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PRELIMINARY RESULTS ON GOLD MINERALIZATION IN VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS, CENTRAL NEWFOUNDLAND

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ABSTRACT

Volcanogenic massive sulphide deposits in central Newfoundland are known to contain high concentrations of precious metals. Anomalous gold values have been found at the Point Leamington, Pilley's Island and Betts Cove massive sulphide deposits. All three deposits show a positive correlation between Au, Zn, As, Ag and Sb and a particular association of gold with Zn-rich ores. Despite geochemical similarities in these deposits, the occurrence of gold is variable. At Pilley's Island, anomalous gold is concentrated in sphalerite–galena ± barite ores. At Betts Cove, gold occupies fractures within brecciated pyrite and replaces chalcopyrite in banded pyrite–sphalerite–chlorite rocks. At Point Leamington, gold is associated with euhedral grains of arsenopyrite in Zn-rich sulphides. It is evident from this preliminary study that a wide range of physical and chemical controls have influenced the occurrence of gold. Further study of other VMS deposits in central Newfoundland will help to better characterize these controls on gold.

INTRODUCTION

Important concentrations of precious metals have been reported for a number of volcanogenic massive sulphide deposits in Newfoundland (Tuach *et al.*, 1988). Gold has been produced at some deposits (e.g., Buchans, Ming, Tilt Cove, and Little Bay) and anomalous gold has been reported from a number of deposits in different paleotectonic settings (Swinden *et al.*, 1988). However, only a few studies of massive sulphides in Newfoundland have examined in detail the controls on gold enrichment (e.g., Hurley and Crocket, 1985; Saunders, 1985). This study will investigate the detailed mineralogical and chemical relationships involving gold in a number of massive sulphide occurrences in central Newfoundland and will characterize the different styles of gold mineralization found in these deposits.

The deposits and mineral occurrences to be examined encompass a wide range of geological environments and sulphide mineral assemblages (Figure 1; Table 1). Preliminary geochemical results for samples from the Betts Cove, Pilley's Island and Point Leamington deposits are summarized here.

METHODS

All samples used in this study contain greater than 50 percent sulphides. Sulphide samples were analyzed using neutron activation analysis (NAA) and inductively coupled plasma spectrometry (ICP) for base metals, precious metals and trace elements. Samples with high Cu–Pb–Zn values were re-analyzed by chemical assay. A reference standard, Zn–Pb–Sn–Ag ore (KC-la), was used as a monitor. Comparisons of the recommended values with the values obtained for this study gives less than 8 percent error for Zn, Pb, Cu, Sn, and Ag.

REGIONAL SETTING

The majority of volcanogenic massive sulphide deposits in Newfoundland occur within the Dunnage Zone of the Appalachian Orogen. It is believed that this zone records the formation and subsequent destruction of the early Paleozoic Iapetus Ocean (Williams, 1979). Swinden (1990) subdivided the geological history of the Dunnage Zone into two stages; (i) pre-accretionary events (dominantly marine volcanic and epiclastic rocks as well as ophiolites) and (ii) syn- and post-accretionary events (mainly epi-continental volcanic and sedimentary rocks). Recent geochemical and geochronological work (e.g., Dunning and Krogh, 1985; Dunning *et al.*, 1987; Swinden, 1990) have demonstrated the complexity of geological relationships within the Dunnage Zone; however, this subdivision is still considered to be accurate. Swinden (1990) proposed a classification scheme

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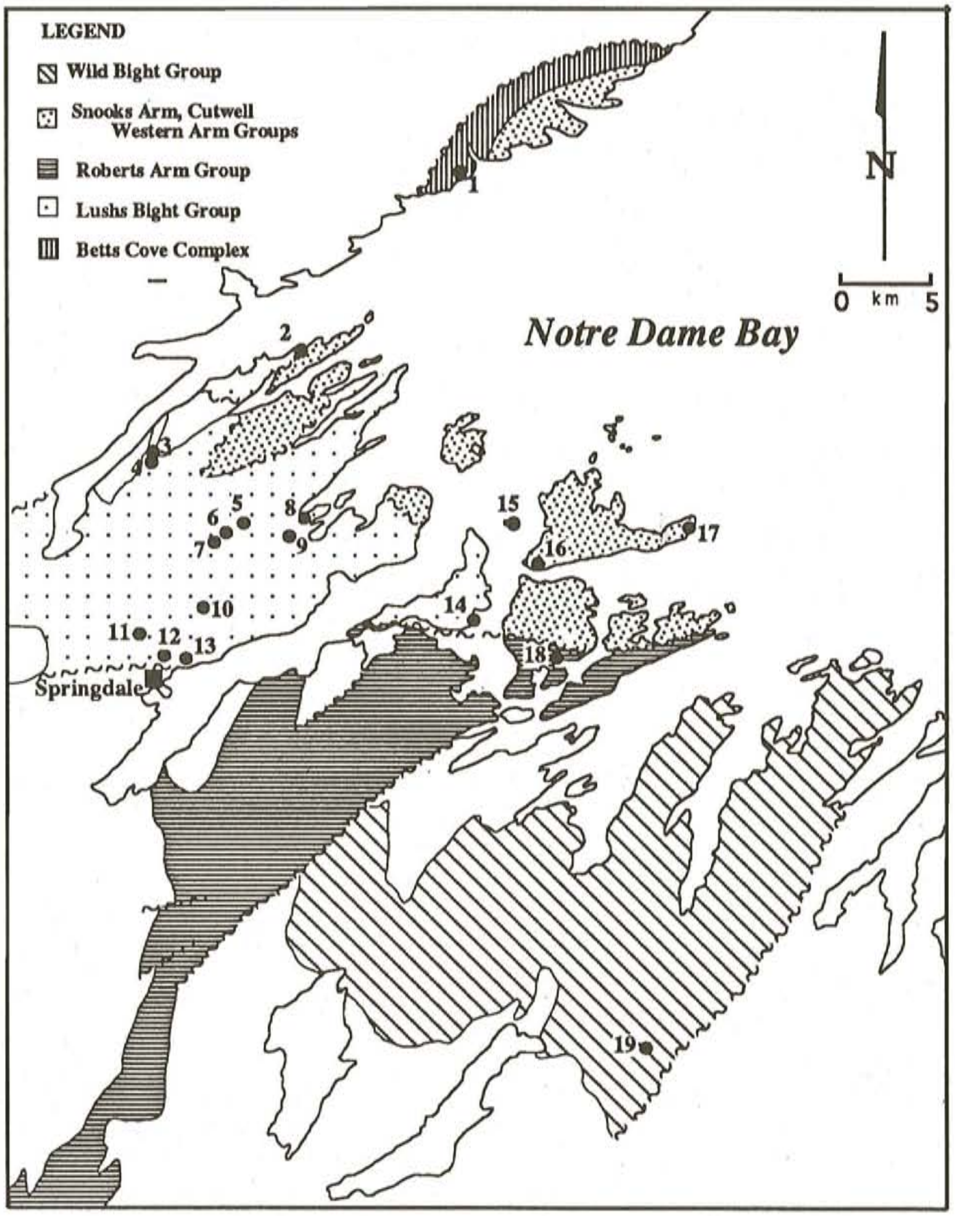

Figure 1. *Simplified regional geology of central Newfoundland (after Kean* et al., *1981); shaded areas are Cambro-Ordovician volcanic belts; sulphide deposit names are given in Table 1.*

for VMS deposits based on paleotectonic environments in the Newfoundland Dunnage Zone (Table 1). This study will examine characteristics of gold enrichment in deposits from different settings in the Dunnage Zone and determine if certain geological or geochemical conditions are systematically associated with gold-rich deposits.

PRELIMINARY RESULTS

Results of analyses from Point Leamington, Pilley's Island and Betts Cove samples are given in Table 2. All three deposits contain locally anomalous concentrations of gold (> 1 ppm). Two samples from the Betts Cove mine dump (BV-BM-G06 and BV-BM-G08) and one sample of drill core from the massive sulphides at Point Leamington (PL1-146.5) returned significant gold values (> 10 ppm). Anomalous gold in all three deposits appears to correlate with high Zn, As, Sb, and Ag (Figure 2). Overall, high gold values appear to be most common in Zn-rich samples, i.e., assemblages with low Cu/Zn ratios (Figure 3).

PILLEY'S ISLAND

The Roberts Arm Group (Figure 1), which hosts the Pilley's Island sulphide deposits, is composed dominantly of mafic volcanic flows and breccias associated with localized felsic flows and pyroclastic rocks (Bostock, 1988). Sulphide mineralization on Pilley's Island occurs as *in situ* massive sulphide horizons and transported massive sulphides, as well as stringers and disseminations in predominantly felsic

Table 1. VMS deposits from central Newfoundland examined in this study

DEPOSIT/SHOWING	GROUP	TYPE	CLASSIFICATION (*)	MINERALOGY
1. Betts Cove	Betts Cove	mass/str	Primitive Arc (ophiolite)	py-cp (sp,Au)
2. Nickey's Nose	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-po-mag (cp)
3. Colchester	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-cp-po (mag,sp)
4. McNeilly	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-cp-po-mag (sp,Au)
5. Whalesback	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-cp-po (sp,mag,Au)
6. Little Deer	Lushs Bight	mass/str	Primitive Arc (ophiolite)	po-cp (py,sp)
7. Duck Pond	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-cp-sp
8. Little Bay	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-cp-po (sp,mag,Au)
9. Delaney	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-cp
10. Lady Pond	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-cp-mag (po)
11. Timber Pond	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-po-cp-sp (Au,Ag)
12. Stirling	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-cp (po,sp)
13. Sullivan Pond	Lushs Bight	str/diss	Primitive Arc (ophiolite)	py-cp
14. Miles Cove	Lushs Bight	mass/str	Primitive Arc (ophiolite)	py-cp (mag,Au,Ag)
15. Oil Island	Cutwell	str/diss	Mature Arc (volc./epi.)	py-sp-cp-gn-ba
16. Shamrock	Cutwell	str/diss	Mature Arc (volc./epi.)	py-sp-cp-gn
17. Southern Head	Cutwell	str/diss	Mature Arc (volc./epi.)	py
18. Pilley's Island	Roberts Arm	mass/str	Mature Arc (volc./epi.)	py-cp-sp-gn
19. Point Leamington	Wild Bight	mass/str	Primitive Arc (mafic)	py-cp-sp

Ore types: mass = massive; str = stringer; diss = disseminated
Minerals: py = pyrite; po = pyrrhotite; cpy = chalcopyrite; sp = sphalerite; mag = magnetite; gn = galena; ba = barite; aspy = arsenopyrite

(*) after Swinden *et al.* (1988).

volcanic rocks (Tuach, 1990). Conformable zoned alteration assemblages are seen to envelope the *in situ* massive sulphides (Tuach, 1990; Santaguida *et al.*, 1992).

At Pilley's Island, anomalous concentrations of gold occur in two Zn-rich samples. Gold is generally higher in sphalerite–galena ± barite assemblages (e.g., sample MH90110b: Table 2 and Table 3), but, late sphalerite–galena stringers are also gold-poor (e.g., HIB91014a and b, and HIB91129). Correlations with other trace elements are erratic. *In situ* massive sulphides are Cu-rich and contain a relatively low gold content (e.g., samples HIB91090a and MH90099). Gold enrichment at Pilley's Island appears to be concentrated toward the hanging wall of the deposit and was likely controlled by the original physical and chemical conditions, which prevailed during primary sulphide deposition.

BETTS COVE

The Betts Cove deposit is hosted by the Betts Cove Complex (Figure 1), a complete ophiolite sequence (Saunders, 1990). The deposit occurs at a stratigraphic position near the sheeted diabase–pillow lava contact (Upadhyay and Strong, 1973). Upadhyay and Strong (1973) describe the sulphide mineralization as massive lenses, stringers and disseminations in chloritic shear zones. Massive sulphide mineralization is associated with an intensely chloritized core surrounded by a less altered peripheral zone (Saunders, 1985).

Sulphides having high gold values (BV-BM-G06 and BV-BM-G08) are finely banded and consist of massive pyrite with thin, interlayered bands of sphalerite and chlorite. Gold-rich sulphides consist dominantly of pyrite, locally massive sphalerite and minor chalcopyrite (Table 3). Chalcopyrite infills fractured pyrite and locally replaces pyrite. Copper-rich stringers in the stratigraphic footwall tend to be gold-poor (e.g., BV-BM-077). Free grains of native gold were observed in massive, coarse-grained pyrite (Plate 1). The gold grains occupy fractures in brecciated pyrite euhedra and locally replace chalcopyrite, suggesting late-stage remobilization of gold during deformation. Further studies are required to determine if the gold was derived locally from the massive sulphides or introduced during deformation.

POINT LEAMINGTON

The Point Leamington deposit occurs within the Wild Bight Group of the Dunnage Zone (Figure 1). Volcaniclastic and sedimentary rocks comprise over 80 percent of the Wild Bight Group (Swinden, 1984). Volcanic rocks, although much less abundant, are the host for all massive sulphides and are dominantly mafic. The massive sulphides at Point Leamington occur as two distinct lenses separated by a strongly chloritized rhyolite breccia (Walker and Collins, 1988). The lower sulphide lens contains a sphalerite-rich zone near the stratigraphic footwall.

Table 2. Chemical composition of sulphide samples from Pilley's Island, Betts Cove and Point Leamington. Values in ppm except where indicated

Sample #	Au	Ag	Cu	Pb	Zn	As	Fe (%)	Ni	Mn	Cd	Bi	Ba
Pilley's Island, Roberts Arm Group												
HIB91014a	<0.01	8	1550	31500	27500	30	2.18	3	19	100.0	6	3100
HIB91014b	<0.01	9	1580	31600	28500	30	2.10	2	23	110.0	12	2900
HIB91059	1.60	50	4540	74200	298000	370	10.50	14	201	910.0	15	39000
HIB91090a	0.56	3	26200	100	300	150	26.00	20	14	1.0	32	200
HIB91101	0.16	1	37000	130	4210	89	39.70	7	113	10.0	5	100
HIB91129	<0.01	7	4680	5120	36700	60	31.80	1	1003	100.0	24	100
HIB91147b	0.38	4	21410	300	1110	290	31.80	6	79	<1	85	100
MH90029	0.22	5	800	680	490	540	29.00	1	301	<1	7	18000
MH90030	0.19	10	390	3070	230	260	31.40	1	292	<1	5	12000
MH90037	0.82	90	13600	148200	285000	340	8.93	14	55	880.0	43	50000
MH90038	0.50	17	21200	1290	4250	410	29.40	3	77	20.0	5	4300
MH90066	<0.01	0	310	30	100	60	19.50	7	2	<1	5	860
MH90097	0.96	8	25300	150	1050	170	29.10	8	61	<1	6	970
MH90099	0.61	4	29100	180	360	410	34.30	3	23	<1	39	230
MH90100	0.89	25	15600	4800	131000	300	22.20	3	94	450.0	14	290
MH90110b	3.51	100	32300	5600	230000	410	20.50	2	92	780.0	7	120
Betts Cove, Betts Cove Complex												
BV-BM-G01	3.73	19	3000	461	1208	390	32.80	2	91	2.5	5	100
BV-BM-G06	30.10	24	4820	239	70266	380	28.10	38	238	183.4	8	100
BV-BM-G07	1.51	8	68200	269	419	20	17.20	80	698	0.5	18	100
BV-BM-G08	29.80	20	2340	190	6273	400	26.50	23	354	9.1	5	100
BV-BM-001	0.28	3	2700	5	89	100	13.80	47	416	0.5	5	100
BV-BM-010	0.68	24	81200	222	206	50	22.10	20	502	0.5	38	160
BV-BM-018	0.94	6	32400	31	253	150	21.40	40	240	0.5	23	100
BV-BM-077	0.25	5	32200	5	111	5	12.70	14	366	0.5	5	100
BV-BM-080	0.16	14	42900	5	211	10	20.20	66	617	0.5	15	100
BV-BM-085	0.10	8	32300	5	275	20	16.40	86	1084	0.8	17	100
BV-BM-099	0.98	6	1000	37	226	230	20.00	85	706	0.5	5	100
BV-BM-101	0.48	2	15600	16	89	90	25.60	29	519	0.5	49	100
BV-BM-103	0.40	1	1270	6	1089	60	20.70	65	1494	1.4	6	100
Point Leamington, Wild Bight Group												
PL1-47.5	1.35	27	8290	460	76600	5000	33.00	5	355	220.0	26	100
PL1-50.5	1.10	93	6760	3400	58500	5800	29.10	8	345	180.0	25	110
PL1-87.5	1.25	22	2450	2480	60500	3000	35.00	13	459	120.0	5	100
PL1-95.0	1.65	42	4510	610	91100	3800	27.60	11	134	210.0	18	110
PL1-108.5	1.30	23	3360	1510	36700	2400	32.00	13	541	120.0	14	100
PL1-110.0	1.13	19	6240	590	14000	1000	15.20	1	1465	40.0	28	100
PL1-119.0	1.25	17	2160	700	3840	3500	37.00	3	499	10.0	6	100
PL1-123.5	2.14	26	5870	2940	7790	23000	33.50	1	160	20.0	25	120
PL1-126.5	5.93	90	1550	2920	173000	51000	23.10	1	429	670.0	5	140
PL1-131.5	3.01	32	3500	170	368000	15000	15.70	2	290	2110.0	14	150
PL1-133.0	0.27	10	3910	220	1990	610	30.70	15	205	6.0	18	100
PL1-134.2	0.56	8	1530	30	421000	1200	14.90	2	424	2090.0	8	150
PL1-139.0	1.80	25	7340	480	447000	9500	15.30	1	1729	2030.0	34	130
PL1-140.5	7.78	39	9140	17100	315000	15000	22.70	1	845	760.0	26	160
PL1-143.6	1.73	75	1890	5620	465000	2600	8.47	1	266	2110.0	10	130
PL1-146.5	14.60	53	1910	260	75700	46000	32.50	30	468	200.0	14	110
PL3-54.5	0.26	32	21300	100	10700	40	47.50	8	50	40.0	31	100
PL3-59.1	0.57	14	4510	140	14500	2100	32.90	7	257	50.0	21	100
PL3-102.1	1.15	22	68300	200	15600	3900	30.30	1	46	50.0	398	100
PL4-36.4	0.45	12	2380	3670	18900	400	28.70	8	234	40.0	18	100
PL4-39.5	0.57	23	1810	5340	13900	460	27.30	5	166	30.0	5	100
PL4-42.6	0.23	9	630	140	7990	310	24.40	1	59	20.0	5	100
PL4-51.4	0.48	13	4160	330	16100	940	29.60	15	239	60.0	14	100
PL4-63.6	0.45	13	3990	810	9470	880	30.30	6	179	30.0	14	100
PL4-72.3	1.19	26	11600	3130	127000	15000	29.70	2	323	330.0	43	100

Table 2. *Continued*

Co	Cr	Hg	Mo	Sb	Se	W	mass (g)
23	10	2	16	1.3	5	99	1.43
24	10	2	19	1.1	5	97	1.80
17	20	340	11	51	5	110	2.28
60	21	1	37	2.2	32	470	1.83
55	14	2	12	1.6	63	300	2.25
180	10	14	8	2.6	14	270	1.96
60	10	1	12	3.6	71	230	1.89
33	10	2	10	9.8	6	220	2.64
29	10	3	13	7.6	5	200	1.91
12	10	4	24	120	37	66	2.96
17	10	1	5	11	19	170	2.46
71	10	1	5	0.6	37	330	1.68
37	10	1	15	3.1	19	370	1.91
17	10	1	30	3.9	46	110	2.75
40	10	12	14	12	32	310	2.09
41	25	21	14	18	55	200	2.07
13	10	1	5	42	10	130	2.56
45	25	1	26	17	5	99	2.23
61	120	1	53	0.5	580	85	1.79
22	90	1	33	15	5	81	2.27
67	170	1	63	2.1	21	210	1.73
43	130	1	7	1.5	870	160	1.55
170	42	1	24	4	130	340	1.63
35	31	1	30	0.3	99	210	1.63
150	61	1	120	0.3	160	210	2.07
130	210	1	23	0.2	300	140	1.75
97	200	1	100	13	18	140	1.97
360	64	1	37	2.1	160	44	2.51
88	170	1	10	1.2	43	34	1.98
12	10	14	22	140	160	82	2.53
16	19	11	28	130	110	120	2.15
16	10	6	33	210	58	78	2.96
18	12	9	41	160	73	150	2.06
16	10	7	29	160	70	120	2.51
33	10	4	20	83	49	310	1.95
33	10	2	39	160	18	140	2.58
15	10	1	17	190	78	140	2.57
14	10	21	14	250	90	160	2.29
6	10	34	25	130	150	5	2.37
35	10	2	54	17	130	130	2.79
8	10	28	8	20	210	35	2.32
5	10	18	7	100	95	33	2.52
5	11	40	14	160	1300	6	1.56
40	10	27	6	140	81	35	2.39
480	10	18	11	260	190	13	3.02
19	15	3	51	2.9	220	18	2.91
15	10	4	29	77	130	89	2.96
490	10	18	11	75	570	100	2.39
24	10	3	19	25	70	150	2.31
27	10	2	14	22	60	180	2.46
39	13	2	16	17	31	290	1.94
29	10	4	45	74	100	140	2.28
23	10	2	37	56	98	120	2.12
89	12	29	13	130	310	59	3.03

High gold values at Point Leamington occur in a mixed pyrite−arsenopyrite−sphalerite assemblage (Table 3). Anomalous gold is pronounced in the sphalerite-rich zone of the lower massive sulphide lens (samples PL1-126.5 to PL1-146.5, Table 2). Sphalerite forms massive, fine-grained bands together with pyrite and arsenopyrite. Euhedral crystals of arsenopyrite are present in most samples, and locally contain gold-rich cores and late pyrite rims (Plate 1d). Silver tellurides occur locally with the gold. Primary crystallization textures are evident from colloform pyrite, which indicate that the present sulphide mineral assemblage may reflect original depositional conditions.

CONCLUSIONS

The overall geochemical trends of gold observed in this study are similar to other studies of gold in VMS deposits. At Tilt Cove, in the Betts Cove Complex, Hurley and Crocket (1985) also found an association of gold enrichment with Zn-rich ores. Relationships of gold with As, Ag and Sb are also reported from the Kuroko massive sulphide deposits (Lambert and Sato, 1974). Gold in massive sulphides at modern mid-ocean ridge spreading centres commonly shows an affiliation with Zn−As−Sb−Ag−Pb mineral assemblages (Hannington *et al.*, 1991). Hannington and Scott (1989) and Large *et al.* (1989) have demonstrated that the gold−zinc association reflects transport of gold as $Au(HS)_2^-$ complexes in low-temperature fluids. This association may also apply to the central Newfoundland deposits, however, further work is needed to evaluate this.

The different styles of gold enrichment recognized during this preliminary study suggest a wide range of physical and chemical controls on gold mineralization. Further investigation of samples from these and other deposits throughout central Newfoundland will help to constrain the contrasting modes of gold occurrence in massive sulphide deposits of the region.

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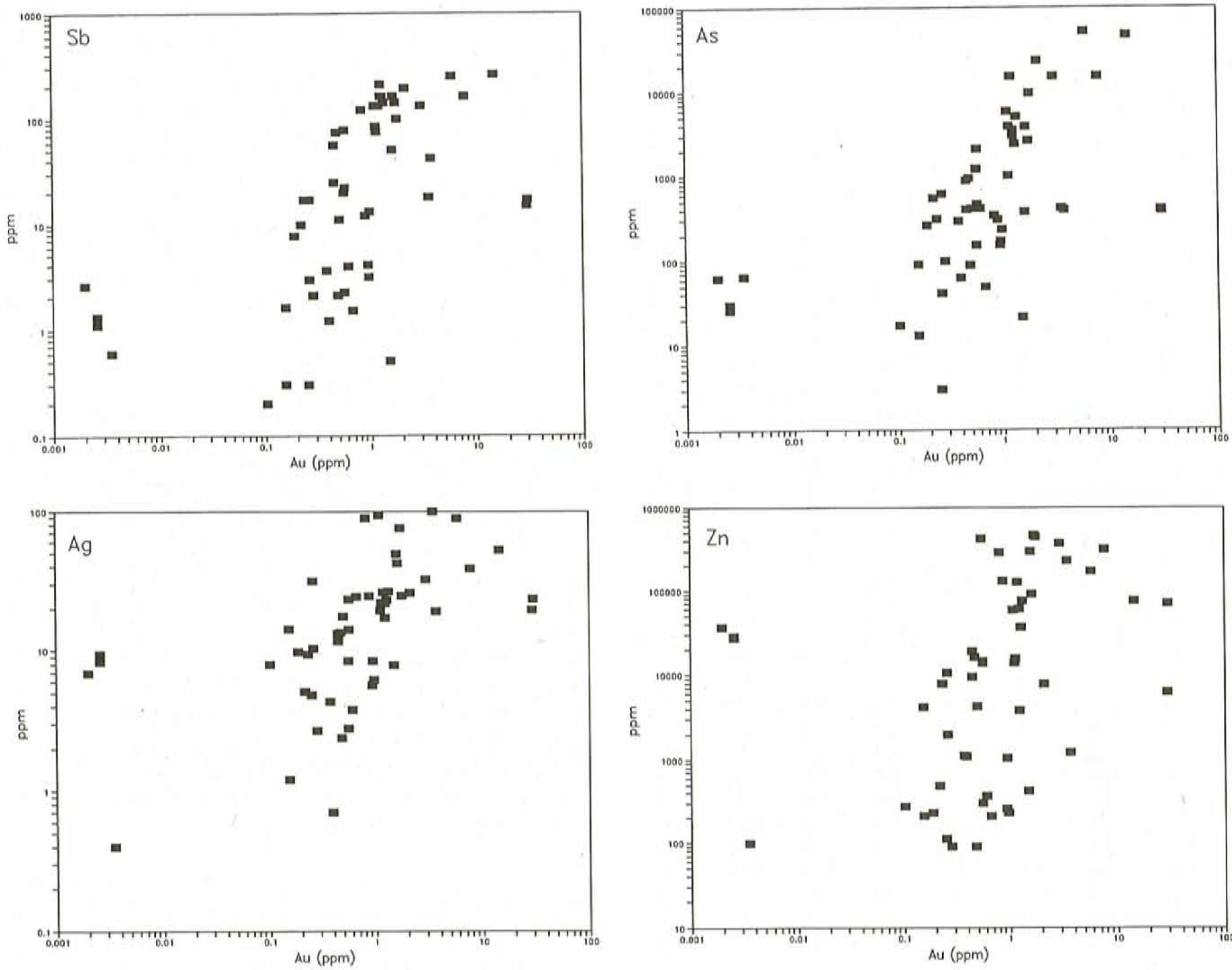

Figure 2. *Positive correlation of Au from all deposits with selected elements (As, Zn, Ag and Sb).*

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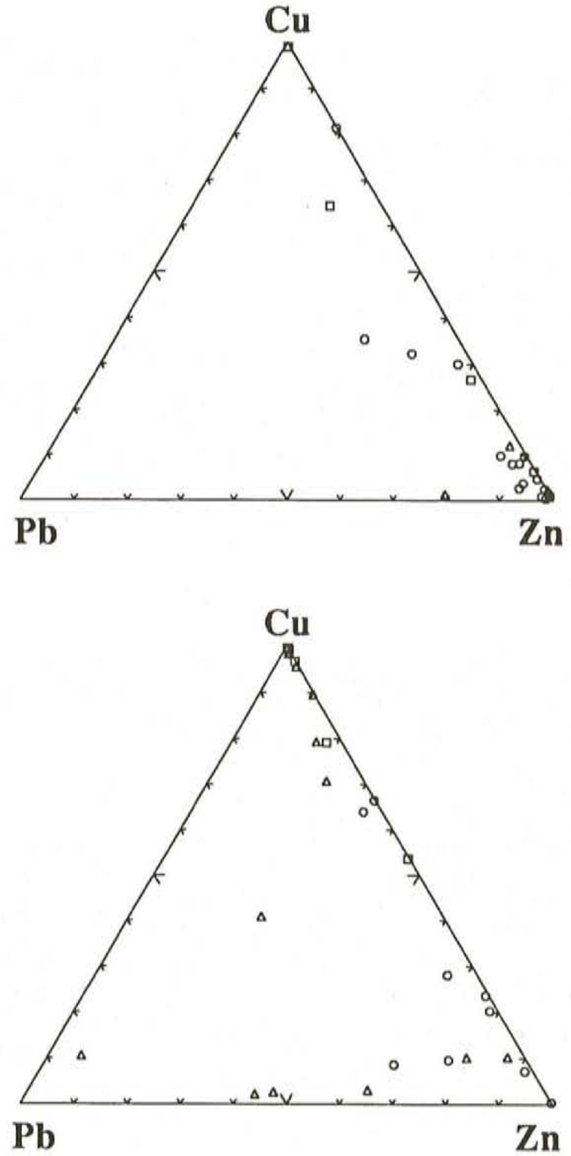

Figure 3. *Cu−Pb−Zn ternary diagrams for (top) gold-rich samples (greater than 1 ppm) (bottom) gold-poor samples (less than 1 ppm). Symbols are; triangles = Pilley's Island, squares = Betts Cove, circles = Point Leamington.*

Table 3. Mineralogy of selected sulphide samples from Pilley's Island, Betts Cove and Point Leamington

	Py	Cpy	Sp	Aspy	Gn	Po	Mag
Pilley's Island							
MH90099	**	**					
MH90110b	*	*	**		*		
HIB91129	*	*	**		**		
Betts Cove							
BV-BM-G01	**	*					
BV-BM-G06	**	*	**				
BV-BM-G08	**	*	*				
Point Leamington							
PL1-47.5	**	*	**	*			
PL1-123.5	**	*	*	*	*		
PL1-126.5	**	*	**	**	*		
PL1-131.5	**	*	**	*		*	
PL1-139.5	*	*	**	*		*	*
PL1-140.5	**	*	*	**		*	
PL1-146.5	**	*	*	**			
PL4-72.5	**	*	**	**	*		

** = major amount; * = minor amount.
Minerals: py = pyrite; po = pyrrhotite; cpy = chalcopyrite; sp = sphalerite; mag = magnetite; gn = galena; ba = barite; aspy = arsenopyrite

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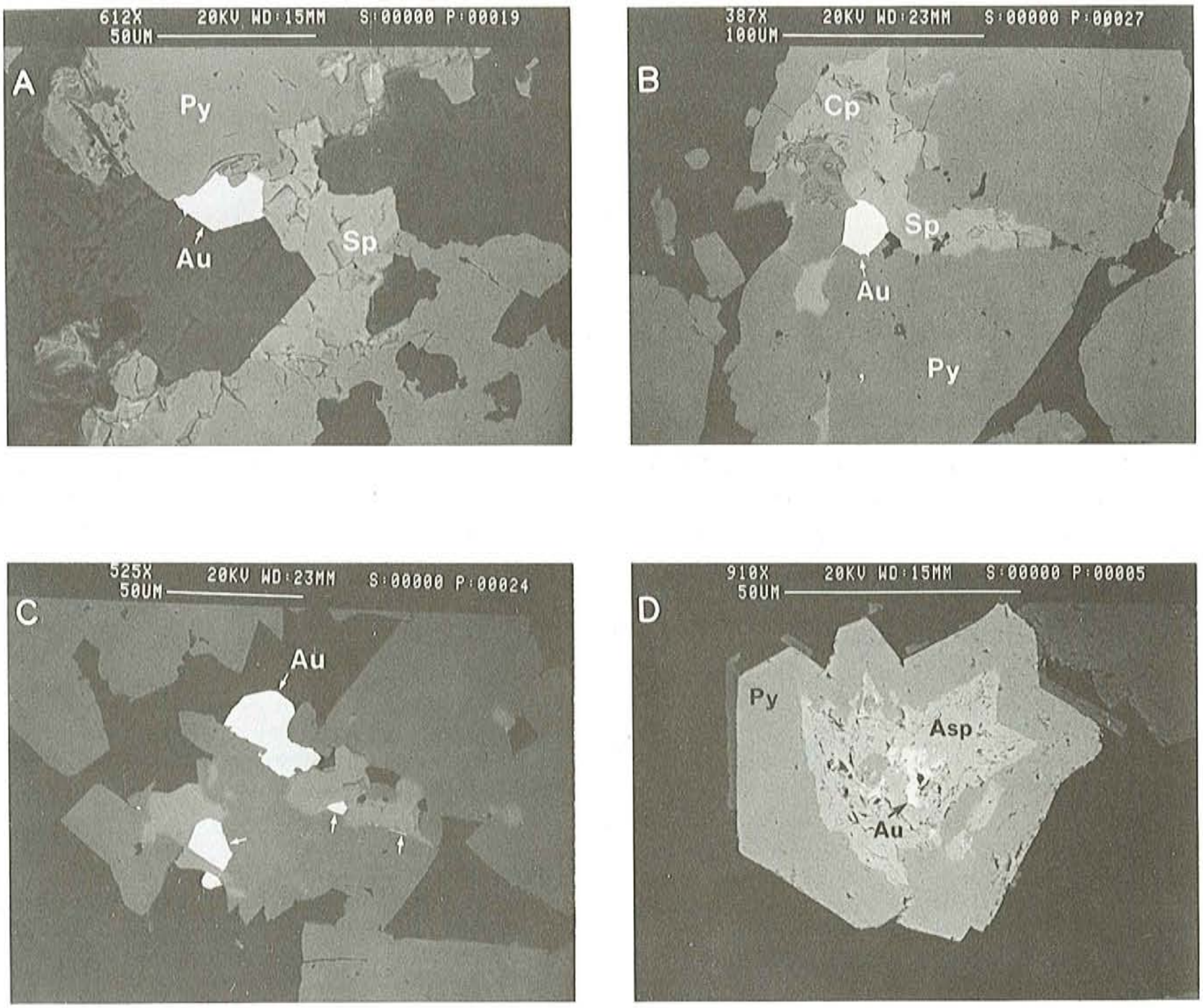

Plate 1. *Scanning electron micrographs which illustrate the occurrence of gold. (a) Large grain of gold (electrum) adjacent to pyrite and sphalerite. Dark gangue minerals are quartz and chlorite. Grab sample from the Betts Cove mine. (b) Large grain of gold (electrum) on a grain boundary between pyrite and sphalerite in Betts Cove sulphides. Note fine gold along grain boundary. (c) Multiple grains of gold (electrum) in Betts Cove pyrite and sphalerite. Note fine gold along grain boundaries. (d) Small grain of gold (electrum) with Ag-tellurides in arsenopyrite from the Point Leamington deposit. Note a late rim of pyrite surrounding arsenopyrite.*

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