A model consisting of the following stages is proposed:

(1) Intrusion of a dioritic laccolith into Triassic sedimentary, volcanic, and volcaniclastic rocks with the production of a first generation of hornfels and introduction of incipient porosity into carbonate-rich layers as a result of devolatilization reactions. At this stage, pyrrhotite is the stable form of iron sulphide adjacent to the intrusion.

(2) Regional metamorphism during Jurassic time of the igneous-sedimentary package producing prograde staurolite-almandine facies assemblages; the associated regional deformation gave rise to a metamorphic foliation. The incipient porosity in the calc-silicate-rich layers was accentuated and metamorphic differentiation resulted in remobilization of finely dispersed gold in the direction of decreasing temperature gradient.

(3) Intrusion of the Goatcanyon-Halifax Creeks stock in Late Jurassic or Early Cretaceous time with associated structural deformation led to a third episode of recrystallization. This modified former metamorphic fabrics and was accompanied by gold mineralization. Presumably acidic hydrothermal solutions emanating from the stock, which may or may not contain additional gold, mobilized the gold and redeposition occurred along favourable sites. The initial deposition occurred in response to pH changes when the solution reacted with calc-silicate assemblages; the temperature was high enough that pyrrhotite remained the prevalent iron sulphide species. Later deposition, however, was caused by a decrease in temperature and the mineralization took place in other host rocks. The introduction of arsenopyrite followed by the replacement of pyrrhotite by marcasite are part of the same mineralization process but occurred at lower temperatures.

In conclusion, gold mineralization observed in the Tillicum Mountain property is mainly epigenetic and mesothermal with the temperature of deposition extending to a lower regime during cooling of the Goatcanyon-Halifax Creeks stock. Whereas the source of gold remains uncertain, there is evidence of metamorphic differentiation affecting gold/silver ratio in the country rocks so that at least part of the precious metal may represent remobilized material concentrated in a convection cell set up by the Jurassic/Cretaceous Goatcanyon-Halifax Creeks stock. Thus, lower grade rocks around the southern and southeastern margins of the stock are favourable sites for gold mineralization whereas higher grade rocks toward Snow Creek are more likely hosts for silver mineralization. Furthermore, if the rock assemblage in the Tillicum Mountain area belongs to the Kaslo series as suggested, then similar rocks along the northwestern corner of the stock may be favourable targets for further exploration.

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