ASSESSMENT REPORT TITLE PAGE AND SUMMARY

TITLE OF REPORT: 2015 Assessment Report for Geology on the Texada Project

TOTAL COST: $7,692.30

AUTHOR(S): Jacques Houle, P.Eng.
SIGNATURE(S):

NOTICE OF WORK PERMIT NUMBER(S)/DATE(S):
STATEMENT OF WORK EVENT NUMBER(S)/DATE(S): 5512274 / 2014/JUL/10

YEAR OF WORK: 2014-2015

PROPERTY NAME: Texada

CLAIM NAME(S) (on which work was done):

See Table 1 in technical report

COMMODITIES SOUGHT: Au, Ag, Cu, Mo, Pb, Zn

MINERAL INVENTORY MINFILE NUMBER(S),IF KNOWN: See Table 3 in technical report

MINING DIVISION: Nanaimo
NTS / BCGS: 092F09E, -09W, -10E / 092F059,-060,-068,-069,-077,-078,-079
LATITUDE: _49_° _38_' _39_"
LONGITUDE: _124_° _23_' _07_" (at centre of work)
UTM Zone: 10N EASTING: 400000E NORTHING: 5500000N

OWNER(S): Dean Bombardier / Northstar Mining Ltd.

MAILING ADDRESS: Dean Bombardier: 285 Seymour Street, Kamloops, BC V2C2E7
Northstar Mining Ltd.: 4250 Franklin Ave, Powell River, BC V8A 3E3

OPERATOR(S) [who paid for the work]: Dean Bombardier

MAILING ADDRESS: Dean Bombardier: 285 Seymour Street, Kamloops, BC V2C2E7

REPORT KEYWORDS (lithology, age, stratigraphy, structure, alteration, mineralization, size and attitude. **Do not use abbreviations or codes**) mafic volcanics, limestone, granodiorite, diorite, sandstone, shale, Cretaceous, Jurassic, Triassic, Permian, Devonian, Coast Plutonic, Island Plutonic, Nanaimo Group, Vancouver Group, Quatsino Formation, Karmutsen Formation, Buttle Lake Group, Sicker Group, NW faults, skarn, vein, porphyry, quartz, gold, silver, copper, molybdenum, lead, zinc, clay

REFERENCES TO PREVIOUS ASSESSMENT WORK AND ASSESSMENT REPORT NUMBERS:

See Table 4 in technical report

TYPE OF WORK IN THIS REPORT	EXTENT OF WORK (in metric units)	ON WHICH CLAIMS	PROJECT COSTS APPORTIONED (incl. support)
GEOLOGICAL (scale, area)			
Ground, mapping			
Photo interpretation	4.25 days	See Table 1	$ 3,534.30
GEOPHYSICAL (line-kilometres)			
Ground			
Magnetic			
Electromagnetic			
Induced Polarization			
Radiometric			
Seismic			
Other			
Airborne			
GEOCHEMICAL (number of samples analysed for …)			
Soil			
Silt			
Rock			
Other			
DRILLING (total metres, number of holes, size, storage location)			
Core			
Non-core			
RELATED TECHNICAL			
Sampling / Assaying			
Petrographic			
Mineralographic			
Metallurgic			
PROSPECTING (scale/area)			
PREPATORY / PHYSICAL			
Line/grid (km)			
Topo/Photogrammetric (scale, area)			
Legal Surveys (scale, area)			
Road, local access (km)/trail			
Trench (number/metres)			
Underground development (metres)			
Other	5 days	See Table 1	$ 4,158.00
		TOTAL COST	$ 7,692.30

2015 Assessment Report for

Geology

On the

Texada Project

Nanaimo Mining Division

BCGS 092F059,-060,-068,-069-077,-078,-079
NTS 092F09E,-09W,-10E

UTM Zone 10N 5500000N 400000E

For
Dean Bombardier,
Coast Minerals Corp. &
Northstar Mining Ltd.

Report written by
Jacques Houle, P.Eng.

March 4, 2015

March 4, 2015

Contents

Introduction

Property location, access and physiography

The Texada Project is located in the Nanaimo Mining Division, on Texada Island in the Strait of Georgia, BC, and Canada. The 85 cell claims occur in three non-contiguous blocks covering much of Texada Island, and are centred approximately in UTM Zone 10N, at 5500000N 400000E. The claims are situated on BCGS map sheets 092F059,-060,-068,-069,-077,-078,-079, and NTS map sheets 092E09E,-09,-10E. Coast Minerals Corp.'s Texada Project consists of 85 cell mineral claims covering 18,600 hectares, including 79 claims covering 17135 hectares held beneficially by Dean Bombardier for, and 6 claims covering 1465 hectares held by Northstar Mining Ltd. through an agreement with, Coast Minerals Corp.

The all-weather Gillies Bay Road and secondary logging roads provide access year round to most the Texada Project from the communities of Van Anda and Gillies Bay, both which have basic services. The provincial power grid between coastal BC and Vancouver Island crosses Texada Island, near the centre of the Texada Project claims. The topography of the claims is forested swampy meadows between rolling hills with elevations ranging from sea level to 885 metres. The claims are covered by a small ponds drained by radiating creeks which drain to the east to Malaspina Strait and to west to Georgia Strait. The claims are covered by first or second growth forest of several ages of regeneration, and logging roads at different stages of degeneration. The area of the claims is temperate rainforest, with heavy rain in the autumn to spring period, warm dry summers, and snow at higher elevations in the winter. Relatively mild coastal climate and low elevation generally allows year round fieldwork to be carried out.

Property definition, owner, operator, geology and history

The operator and beneficial owner of the Texada Project is Coast Minerals Corp., a private B.C. corporation, and the work documented in this report was paid for by Dean Bombardier. See Figure 1 for the mineral tenure map, Figure 2 for the infrastructure map, Figure 3 for the BC MINFILE occurrence map, Figure 4 for the BC ARIS report map, and Figures 5 and 6 for the BC RGS (regional geochemical survey) maps for gold (ppb) and copper (ppm), all at 1:250,000 scale for the Texada Project area. The Texada Project claim details and status are listed in Table 1:

Table 1 – Cell Mineral Claims and Status as of March 4, 2015:

Title Number	Claim Name	Owner	Tenure Type	Map	Issue Date	Good To Date	Status	Area (ha)
592648	DARYL1	143663 (100%)	Cell Mineral Claim	092F	2008/oct/07	2015/apr/21	GOOD	523.1578
592649	DARYL2	143663 (100%)	Cell Mineral Claim	092F	2008/oct/07	2015/apr/21	GOOD	230.2728
592650	DARYL3	143663 (100%)	Cell Mineral Claim	092F	2008/oct/07	2015/apr/21	GOOD	41.8675
918829	VICTORIA	143663 (100%)	Cell Mineral Claim	092F	2011/oct/19	2016/oct/19	GOOD	83.5232
918869	DANDT	143663 (100%)	Cell Mineral Claim	092F	2011/oct/19	2015/apr/21	GOOD	523.7318
918870	TAKE	143663 (100%)	Cell Mineral Claim	092F	2011/oct/19	2015/apr/21	GOOD	62.851
946394	TI100	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	250.8676

946397	TI200	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	334.3442
946399	TI300	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	502.6963
946401	TI400	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	376.9417
946402		203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	417.7504
946405	TI600	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	146.2429
946408		203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	188.0132
946409	T800	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	20.9205
946412	TI900	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	251.2597
946413	TI1000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	293.1421
946414	TID1	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	20.9293
946415	TI3000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	209.153
946416	TI4000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	104.5241
946417	TI5000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	480.4972
946418	TI6000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	480.5203
946419	TI7000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	480.6734
946420	TI8000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	501.5475
946421	TI9000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	522.7567
946422	TI10000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	522.6142
946423	TI11000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	501.7262
946424	TI12000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	502.137
946425	TI13000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	480.988
946429	TI17000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	188.2555
946430	TI18000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	167.3282
946431	TI19000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/05	2015/apr/21	GOOD	104.6031
946457	TI20000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	313.4592
946467	TI21000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	502.8709
946474	TI22000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	502.9373
946479	TI23000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	524.0834
946481	TI23000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	230.5368
946486	TI24000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	523.9197
946487	TI25000	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	398.2881
946489	TI26	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	293.1321
946491	TI27	203667 (100%)	Cell Mineral Claim	092F	2012/feb/06	2015/apr/21	GOOD	125.4874
946809	TI28	203667 (100%)	Cell Mineral Claim	092F	2012/feb/07	2015/apr/21	GOOD	83.8772
976765	TID101	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	418.2283
976766	TID102	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	460.244
976768	TID103	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	460.4581
976769	TID104	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	293.0283
976771	TID105	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	293.0792
976772	TID106	203667 (100%)	Cell Mineral Claim	092F	2012/apr/02	2015/apr/21	GOOD	167.5597
1004402	TI61201	203667 (100%)	Cell Mineral Claim	092F	2012/jun/28	2015/apr/21	GOOD	20.9662
1004422	TI61202	203667 (100%)	Cell Mineral Claim	092F	2012/jun/28	2015/apr/21	GOOD	20.9645
1005182	TI61203	203667 (100%)	Cell Mineral Claim	092F	2012/jun/28	2015/apr/21	GOOD	293.2378
1005202	TI61204	203667 (100%)	Cell Mineral Claim	092F	2012/jun/28	2015/apr/21	GOOD	292.3359
1006843	TI61205	203667 (100%)	Cell Mineral Claim	092F	2012/jun/29	2015/apr/21	GOOD	20.8873
1013507	TI101201	203667 (100%)	Cell Mineral Claim	092F	2012/oct/03	2015/apr/21	GOOD	62.7597
1013508	TI101202	203667 (100%)	Cell Mineral Claim	092F	2012/oct/03	2015/apr/21	GOOD	146.5068
1013509	TI101203	203667 (100%)	Cell Mineral Claim	092F	2012/oct/03	2015/apr/21	GOOD	20.9399

1013691	TI101204	203667 (100%)	Cell Mineral Claim	092F	2012/oct/11	2015/apr/21	GOOD	62.6526
1013692	TI101205	203667 (100%)	Cell Mineral Claim	092F	2012/oct/11	2015/apr/21	GOOD	41.7727
1013694	TI101206	203667 (100%)	Cell Mineral Claim	092F	2012/oct/12	2016/feb/24	GOOD	41.7689
1014340	TIJ1	203667 (100%)	Cell Mineral Claim	092F	2012/nov/06	2015/apr/21	GOOD	501.9306
1014375	TI111201	203667 (100%)	Cell Mineral Claim	092F	2012/nov/08	2015/apr/21	GOOD	20.968
1014376	TI111202	203667 (100%)	Cell Mineral Claim	092F	2012/nov/08	2015/apr/21	GOOD	62.9023
1014377	TI111203	203667 (100%)	Cell Mineral Claim	092F	2012/nov/08	2015/apr/21	GOOD	146.7233
1014378	TI111204	203667 (100%)	Cell Mineral Claim	092F	2012/nov/08	2015/apr/21	GOOD	62.8916
1016059	TI130101	203667 (100%)	Cell Mineral Claim	092F	2013/jan/17	2015/apr/21	GOOD	83.7686
1016379	TI130102	203667 (100%)	Cell Mineral Claim	092F	2013/jan/28	2015/apr/21	GOOD	41.899
1016662	TI130201	203667 (100%)	Cell Mineral Claim	092F	2013/feb/04	2015/apr/21	GOOD	292.5565
1016680	TI130202	203667 (100%)	Cell Mineral Claim	092F	2013/feb/05	2015/apr/21	GOOD	104.486
1016681	TI130203	203667 (100%)	Cell Mineral Claim	092F	2013/feb/05	2015/apr/21	GOOD	41.8012
1016682		203667 (100%)	Cell Mineral Claim	092F	2013/feb/05	2015/apr/21	GOOD	167.2402
1016746	TI130205	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	83.8119
1016747	TI130206	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	188.1924
1016749	TI130207	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	20.9364
1016755	TI130208	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	62.9057
1016766	TI130209	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	41.9413
1016767	TI130210	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	41.9448
1016768	TI130211	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	20.9715
1016769	TI130212	203667 (100%)	Cell Mineral Claim	092F	2013/feb/07	2015/apr/21	GOOD	20.968
1018582	TI20130401	203667 (100%)	Cell Mineral Claim	092F	2013/apr/15	2015/apr/21	GOOD	20.8797
1021099	TI20130701	203667 (100%)	Cell Mineral Claim	092F	2013/jul/19	2015/apr/21	GOOD	41.7745
1021796	TI20130801	203667 (100%)	Cell Mineral Claim	092F	2013/aug/21	2015/apr/21	GOOD	125.2688
1026822	TI201401	203667 (100%)	Cell Mineral Claim	092F	2014/mar/22	2015/mar/22	GOOD	20.8997
1026823	TI201402	203667 (100%)	Cell Mineral Claim	092F	2014/mar/22	2015/mar/22	GOOD	20.9697
1027256	TO20140401	203667 (100%)	Cell Mineral Claim	092F	2014/apr/04	2015/apr/04	GOOD	146.6633
1027257	TI20140402	203667 (100%)	Cell Mineral Claim	092F	2014/apr/04	2015/apr/04	GOOD	41.9059
1029548	TI20140701	203667 (100%)	Cell Mineral Claim	092F	2014/jul/11	2015/jul/11	GOOD	41.7779
Totals	**85 claims**							**18600.8**

The claims of the Texada Project are underlain primarily by mafic volcanics of the Triassic Vancouver Group Karmutsen Formation, representing a substantially complete section from the basal part of the unit in the southeast to the upper part in the northwest. The extreme southeast tip of the claims is underlain by meta-volcanics and interbedded limestones interpreted as part of the Devonian Sicker Group and possibly Permian Buttle Lake Group, respectively. The area immediately northwest of the claims is underlain by limestones of the Triassic Vancouver Group Quatsino Formation, and the western part of the claims is locally underlain by Quaternary sands and clays, which may overlie Cretaceous Nanaimo Group shales and sandstones, Quatsino limestones or Karmutsen mafic volcanics. Granodioritic to dioritic stocks and dikes of the Jurassic Island Intrusive Suite or Cretaceous Coast Plutonic Suite locally intrude younger layered units. The WNW-trending Marble Bay fault is a steeply dipping, major structure which runs the length of Texada Island, bisects the claims, and becomes a braided structure to the southeast. See Figure 7 for the geological map, and Figure 8 for the1st vertical derivative aeromagnetic map of the claims, both at 1:250,000 scale.

The following geology legend lists rocks which may be found on the Texada Project, taken from the BCGS 2005 Geology layer in BC MapPlace, which applies to Figure 7:

CRETACEOUS
Coast Plutonic Suite
Kgd granodioritic to dioritic intrusive rocks

UPPER CRETACEOUS
Nanaimo Group
uKN undivided sedimentary rocks

EARLY JURASSIC TO MIDDLE JURASSIC
Island Plutonic Suite
EMJIgd granodioritic to diorite intrusive rocks

UPPER TRIASSIC
Vancouver Group
Quatsino Formation
uTrVKQ limestone, marble, calcareous sedimentary rocks
Karmutsen Formation
uTrVK mafic volcanics, interbedded limestone

MIDDLE PERMIAN
Buttle Lake Group
MPBN limestone, sedimentary rocks

UPPER DEVONIAN
Sicker Group
uDSiM mafic volcanics

Sedimentary limestone and iron/copper skarn deposits have historically been the main sources of mineral production from the northern part of Texada Island as documented in BC MINFILE, including the 2 currently operating quarries Imperial 092F394 and Gillies Bay 092F395, plus 20 other past producers of limestone and related products. From 1896 to 1976, two (2) past producers mined a total of about 20 million tonnes of iron (magnetite) ore averaging 46% iron; and eight (8) past producers mined a total of about 400,000 tonnes of polymetallic ore averaging 2.31% copper, 41.2 g/t silver and 6.14 g/t gold. Historic production from all of Texada Island is summarized in Table 2, extracted from BC MINFILE records, which are complete to 2005.

Table 2 – BC MINFILE Historic Mineral Production from Texada Island as of 2005:

MINFILE #	MINFILE Name	From - To	Mined t	Gold g/t	Silver g/t	Cu %	Fe %	Lst %
092F 088	ANDERSON BAY	1916 - 1916	97					99.7
092F 095	MARBLE BAY LIMESTONE	1917 - 1956	471,795					100.0
092F 105	LITTLE BILLIE	1896 - 1952	63,713	5.70	18.81	1.29		
092F 106	PRESCOTT-TEXADA MINES	1952 - 1956	1,997,313				65.11	

092F 109	MARJORIE (L.217)	1903 - 1938	206	5.59	14.65	0.83		
092F 112	CORNELL (L.201)	1987 - 1919	40,687	11.58	53.94	3.36		
092F 139	WHITE ROCK QUARRY	1988 - 1990	75,305					100.0
092F 258	YELLOW KID-TEXADA MINES	1957 - 1976	18,181,433	0.05	1.30	0.14	43.94	
092F 259	LAKE-TEXADA MINES	1901 - 1921	946	3.19	38.01	5.04	0.00	
092F 265	LOYAL	1917 - 1918	54	6.33	89.28	8.64		
092F 270	MARBLE BAY (L.154)	1899 - 1929	285,028	5.46	44.28	2.38		
092F 271	COPPER QUEEN (L.40)	1907 - 1917	749	13.21	100.45	4.33		
092F 357	RETRIEVER (L.150)	1916 - 1917	334	0.83	0.29	0.03		
092F 394	IMPERIAL	1951 - 1991	5,185,481					100.0
092F 395	GILLIES BAY	1952 - 2005	57,523,653					92.9
092F 396	LAFARGE LIMESTONE	1934 - 1986	22,299,109					100.0
092F 397	HIESHOLT	1948 - 1966	5,689,045					100.0
092F 471	B.C. CEMENT	1929 - 1957	2,075,419					100.0
092F 472	BEALE	1941 - 1941	1,579					100.0
092F 473	COULTER	1937 - 1937	54					100.8
092F 474	FOGH	1930 - 1931	8,356					100.0
092F 479	BLUBBER BAY	1911 - 1998	24,085,729					98.1
Totals/Avg	**22 Producers + Past Producers**	**1896 - 2005**	**137,986,085**					
Totals/Avg	**2 Fe Past Producers**	**1952 - 1976**	**20,178,746**	**0.04**	**1.17**	**0.13**	**46.04**	
Totals/Avg	**8 Metallic Past Producers**	**1896 - 1952**	**391,717**	**6.14**	**41.19**	**2.31**	**0.00**	

The first documented exploration work on Texada Island is from the late 1800's, referenced in Geological Survey of Canada publications and BC Minister of Mines annual reports. Some of these reports are listed in the Bibliographies of the BC MINFILE records for all 103 occurrences located on Texada Island, summarized in Table 3, including a column indicating the thirteen (13) occurrences located on the Texada Project claims, and on which claims they are located, subject to the plotting accuracy of BC MINFILE.

Table 3 – BC MINFILE Occurrences on Texada Island & the Texada Project claims:

MNFILE #	MINFILE Name	Status	Deposit Type	Commodities	On Claim
092F 059	MAY	Showing	Pb-Zn skarn	Zn,Pb,Cu,Ag	1016746
092F 087	COMET MOUNTAIN	Showing	Cu+/-Ag quartz veins	Cu	946402
092F 088	ANDERSON BAY	Past Producer	Limestone	Ls,Mb,Bs,Do,Ds	
092F 095	MARBLE BAY LIMESTONE	Past Producer	Limestone	Ls	
092F 104	TEXADA LIMESTONE	Dev. Prospect	Limestone	Ls	
092F 105	LITTLE BILLIE	Past Producer	Cu skarn	Au,Cu,Wl,Ag,Mo,Zn,Pb,W	
092F 106	PRESCOTT-TEXADA MINES	Past Producer	Cu skarn	Fe,Cu,Ag,Au,Zn,Mt,Co,Mo	
092F 107	PAXTON-TEXADA MINES	Past Producer	Cu skarn	Fe,Cu,Ag,Au,Mo,Zn,Mt,Co	
092F 108	GRAD	Showing	Cu skarn	Au,Cu,Mt	1033930
092F 109	MARJORIE (L.217)	Past Producer	Cu+/-Ag quartz veins	Au,Ag,Cu,Pb	

092F 110	COMMODORE	Prospect	Cu+/-Ag quartz veins	Ag,Zn,Au,Cu,Pb	
092F 111	RAVEN	Prospect	Cu skarn	Cu,Fe,Co	
092F 112	CORNELL (L.201)	Past Producer	Cu skarn	Cu,Ag,Au,Mo,W	
092F 113	SENTINEL	Showing	Cu+/-Ag quartz veins	Ag,Au,Zn,Cu,Pb	
092F 135	JERVIS ISLAND	Showing	Cu+/-Ag quartz veins	Cu,Ag	
092F 139	WHITE ROCK QUARRY	Past Producer	Limestone	Ls	
092F 174	STURT BAY	Past Producer	Limestone	Ls,Mb,Ds,Bs	
092F 200	CISCO	Showing	Cu+/-Ag quartz veins	Au,Cu	918869
092F 223	STROMBERG	Showing	Volcanic redbed Cu	Cu,Zn,Ag,Pb	
092F 258	YELLOW KID-TEXADA MINES	Past Producer	Cu skarn	Fe,Cu,Ag,Au,Mt,Zn	
092F 259	LAKE-TEXADA MINES	Past Producer	Cu skarn	Ag,Au,Cu,Mt,Fe,Ls,Zn,Co	
092F 260	GOLDEN SLIPPER	Showing	Cu+/-Ag quartz veins	Au	
092F 261	SILVER TIP (L.44)	Prospect	Cu+/-Ag quartz veins	Au,Ag,Cu,Zn,Pb	
092F 262	SURPRISE (L.67)	Prospect	Cu+/-Ag quartz veins	Cu,Ag,Au,Zn,Pb	
092F 263	COPPER KING (L.149)	Showing	Cu+/-Ag quartz veins	Cu,Au,Ag	
092F 264	VICTORIA (L.47)	Showing	Cu+/-Ag quartz veins	Au,Cu,Pb	918829
092F 265	LOYAL	Past Producer	Cu skarn	Cu,Au,Ag,Pb,Zn	
092F 266	PARIS	Prospect	Cu skarn	Cu,Au,Ag,Zn	
092F 267	CANADA	Showing	Cu skarn	Cu,Au,Pb,Zn	
092F 268	VOLUNTEER (L.131)	Prospect	Cu skarn	Au,Ag,Cu,Fe,Mt	
092F 269	FLORENCE-SECURITY	Prospect	Cu skarn	Cu,Au,Ag,Co,Fe,Mt,Mo	
092F 270	MARBLE BAY (L.154)	Past Producer	Cu skarn	Cu,Au,Ag,Mo	
092F 271	COPPER QUEEN (L.40)	Past Producer	Cu skarn	Cu,Au,Ag,Mo,W	
092F 272	GOOD HOPE FR. (L.329)	Past Producer	Cu skarn	Fe,Cu	
092F 273	CORNET	Showing	Cu skarn	Cu	
092F 274	MAGNOLIA	Prospect	Cu skarn	Cu,Au,Ag,Pb,Zn,Mt,Fe	
092F 275	VERN	Showing	Cu+/-Ag quartz veins	Cu	1016681
092F 276	TEX	Showing	Por. Cu +/- Mo +/- Au	Mo,Cu	
092F 280	LUCKY JACK (L.79)	Showing	Cu skarn	Cu	
092F 287	PJ	Showing	Cu+/-Ag quartz veins	Au,Ag,Pb,Zn	
092F 295	CHARLES DICKENS	Showing	Cu+/-Ag quartz veins	Cu,Zn	
092F 296	SMUGGLER	Showing	Cu+/-Ag quartz veins	Cu	
092F 297	LORINDALE (L.146)	Showing	Cu+/-Ag quartz veins	Au,Ag,Cu	
092F 300	DE OAR	Showing	Cu skarn	Cu	
092F 301	STURT 1	Showing	Cu skarn	Cu	
092F 303	POTOSA	Showing	Cu+/-Ag quartz veins	Au	
092F 304	BUTTERFLY	Showing	Cu skarn	Fe,Cu	
092F 305	ROSE AND BELLE	Showing	Cu+/-Ag quartz veins	Cu,Au	946421
092F 321	HOLLY (L.56)	Prospect	Cu+/-Ag quartz veins	Au,Ag,Cu	
092F 327	ANGEL	Showing	Cu+/-Ag quartz veins	Au,Cu,Ag	918869
092F 355	DECEMBER	Showing	Cu skarn	Cu	
092F 357	RETRIEVER (L.150)	Past Producer	Cu+/-Ag quartz veins	Cu,Pb,Zn,Ag,Au	
092F 359	GEM (L.441)	Prospect	Cu+/-Ag quartz veins	Au,Ag,Pb,Cu	
092F 363	WILL	Dev. Prospect	Limestone	Ls,Cu	
092F 364	BOLIVAR	Dev. Prospect	Cu+/-Ag quartz veins	Au,Ag,Cu,Zn	
092F 368	GLADYS C - CADET	Showing	Cu skarn	Cu,Au,Zn,Pb	
092F 373	SANDY	Showing	Cu+/-Ag quartz veins	Pb,Zn	
092F 374	OKE	Showing	Cu+/-Ag quartz veins	Au,Ag,Cu,Zn,Pb	

092F 393	VAUXHALL	Showing	Pb-Zn skarn	Zn	
092F 394	IMPERIAL	Producer	Limestone	Ls,Zn,Ag,Pb,Cu,Au,At,Bs	
092F 395	GILLIES BAY	Producer	Limestone	Ls,At,Rb,Bs	
092F 396	LAFARGE LIMESTONE	Past Producer	Limestone	Ls	
092F 397	HIESHOLT	Past Producer	Limestone	Ls	
092F 405	CRESCENT BAY	Showing	Clay	Cy	
092F 406	IRISH	Showing	Cu skarn	Cu,Pb,Zn,Au,Ag	
092F 407	LIMEKILN BAY	Past Producer	Limestone	Ls	
092F 471	B.C. CEMENT	Past Producer	Limestone	Ls	
092F 472	BEALE	Past Producer	Limestone	Ls	
092F 473	COULTER	Past Producer	Limestone	Ls	
092F 474	FOGH	Past Producer	Limestone	Ls	
092F 476	JOHNSON QUARRIES	Past Producer	Limestone	Ls	
092F 477	MCMILLAN LIME	Prospect	Limestone	Ls	
092F 478	MT. DICK	Showing	Limestone	Ls	
092F 479	BLUBBER BAY	Producer	Limestone	Ls,At,Bs	
092F 495	DECEMBER LIMESTONE	Dev. Prospect	Limestone	Ls	
092F 503	IRON HORSE (L.176)	Showing	Cu+/-Ag quartz veins	Cu,Ag	
092F 504	LONG B	Showing	Por. Cu +/- Mo +/- Au	Au,Cu,Ag	
092F 505	DAVE'S	Showing	Cu+/-Ag quartz veins	Au,Ag	
092F 506	FRISKY	Showing	Cu+/-Ag quartz veins	Cu,Pb,Zn,Au,Ag	1013509
092F 507	BOLT	Showing	Cu skarn	Cu	1026822
092F 508	TEX AND ADA	Showing	Cu+/-Ag quartz veins	Cu,Ag	
092F 511	M-21	Showing	Cu skarn	Au,Cu	
092F 516	YEW	Dev. Prospect	Cu skarn	Au,Cu,Ag	
092F 517	LUCKY LEAD	Showing	Cu+/-Ag quartz veins	Cu,Au,Ag	
092F 518	BASELINE	Showing	Cu+/-Ag quartz veins	Au	
092F 519	ROAD SHOW	Showing	Cu skarn	Cu	
092F 520	LOCALITY 6	Showing	Cu skarn	Cu	
092F 521	LOCALITY 7	Showing	Cu+/-Ag quartz veins	Au	1021099
092F 522	MOLLY SKARN	Showing	Cu skarn	Cu,Co,Ag	
092F 523	MAUDE ADAMS (L.57)	Showing	Cu+/-Ag quartz veins	Au,Cu	
092F 524	GOLDEN ROD	Showing	Cu+/-Ag quartz veins	Au,Cu	1013694
092F 525	LINDSAY FR. (L.50)	Showing	Cu+/-Ag quartz veins	Au,Cu,Pb	
092F 526	LION (L.174)	Showing	Cu+/-Ag quartz veins	Au,Cu	
092F 527	TYHEE (L.105)	Showing	Cu+/-Ag quartz veins	Au,Cu,Ag,Pb,Zn	
092F 528	FRANCIS (L.122)	Showing	Cu+/-Ag quartz veins	Au,Ag,Cu,Zn	
092F 529	SILVER KING (L.181)	Showing	Cu+/-Ag quartz veins	Au	
092F 530	RAM (L.147)	Showing	Cu+/-Ag quartz veins	Cu	
092F 531	TIP TOP	Showing	Cu+/-Ag quartz veins	Cu,Ag	
092F 532	MOUNTAIN CHIEF (L.55)	Showing	Cu+/-Ag quartz veins	Au,Ag,Pb,Zn,Cu	
092F 533	NANCY BELL (L.46)	Prospect	Cu+/-Ag quartz veins	Au,Ag,Cu,Zn,Pb	
092F 534	MANTO	Showing	Manto Ag-Pb-Zn	Au,Ag,Zn,Cu	
092F 537	ALLADIN (L.189)	Showing	Cu+/-Ag quartz veins	Pb	
092F 685	LAST LINK	Showing	Cu+/-Ag quartz veins	Zn,Pb,Ag,Au,Cu	918829

Since the implementation of the BC Assessment Report Information System (ARIS) in the 1940's, 132 technical assessment reports have been submitted and are publicly available for Texada Island, listed in Table 4.

Table 4 – ARIS Reports submitted for Texada Island as of March 4, 2014:

Report #	Year	Author	Owner/Operator	Work Program / MINFILE #
3	1947	McElroy,B., McNaughton,D.		Geological / 092F304,-355,-363,-394,-396,-522
121	1956	Coolbaugh, D.		Geophysical / 092F112,-280,-321,-395,-476,-495,-523,-534
612	1964	Dolmage, V.	Lafarge Cement	Geochemical / 092F105,-271,-304,-355,-394,-395,-495
1932	1969	Cross,P., Arscott,D.	Cambrian Expl.Ltd.	Geochemical / 092F104
2918	1970	Boissoneault, J.	Bellex Mines Ltd.	Geological / 092F265,-266,-267,-474
2919	1970	Baird, J.	Bellex Mines Ltd.	Geophysical / 092F265,-266,-267,-474
3244	1971	Wober, H.	Texada Lime Ltd.	Geochemical, Geophysical / 092F111,-272,-300,-363,-355,-522
4723	1973	Loach, A.	Lafarge Canada Ltd.	Geological / none
4903	1974	MacLeod,J.	Texada Lime Ltd.	Diamond Drilling / 092F363
5019	1974	Geiger,W.		Diamond Drilling / 092F364
5077	1974	Anderson,T.	Ideal Basic Industries	Geological, Geochemical, Geophysical / 092F105,-112,-271,304,-396
5234	1974	Christensen,K.	Christensen,K.	Diamond Drilling / 092F397
5273	1974	Savelieff,R.	Lafarge Canada Inc.	Diamond Drilling / 092F104
5386	1974	Beale, S.	Beale,S.	Diamond Drilling / 092F516
5410	1975	Passchier,D.	Passchier,D.	Diamond Drilling / 092F364
5517	1975	Geiger,W.	Longbar Minerals Ltd.	Diamond Drilling / 092F269,-295,-368,-473,-511
5645	1975	Whittles,A.	Longbar Minerals Ltd.	Geophysical / 092F406
5655	1975	Stiles,P.	Ideal Basic Industries	Diamond Drilling / 092F110,-280,-395,-534
5693	1975	Geiger,W.	Longbar Minerals Ltd.	Diamond Drilling / 092F109,-364,-406,-477
5699	1975	Geiger,W.	Longbar Minerals Ltd.	Diamond Drilling / 092F274
5700	1975	Geiger,W.	Longbar Minerals Ltd.	Diamond Drilling / 092F397
5749	1975	Whittles,A.	Longbar Minerals Ltd.	Geophysical / 092F274,-507,-520
5885	1975	Anderson,T.	Ideal Basic Industries	Geological, Geophysical / 092F095,-105,-110,-112,268,-269,-270,-271,-280,-295,-304,-395,-473,-476,-495,-511,-516,-534
5898	1976	Lee,M.	Longbar Minerals Ltd.	Geological, Geophysical / 092F268,-269,-295,-368,-516
5912	1976	Stiles,P.	Ideal Basic Industries	Diamond Drilling / 092F110,-280,-395,-534
6160	1976	Mullan,A.	Margetts,R., Beale,C.	Geophysical / 092F516
6156	1976	Lee,M.	Longbar Minerals Ltd.	Geological, Geochemical, Geophysical / 092F405
6335	1977	Cochrane,D., Paterson,R.	Aaron Mining Ltd.	Geological, Geochemical, Geophysical / 092F223
6414	1977	Manifold,A.	Gordon,E./Manifold,A.	Geochemistry / 092F359
6770	1978	Ager,C.	Shima Res.	Geophysical / 092F105,-110,-112,-113,-260,-269,-270,-271,-280,-295,-301,-304,-357,-368,-373,-393,-395,-396,-406,-472,-473,476,-511,-516,-530,-534,-537
6955	1978	Dove,K.	Michaud,J.	Diamond Drilling / 092F266
7559	1979	Brennan,F.	Brennan,F.	Diamond Drilling / 092F276
7939	1979	Beale, S.	Beale, C.	Geochemical / 092F264,-297,-321,-524,-525,-685
8175	1980	Wolfe,R.	Aaron Mining Ltd.	Geochemical / 092F104
9264	1981	Shearer,J.	Carolin Mines Ltd.	Geochemical / 092F504

9300	1980	Fahrni,K.	Shima Res.	Diamond Drilling / 092F105
9511	1981	Beale, S.	Beale, S.	Geochemical / 092F264,-297,-321,-524,-525,-685
10065	1981	Brennan,F.	Brennan,F.	Diamond Drilling / 092F276
10292	1982	Snell,J.	Jordan Valley Res.	Prospecting / 092F108
10573	1982	Wares,R.	Charlesmagne O.&G.	Geochemical / 092F287
10600	1982	Cochrane,D., Chase,W.	Aquarius Res. Ltd.	Geochemical / 092F268,-269,-270,-295,-368,-473,-511,-516
11383	1983	Wares,R.	Charlesmagne O.&G.	Geochemical, Geophysical / 092F287
12085	1984	Stanta, A.	Packard Res. Ltd.	Geological, Geochemical / 092F503,-508,-526,-527
12103	1984	MacLeod,J.	Carmac Res. Ltd.	Geochemical / none
12701	1985	Wares,R.	Rhyolite Res. Ltd.	Diamond Drilling, Geochemical / 092F321,523,-524,-525
13747	1985	Shearer,J.	Johanson,E., Mickle,R., Newman,J. / Caribou Gold Corp.	Geochemical / 092F276,-504
13911	1985	Cukor,V.	Cukor,D.	Geophysical / 092F108,-275
13912	1985	Cukor,V.	Cukor,D.	Geophysical / 092F507
14444	1986	Medford,G.	Packard Res. Ltd.	Geochemical, Geophysical / 092F092F503,-508,-526,-527
14445	1986	Medford,G.	Packard Res. Ltd.	Geochemical, Geological / 092F087
14446	1986	Medford,G.	Packard Res. Ltd.	Geochemical, Geophysical / 092F397
14447	1986	Medford,G.	Packard Res. Ltd.	Geochemical, Geological / none
14817	1986	Levaque,J.	Lafarge Canada Inc.	Geophysical / 092F104
14916	1985	Shearer,J.	Duker,R., Johanson,E., Mickle,R., Newman,J. / Caribou Gold Corp.	Drilling, Geochemical / 092F059,-200,-327,-504,-506
15229				
15750	1986	Peatfield, G.	Ideal Cement Co. Ltd. / Vananda Gold Ltd.	Geological / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,368,-374,-395,-472,-473,-511,-534,-537
16013	1987	Newman, J.	Duker,R., Johanson,E., Mickle,R., Newman,J.	Prospecting / 092F059,-200,-327,-506
16019	1987	Melnyk, W.	Trueman,E. / Esso Res. Canada Ltd.	Geological, Geochemical, Geophysical / 092F478
16104	1987	Peatfield, G.	Ideal Cement Co. Ltd. / Vananda Gold Ltd.	Geological, Gechemical / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,368,-374,-395,-472,-473,-511,-534,-537
16702	1987	Grainger, R.	Duker,R., Johanson,E., Mickle,R., Newman,J. / Rhyolite Res. Inc.	Bulk Sampling / 092F109,-174,-265,-266,-267,-364,397,-407,-471,-474,-477,-479,-511
16749	1988	Hardy, J.	Ideal Cement Co. Ltd. / Vananda Gold Ltd.	Geological, Gechemical / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-374,-395,-472,-473,-511,-534,-537
17301	1987	Perry,R.	Perry,R.	Geochemical, Geophysical, Physical / 092F506
17586	1988	Wares,R.	Grayson,E. / Tiffany Res. Ltd.	Geological, Geochemical / none
17685	1988	Kowalchuk, J.	Duker,R., Johanson,E., Mickle,R., Newman,J./ Rhyolite Res. Ltd.	Prospecting / 092F276,-327,-504,-505,-506,-511
17692	1988	Cukor,D.	Cukor,D.	Geophysical / 092F507

17693	1988	Cukor,D.	Cukor,D.	Geophysical / 092F108,-275
17947	1988	Findlay,A., Hoffman, S.	Duker,R., Murphy,D., Newman,J. / BP Res. Canada Ltd.	Geological, Geochemical / 092F273,-519,-520,-521
17995	1988	Newman,J.	Murphy,D.	Prospecting, Geochemical / 092F305
17996	1988	Newman,J.	Murphy,D.	Geochemical / none
18087	1988	Findlay,A., Hoffman, S.	BP Res. Canada Ltd.	Geochemical / 092F111,-273,-300,-363,-519,-520,-521,-522
18212	1988	Wares,R.	Beale,S.	Geochemical / 092F264,-524,-525
18246	1988	Konings, M.	Canquest Res. Corp.	Geophysical / 092F087,-274,-287,-520
18671	1989	Sargeant, P.	Rhyolite Res. Inc., Samuelson,R., Cook, J. / Echo Bay Mines Ltd.	Geological, Gechemical, Physical / 092F276,-327,-504,-505,-506
19017	1989	Cukor,D.	Cukor,D.	Geophysical / 092F108,-275
19022	1989	Sargeant, P., Stakiw.S.	Rhyolite Res. Inc., Murphy,D. / Echo Bay Mines Ltd.	Geological, Geochemical / 092F531
19315	1989	Forster, C.	Ideal Cement Co. Ltd., Vanada Gold Ltd. / Freeport-McMoRan Gold Co. (Canada) Ltd.	Diamond Drilling / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
19509	1989	Benvenuto,G.	Duker,R., Johanson,E., Mickle,R., Newman,J., Rhyolite Res. Ltd. / Nexus Res. Corp.	Geological, Geochemical, Diamond Drilling / 092F276,-327,-504,-505,-506
19598	1989	Forster, C.	Ideal Cement Co. Ltd., Vanada Gold Ltd. / Freeport-McMoRan Gold Co. (Canada) Ltd.	Diamond Drilling / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
20217	1990	Cukor,D.	Cukor,D.	Geophysical / 092F108,-275
20248	1990	Beale, S.	Beale,S.	Prospecting / 092F355,-394,-495,-522
20780	1991	Benvenuto,G.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geological, Geochemical / 092F087,-274,-287,-520
21100	1991	Davies,M., McLeod,H.	Fargo Res. Ltd.	Geological, Geochemical / none
21338	1991	Wilson,G.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geophysical / 092F087,-274,-287,-520
21960	1991	Hendrickson,G.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geophysical / 092F087,-274,-287,-520,-521
22088	1991	Grosbois,M.	Lafarge Canada Inc.	Geological, Geochemical / none
23017	1993	Perry,R.	Perry,R.	Geochemical / 092F264,-321,-359,-476,-516,-523,-524,-525,-685
22315	1992	Benvenuto,G.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geological, Geochemical, Geophysical / 092F087,-274,-287,-520,-521
22331	1992	Pilon,C., Davies,M.	Lang Bay Res. Ltd.	Geophysical, Geochemical / none
22467	1992	Cukor,D.	Cukor,D.	Geological / 092F507
22468	1992	Cukor,D.	Cukor,D.	Geophysical / 092F108,-275
22887	1993	Bates,C.	Texada Lime of Canada Ltd.	Diamond Drilling / 092F111,-273,-300,-363,-522
23017	1993	Perry,R.	Rhyolite Res. Inc. / Perry,R.	Geochemical / 092F264,-297,-321,-516,-524,-525

23311	1994	Ryan,M., Forster, C.	Holnam Inc. / Vananda Gold Ltd.	Diamond Drilling / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
23335	1994	Reynolds,P.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geological, Geochemical / 092F087,-274,-287,-520,-521
23662	1994	Villeneuve,A.	Duker,R.,Murphy,D.,Newman / Suncoast Mining Ltd.	Geochemical, Geophysical, Diamond Drilling / 092F517,-518
24321	1996	Reynolds,P.	White,D., Bethlehem Res. Corp. / Canquest Res. Corp.	Geological, Geochemical / 092F087,-274,-287,-520,-521
24556	1995	Levaque,J., Grosbois,M.	Lafarge Canada Inc.	Diamond Drilling / 092F355,-394,-495,-522
24629	1996	Beale, S.	Consolidated Van Anda Gold Ltd.	Prospecting / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
25126	1997	Perry,R.	Metals Research Corp. of America / Perry,R.	Geophysical / 092F264,-297,-321,-516,-524,-525
25580	1998	Perry,R.	Ash Grove Cement West Inc.,Tilbury Cement / Perry,R.	Geophysical / 092F266
25853	1999	Keays,G.	Keays,G.	Geochemical / none
26207	1999	Shearer,J.	CBR Cement / Lehigh Portland Cement Ltd.	Diamond Drilling / 092F104
26346	2000	Shearer,J.	Lehigh Portland Cement / Chemical Lime Company of Canada Ltd.	Diamond Drilling / 092F111,-273,-300,-363,-522
26582	2001	Shearer,J.	Shearer,J.	Geological / 092F504
26690	2001	Bowen,B.	Northstar Mining Ltd.	Geological, Geochemical / 092F276
26729	2001	Perry,R.	Perry,R.	Geophysical, Physical / 092F109
27209	2003	Reynolds,P.	Archibald,L. / Greenlite Ventures Inc.	Geochemical / 092F087,-274,-287,-520
27263	2003	Pinsent,R.	Consolidated Van Anda Gold Ltd.	Geochemical / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
27275	2003	Thompson,G.	555 Corporate Ventures Inc.	Geophysical / 092F109,-261,-262,-265,-266,-267,-268,-295,-321,-364,-405,-407,-471,-474,-476,-479,-508,-511,-516,-523,-524,-526,-533
27461	2004	Shearer,J.	Lehigh Northwest Cement Ltd.	Diamond Drilling / none
27464	2004	Shearer,J.	Lehigh Northwest Cement Ltd.	Diamond Drilling / 092F104
27477	2004	Shearer,J.	Lehigh Portland Cement / Chemical Lime Company of Canada Ltd.	Diamond Drilling / 092F111,-273,-300,-363,-522
27551	2004	Peters,L.	Northstar Mining Ltd. / Pathfinder Resources Ltd.	Geochemical / 092F276
27618	2004	Thompson,G.	555 Corporate Ventures Inc.	Diamond Drilling / 092F109,-261,-262,-265,-266,-267,-268,-295,-321,-364,-405,-407,-471,-474,-476,-479,-508,-511,-516,-523,-524,-526,-533
27799	2005	Shearer,J.	Lehigh Northwest Cement Ltd.	Percussion Drilling / 092F504

28050	2006	Reynolds,P.	Archibald,L. / Greenlite Ventures Inc.	Geochemical / 092F087,-274,-287,-520
28183	2006	Peters,L.	Northstar Mining Ltd., Lehigh Northwest Cement Ltd. / Pathfinder Resources Ltd.	Diamond Drilling / 092F276,-504
29718	2007	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
29719	2007	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
29720	2007	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
30596	2008	Pinsent,R.	Consolidated Van Anda Gold Ltd.	Diamond Drilling / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
30688	2008	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
30689	2008	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
30820	2008	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
30863	2008	Javorsky,D.	Funk,K.	Prospecting / none
31312	2009	McLelland,D.	Northstar Mining Ltd.	Geophysical / 092F059,-200,-276,-327,-504,-505,-506
31583	2009	Pinsent,R.	Consolidated Van Anda Gold Ltd.	Diamond Drilling / 092F095,-105,-106,-107,-110,-112,-113,-139,-174,-258,-259,-268,-270,-271,-280,-295,-301,-368,-373,-374,-396,-472,-473,-476,-495,-537
33051	2012	Thompson,G.	Zyrox Mining Co.	Geochemistry / 092F109,-261,-262,-265,-266,-267,-268,-295,-321,-364,-405,-407,-471,-474,-476,-479,-508,-511,-516,-523,-524,-526,-533
33064	2012	Thompson,G.	069746 BC Ltd.	Geochemical / 092F516
33753	2012	Houle,J.	Northstar Mining Ltd. / Coast Minerals Corp.	Geological, Geochemical / 092F264,-524
33754	2012	Houle,J.	Northstar Mining Ltd. / Coast Minerals Corp.	Geological, Geochemical / 092F200,-327
33841	2013	McLelland,D.	Bombardier,D., Northstar Mining Ltd.,Imperial Limestone / Coast Minerals Corp.	Geophysical / 092F059,-087,-200,-264,-275,-305,-327,-394,-506,-522,-524

Assessment work completed on Texada Island occurred in distinct pulses with various themes over time, summarized as follows:

- 1947 – focused geological and drilling program around current producers of copper, silver and gold
- 1956 – focused ground geophysical program on small claim group
- 1964 – focused geochemical program testing for industrial mineral products
- 1969 – 1973 – initial multi-parameter programs for metallic minerals on small claim groups by junior explorers, and for industrial minerals by major producers
- 1974 – 1981 – mainly focused diamond drill programs, and a few geochemical, or geophysical or multi-parameter programs by junior explorers

- 1982 – 1987 – multi-parameter programs by prospectors and junior explorers, following increased precious and base metal prices, and flow through funding

- 1988 – 1989 – systematic, well-funded, multi-parameter but short-lived programs by major companies on large claim groups, including Echo Bay, BP Resources, and Freeport-McMoRan, targeting both porphyry/skarn copper-molybdenum-gold deposits and shear-hosted vein gold-silver-zinc deposits

- 1990 – 2013 – mainly focused and/or limited tenure maintenance programs by prospectors, junior explorers, major industrial mineral producers, plus systematic but short-lived programs by junior explorers, including 555 Corporate and Pathfinder, targeting porphyry/skarn copper-molybdenum-gold-silver deposits

In eight (8) assessment reports for work completed from 2007 to 2013 D. McLelland of Auracle Geospatial Science Inc. documented progressively more sophisticated remote sensing survey techniques implemented over larger areas on Texada Island, culminating in the most recent ARIS Report 33841 completed in 2013 over the current Texada Project claims. J. Houle completed a memo and map which appear on pages 34-36 of ARIS Report 33841, the map from which has been repeated and enhanced in Figure 9 and the memo which has been repeated in Appendix 1 of the current technical report.

List of claims and work completed

Intermittently from March 19 to April 4, 2014 J. Houle generated nine (9) new mineral exploration target areas for the Texada Project claims for Coast Minerals Corp. by integrating remote sensing targets in Figure 9 with selected BC ARIS data from Table 4, while honouring appropriate BC Mineral Deposit Profiles as listed in Appendix 2. These new target areas are shown in Figures 10 to 18 inclusive at 1:20,000 scale. From February 23 to March 4, 2015 the author completed the current technical report, which carries on the necessary preparatory geological work following up the recommendations presented in ARIS 33841, prior to future ground-truthing of prioritized target areas.

Technical Data, Interpretation and Conclusions

In Figure 9, eighty-tree (83) selected metallic mineral spectral anomalies appear as labelled red polygons, and twenty-eight (28) selected alteration mineral spectral anomalies appear as un-labelled green polygons (McLelland, 2013 ARIS 33841) for the Texada Project area at 1:250,000 scale. These clusters of polygons have been grouped into nine (9) detailed map areas shown as black labeled boxes on Figure 9, which appear as detailed target area maps in Figures 10 -18.

For each of these detailed target areas, selected highlights from key ARIS reports have been plotted and referenced, and conceptual exploration targets have been suggested based on appropriate BC Mineral Deposit Profiles (Appendix 2) and target areas outlined schematically on each map. These targets are presented individually by map area, claim tenure block, and anomaly number, from northwest to southeast, for the entire Texada Project area.

Surprise Mountain Target Area, North Texada Island – Figure 10

- **Tenure Block L – 1005202, 1021796**
  - Metallic spectral anomalies I6, J6, K6, L6, T5, U5 on NW corner of Block L
  - NW-trending 1st vertical derivative aeromagnetic high zone crosses Tenure Block L and 5 of 6 metallic spectral anomalies
  - E-W fault structure crosses and bisects 6 metallic spectral anomalies
  - BC RGS anomaly of 43 ppb Hg immediately west and downstream from anomaly K6, the largest of the 6 metallic spectral anomalies
  - Up to 17 g/t Ag, 4.8% Cu in rocks, 1000 ppb Ag in soils (ARIS 14444) located within NE portion of Tenure Block L
  - Up to 900 ppb Au in soils (ARIS 14444) and up to 1500 ppm Cu in rocks (ARIS 12084) immediately SE of Tenure Block L
  - Up to 1018 ppm Cu in soil
  - (SP) Self-potential anomaly (ARIS 25126) straddles E boundary of Tenure Block L
  - Four BC MINFILE Au/Ag/Cu/Pb vein showings 092F 304 – Potosa, 092F 503 – Iron Horse, 092F 508 – Tex and Ada and 092F 525 – Lindsay Fr. located immediately adjacent to Tenure Block L
  - Seven BC MINFILE Au/Ag/Cu/Pb/Zn vein showings SE of Tenure Block L
  - Suggested Shear-hosted Au-Ag-Cu-Zn Vein primary targets (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along NW structures hosted by mafic volcanics crossing Tenure Block L in two locations
- **Tenure Blocks J and K – 918829, 1013694**
  - Metallic spectral anomalies M5 and N5 on centre of Tenure Blocks J, K
  - Relative low within NW-trending 1st vertical derivative aeromagnetic high zone crosses Tenure Block K and largest metallic spectral anomaly N5
  - E-W fault structure projected to cross northern portion of Tenure Block K
  - NE and NW trending block faulting of contact between Quatsino limestones and Karmutsen volcanics contact immediately east of Tenure Block J
  - BC RGS anomaly of120 ppb Hg northeast and downstream from Tenure Blocks J and K
  - Two BC MINFILE Au/Ag/Cu/Pb vein showings 092F 264 – Victoria and 092F 524 Golden Rod located on Tenure Blocks K and J, respectively
  - Two BC MINFILE Au/Ag/Cu/Pb vein prospects 092F 321 – Holly and 092F 359 – Gem and one showing 092F 297 – Lorindale immediately adjacent to Tenure Blocks J or K
  - Up to 2120 ppm Cu and 950 ppm Zn in soils (ARIS 6414) on Tenure Block K
  - Up to 1250 ppb Au in soils (ARIS 7939) on Tenure Block K
  - Up to 1500 ppb Au in soils (ARIS 9511) on Tenure Block K
  - Up to 1.8 g/t Au over 1 m. in 6 diamond drill holes (ARIS 12701) on Tenure Block J
  - Up to 615 ppb Au and 433 ppm Cu in soils (ARIS 18212) on Tenure Block K
  - Up to 6.3 g/t Au in rocks (ARIS 18672) on Tenure Block J
  - (SP) Self-potential anomaly (ARIS 25126) straddles NW boundary of Tenure Block K
  - Suggested Shear-hosted Au-Ag-Cu-Zn Vein primary targets (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along NW structures hosted by mafic volcanics crossing Tenure Blocks J and K in two locations
  - Suggested deep Porphyry/Skarn Cu-Mo-Au secondary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) peripheral to possible intrusive stocks centred immediately SW of Tenure Blocks J and K

Comet Mountain Target Area, Central Texada Island – Figure 11

- **Tenure Blocks I & G – 946402,-405,-408,-417,-419,-457, 1013691,-692, 1029548**
  - Metallic spectral anomalies A5, T4, U4, V4 and W4 within SW portion of Tenure Block I; metallic spectral anomaly P4 within Tenure Block G
  - Large and intense 1st vertical derivative aeromagnetic high zone straddling northern boundary of Tenure Blocks I and G
  - Contact between Quatsino limestone and Karmutsen volcanics located immediately west of Tenure Block I
  - Cretaceous granodioritic to dioritic intrusive stock outcropping north of and probably underlying northern boundary of Tenure Blocks I and G
  - Major NW-trending Marble Bay Fault bisects Tenure Blocks I and G
  - BC RGS multi-element anomaly site with 315 ppb Au, 35 ppm Cu and 46 ppm Hg located north and downstream of Tenure Block I
  - Two BC MINFILE Au/Cu vein showings 092F 087 – Comet Mountain and 092F 521 – Locality 7 on Tenure Blocks I and G, respectively
  - Four BC MINFILE Au/Ag/Cu vein showings 092F 517 – Luck Lead, 092F 518 – Baseline, 092F 519 Road Show and 092F 520 - Locality 6 immediately adjacent to Tenure Blocks I and G
  - Three BC MINFILE Cu/Fe/Co skarn showings 092F 111 – Raven, 092F 273 – Cornet and 092F 300 – De Oar located between outcropping intrusives and northern boundary of Tenure Blocks I and G
  - Up to 4.5 m. wide intercepts of Fe/Cu skarn mineralization in 5 diamond drill holes (ARIS 5699) on Tenure Block I
  - Up to 675 ppb Au in rocks, 230 ppb Au and 0.44% Cu in rocks, and Au-Cu-Fe anomalies in soils in five locations (ARIS 17947) along northern boundary of Tenure Blocks I and G
  - Airborne resistivity low anomaly (ARIS 18246) along Marble Bay Fault on Tenure Block G
  - Up to 2800 ppm Cu, up to 420 ppb Au and 845 ppm Cu, Au-As anomaly in soils, and Cu-As-Zn anomaly in soils, in four locations (ARIS 22315) on Tenure Blocks I and G
  - Up to 1.5 g/t Au over 5.1 m., 0.16 g/t Au and 0.28% Cu over 2.4 m. in 15 diamond drill holes (ARIS 23662) in northern portion of Tenure Block G
  - Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) peripheral to Cretaceous intrusive stocks along the northern boundary of Tenure Blocks I and G

Grad Target Area, Central Texada Island – Figure 12

- **Tenure Block G – 946402, 946417 to 946420, 1016662, 1006843, 1016680**
  - Metallic spectral anomalies A4, B4, C4, K4, O4 on Tenure Block G
  - Large and intense 1st vertical derivative aeromagnetic high within and along northern boundary of Tenure Block G continuing south to PJ & Vern Target
  - Cretaceous granodioritic to dioritic intrusive stock outcropping within and along northern boundary of Tenure Block G
  - BC RGS multi-element anomaly site with 73 ppb Au, 22 ppm Cu and 55 ppm Hg located immediately north and downstream of Tenure Block G
  - One BC MINFILE Au-Cu-Fe skarn showing 092F 108 – Grad and one BC MINFILE Cu vein showing 092F 275 – Vern on Tenure Block G

- Up to 850 ppb Au, 3.8 ppm Ag and 870 ppm Cu in rocks, up to 1250 ppb Au and 104 ppm Cu in soils, and up to 590 ppb Au and 1745 ppm Cu in soils, in three locations near the centre of Tenure Block G
- Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) peripheral to Cretaceous intrusive stock near the centre of Tenure Block G

PJ & Vern Target Area, Central Texada Island – Figure 13

- **Tenure Block G – 946422 to 946425, 1014340,1016681 to 1016682**
  - Metallic spectral anomalies B4, D4, I3, J3, M3, N3, O3, W3, V3 on Tenure Block G, along south flank of large and intense 1st vertical derivative aeromagnetic high and surrounding aeromagnetic low
  - Large and intense 1st vertical derivative aeromagnetic high bisects Tenure Block G continuing north to Grad Target
  - Moderate 1st vertical derivative aeromagnetic low along Marble Bay Fault
  - Major NW-trending Marble Bay Fault bisects Tenure Block G and underlies largest metallic spectral anomalies, SW edge of aeromagnetic high
  - One BC MINFILE Cu vein showing 092F 275 – Vern on Tenure Block G
  - One BC MINFILE Au/Ag/Pb/Zn showing 092F 287 – PJ surrounded by Tenure Block G
  - Up to 32 ppm Au, 78 ppm Ag, 3.1% Pb, 3.0% Zn in trench at PJ showing surrounded by Tenure Block G
  - Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) peripheral to Cretaceous intrusive stock near the centre of Tenure Block G
  - Suggested Shear-hosted Au-Ag-Cu-Zn Vein secondary target (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along NW structure hosted by mafic volcanics crossing Tenure Block B

Rose & Belle Target Area, Central Texada Island – Figure 14

- **Tenure Block G – 592648, 946415, 946421 to 946425, 946429 to 946431, 976766**
  - Metallic spectral anomalies C3, I3, G3, H3 on Tenure Block G along SW and SE flanks of intense 1st vertical derivative aeromagnetic high and surrounding aeromagnetic low
  - Intense 1st derivative aeromagnetic high bisects Tenure Block G continuing NW to PJ & Vern Target
  - Intense 1st derivative aeromagnetic low along Marble Bay Fault
  - One BC MINFILE Au/Cu vein showing 092F 305 – Rose and Belle on Tenure Block G
  - Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) on Tenure Block G
  - Suggested Shear-hosted Au-Ag-Cu-Zn Vein secondary target (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along NW structure hosted by mafic volcanics crossing Tenure Block G

Dude & Tex Target Area, Central Texada Island – Figure 15

- **Tenure Block G – 592650, 946409, 946414, 976766, 976768 to 976771**
  - Metallic spectral anomalies A3, N2, S2, T2, U2, V2 on Tenure Block G along SW flank of intense1st vertical derivative aeromagnetic high
  - Intense 1st derivative aeromagnetic low along Marble Bay Fault Zone

- Jurassic granodioritic to dioritic intrusive stock outcropping within and along NE boundary of Tenure Block G
- One BC MINFILE Cu/Mo/Au porphyry showing 092F 276 – Tex showing surrounded by Tenure Block G
- Up to 861 ppm Cu, 338 ppm Mo in rocks (ARIS 27551) at Tex showing
- Up to 0.055% Cu, 0.011% Mo over 171 m. in 6 diamond drill holes (ARIS 28183) at Tex showing
- Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) associated with Jurassic intrusive stocks on Tenure Block G
- Suggested Shear-hosted Au-Ag-Cu-Zn Vein secondary target (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along braided NW structure hosted by mafic volcanics crossing Tenure Block G

Stromberg Target, Southern Texada Island – Figure 16

- **Tenure Blocks D and G – 592649, 946399,-412,-413,-467, 1005182, 1016059, -376**
    - Metallic spectral anomalies A2, F2, G2, X1, Y1, Z1 straddling Tenure Blocks G and D surrounding 1st vertical derivative aeromagnetic high
    - One BC MINFILE Ag-Cu-Pb-Zn redbed copper showing 092F 223 – Stromberg located immediately SW of Tenure Block B
    - Up to 8.7% Cu in open cuts & shafts (BC Property File 28610) at Stromberg showing
    - Suggested deep Porphyry/Skarn Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) associated with Jurassic intrusive stocks on Tenure Blocks G and D
    - Suggested Redbed Copper Cu-Ag secondary target (BC Mineral Deposit Profile D03) hosted by mafic volcanics on Tenure Blocks G and D

Angel & Cisco Target, Southern Texada Island – Figure 17

- **Tenure Blocks B and E – 918869, -870, 946474, -481, 976772, 1013509, 1027257**
    - Metallic spectral anomalies D2 and E2 on Tenure Block E, extending NW and flanking two 1st vertical derivative aeromagnetic highs and northern splay of major NW-trending Marble Bay Fault Zone
    - Four BC MINFILE showings including three vein Au-Ag-Cu-Pb-Zn showings (092F 200 – Cisco, 092F 327 – Angel, and 092F 506 – Frisky) on Tenure Block E and one Ag-Cu-Pb-Zn skarn showing (092F 059 – May) on Block B
    - Up to 10.9 g/t Au in rock and 15 g/t Au over 1 m. in diamond drilling from Angel Showing (ARIS14916)
    - Up to 1350 ppb Au, 980 ppb Au, 880 ppb Au, >1%Zn, 1820 ppm, Pb in rocks from 4 outcrops along 2.5 km. strike length of Marble Bay Fault (ARIS 16013)
    - Up to 1165 ppb Au, 26 ppm Ag, 1055 ppm Cu, >1%Pb, 4310 ppm Zn in rock from Frisky showing (ARIS 17301)
    - Up to 24,000 ppb Au in silt from creek NE of Angel Showing (ARIS 17301)
    - Up to 15.9 g/t Au in trench sample from Angel Showing (ARIS 17685)
    - Up to 10.8 g/t Au in diamond drilling from Angel Showing (ARIS 18671)
    - Up to 242 ppb Au, 17.3 g/t Ag, 4662 ppm Cu from Bob Lake (ARIS 18671)
    - Suggested deep Porphyry Cu-Mo-Au primary target (BC Mineral Deposit Profiles K01, K03, K04, L01, L02, L04) associated with possible Jurassic intrusive stocks on Tenure Block E

        - Suggested Shear-hosted Au-Ag-Cu-Zn Vein primary target (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along northern splay structure hosted by mafic volcanics crossing Tenure Blocks B and E

Cook Bay Target, Southern Texada Island – Figure 18

- **Tenure Block B – 946481, 946486, 946487, 1004402, 1004422, 1014375**
    - Metallic spectral anomalies H1, I1, J1, K1, M1, N1, O1, P1, Q1, R1 flanking 1st vertical derivative aeromagnetic low and central splay of major NW-trending Marble Bay Fault Zone
    - BC RGS multi-element anomaly of 98 ppm Cu, 45 ppm Hg west of fault zone
    - BC RGS multi-element anomaly of 4400 ppb Au, 89 ppm Cu, 86 ppm Hg south of shear zone, and 2695 ppb Au from stream sediment panned concentrate north and upstream from RGS site (ARIS 30863)
    - Suggested Shear-hosted Au-Ag-Cu-Zn Vein primary target (BC Mineral Deposit Profiles H04, H05, H06, H08, I01, I02, I05, I06) along central splay structure hosted by mafic volcanics crossing Tenure Block B

Acquisition of additional mineral tenures to secure any available internal tenure gaps within the Texada Project is recommended prior to initiating any field exploration work. Industry standard GIS data compilation followed by phased, systematic exploration work is appropriate and warranted to test all nine (9) target areas for precious/base metal quartz-sulphide vein, and/or porphyry/skarn copper-molybdenum-gold deposits, culminating in trenching and initial shallow diamond drilling of any priority targets.

Table 5 – Proposed Phase 1 Year 1 Work Program for the Texada Project:

Item	**Units**	**Unit Cost**	**Scheduling**	**Program Cost**
MTO Cell Acquisition	100 cells – by owner	$ 50 per cell	Winter	$ 5,000
GIS Data Compilation	50 days – 1 GIS tech., 1 geo.	$1,500 per day	Spring	$ 75,000
Airborne Geophysics	5000 line-km Mag-EM-Rad.	$100 per ln-km	Spring	$ 500,000
Stream moss sampling	50 days - 2 samplers, 2 geo's	$4,000 per day	Summer-Fall	$ 200,000
Grid soils, mapping	100 days - 2 samplers, 2 geo's	$4,000 per day	Summer-Fall	$ 400,000
Geochemistry	2000 moss, soil, rock samples	$35 per sample	Summer-Fall	$ 70,000
Ground Geophysics	400 line-km Mag-IP-Gravity	$500 per ln-km	Fall	$ 200,000
Compilation, Reports	20 days for 2 geologists	$1,500 per day	Winter	$ 30,000
Permitting, Bonding	Estimate		Winter	$ 20,000
Totals				**$ 1,500,000**

Additional work programs may be recommended conditional upon results of Phase 1.

Respectfully submitted by:

March 4, 2015

Jacques Houle, P.Eng.

Author's Qualifications

I, Jacques Houle, P.Eng. Do hereby certify that:

I am currently self-employed as a consulting geologist by:
Jacques Houle, P.Eng. Mineral Exploration Consulting
6552 Peregrine Road, Nanaimo, British Columbia, Canada V9V 1P8

I graduated with a Bachelor's of Applied Science degree in Geological Engineering with specialization in Mineral Exploration from the University of Toronto in 1978.

I am a member in good standing with the Association of Professional Engineers and Geoscientists of British Columbia, the Society of Economic Geologists, the Association for Mineral Exploration British Columbia, and the Vancouver Island Exploration Group; I am also a member of the Technical Advisory Committee for Geoscience B.C., and of the advisory committee for the Earth Science Department of Vancouver Island University.

I have worked as a geologist for 38 years since graduating from university, including 5 years as a mine geologist in underground gold and silver mines, 15 years as an exploration manager, 3 years as a government geologist and 13 years as a mineral exploration consultant.

I have previously visited the Texada Project area as the Southwest Regional Geologist for the B.C. government and as a independent consultant for Auracle Geospatial Science Inc. and Coast Minerals Corp. I am independent of Coast Minerals Corp. and Northstar Elements LLC, and hold no interest in the subject property of this report.

References

B. C. Ministry of Energy and Mines websites:

Assessment Reports
http://www.empr.gov.bc.ca/Mining/Geoscience/ARIS/Pages/default.aspx

MapPlace
http://www.empr.gov.bc.ca/Mining/Geoscience/MapPlace/Pages/default.aspx

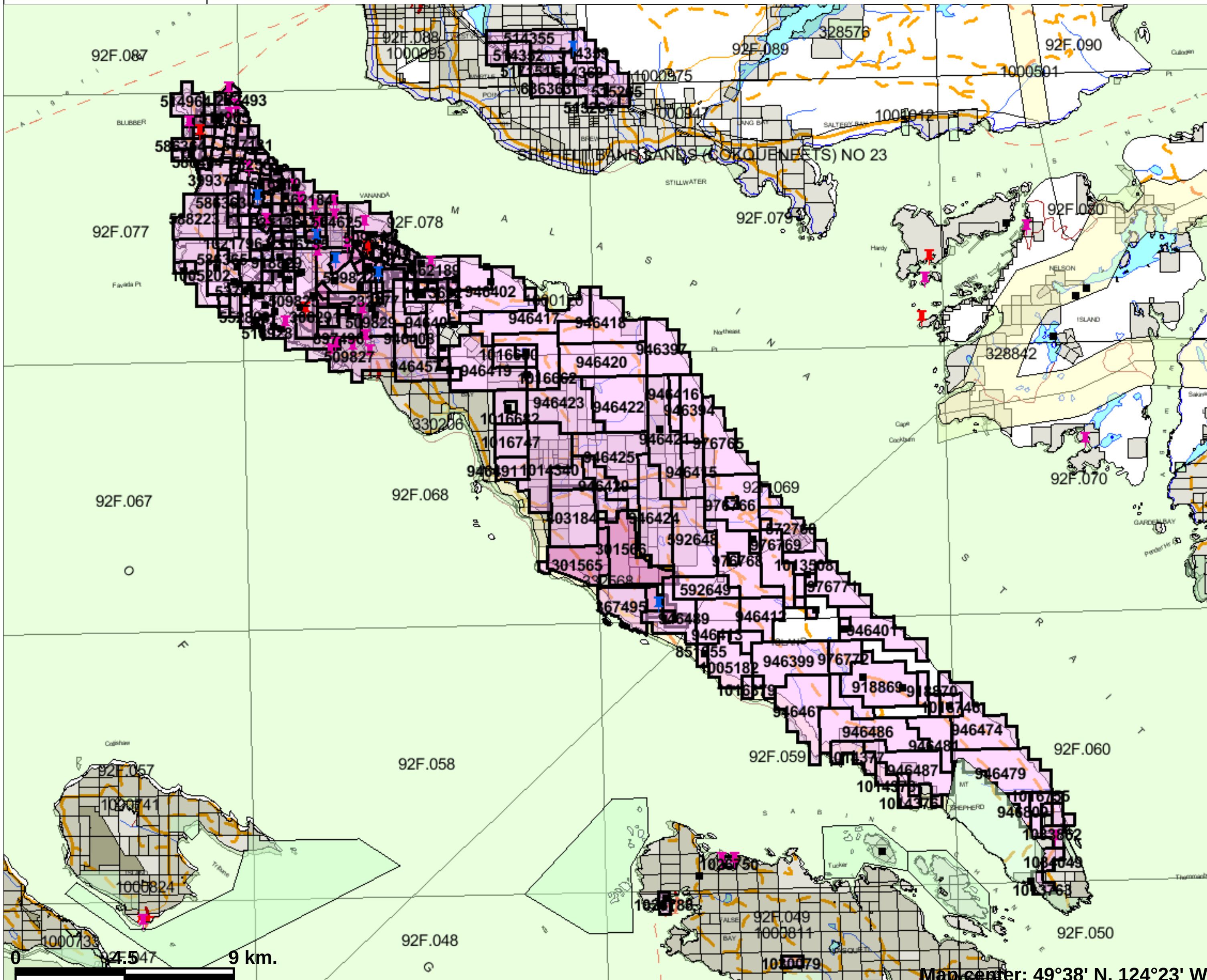
Mineral Deposit Profiles
http://www.empr.gov.bc.ca/Mining/Geoscience/MineralDepositProfiles/Pages/default.aspx

MINFILE
http://www.em.gov.bc.ca/Mining/Geolsurv/Minfile/

Ministry Publications
http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/Pages/default.aspx

Mineral Titles Online
https://www.mtonline.gov.bc.ca/mtov/home.do

Texada Project



Legend

MINFILE Status

- Producer
- Past Producer
- Developed Prospect
- All others

- Indian Reserves
- National Parks
- Conservancy Areas
- Parks
- Federal Transfer Lands

Mineral Tenure (current)

- Mineral Claim
- Mineral Lease

Mineral Reserves (current)

- Placer Claim Designation
- Placer Lease Designation
- No Staking Reserve
- Conditional Reserve
- Release Required Reserve
- Surface Restriction
- Recreation Area
- Others

- First Nations Treaty Related Lands
- First Nations Treaty Lands
- Survey Parcels
- BCGS Grid

Annotation (1:250K)

Transportation - Points (1:250K)

- Airfield
- Anchorage - Seaplane

N

Scale: 1:250,000

This map is a user generated static output from an Internet mapping site and is for general reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable. THIS MAP IS NOT TO BE USED FOR NAVIGATION.

Mineral Titles and MINFILE Occurrences

Figure 1

BC Administrative Area Layers

BC Communities
- City
- Town
- Village
- Resort Municipality
- Settlement
- Community
- District Municipality

BC Municipality labels

First Nations Layers

Indian Reserves

Parks Layers

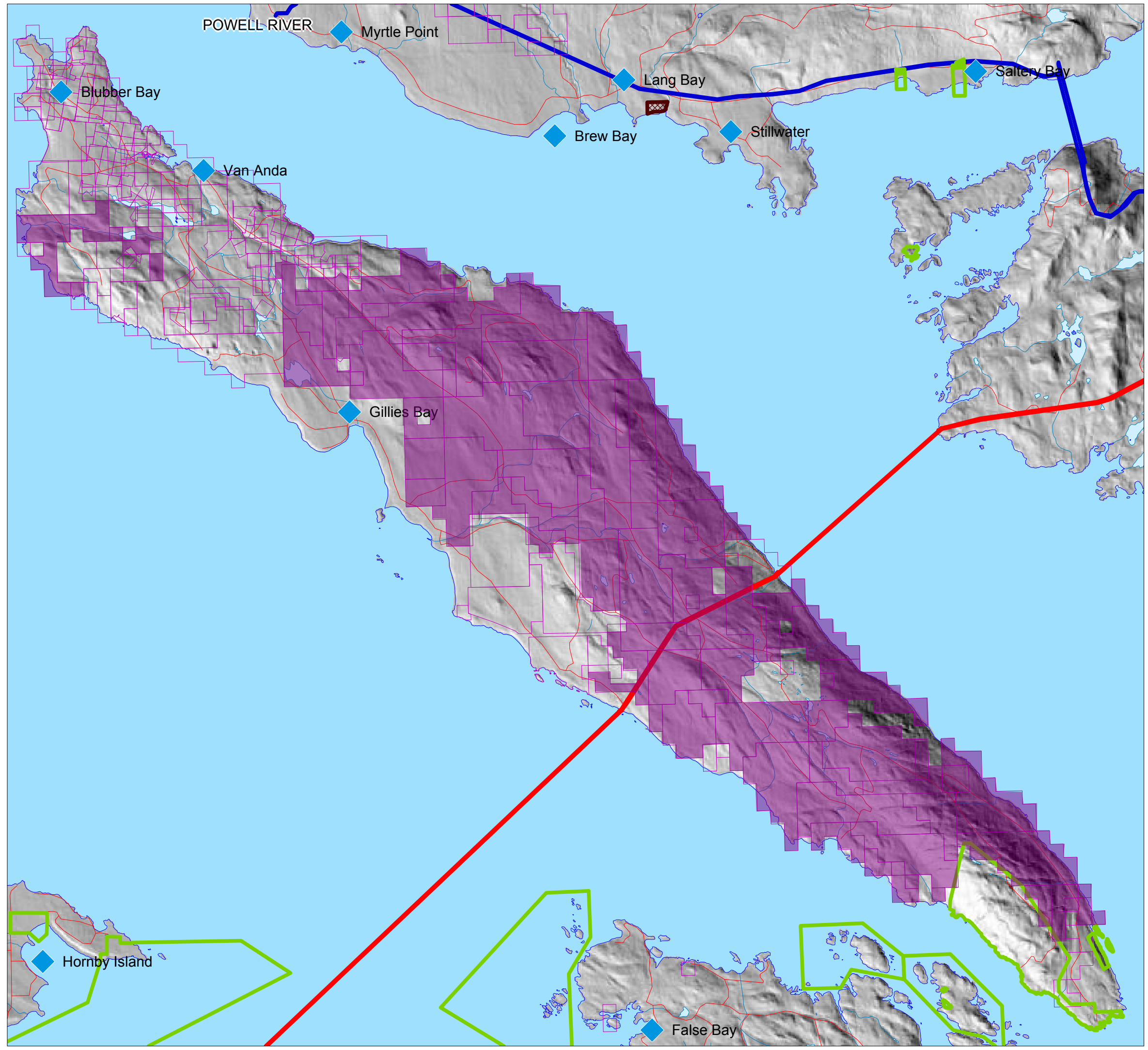
Provincial Parks & Protected Areas (<1M)

Mineral Titles Layers

MTO Mineral Titles Online Polygons
- Coal
- Placer
- Mineral
- Titles Held by Bombardier/Northstar

Topographic Layers

BC Power Grid 2007
- 69 KV
- 138 KV
- 150 KV
- 230 KV
- 287 KV
- 360 KV
- 500 KV



SCALE 1 : 250,000

5 0 5 10 15

KILOMETERS

N

Figure 2

Texada Project Infrastructure

Mineral Inventory Layers

MINFILE name label
- Developed Prospect
- Past Producer
- Producer
- Prospect
- Showing
- All Others

Mineral Titles Layers

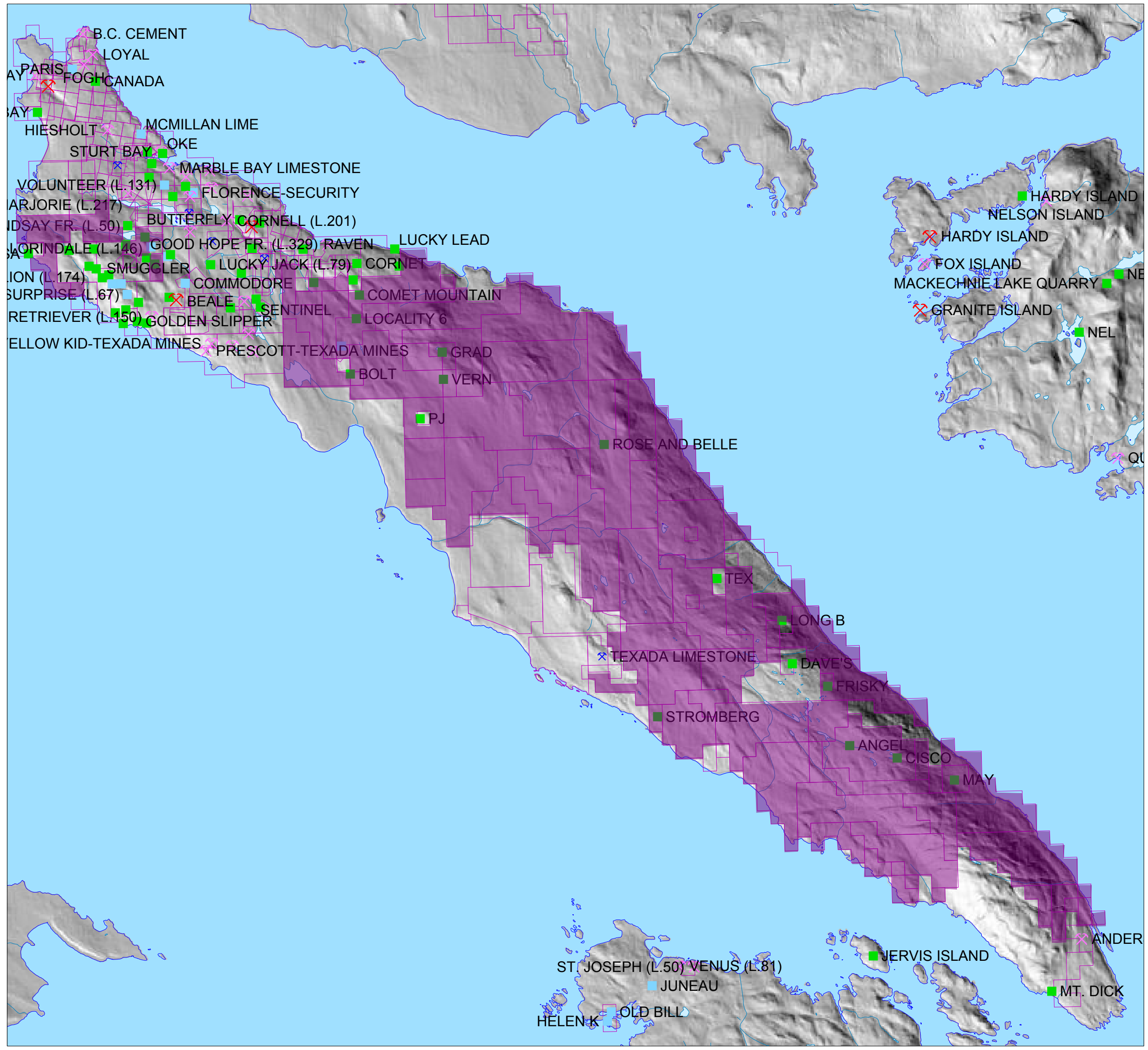
MTO Mineral Titles Online Polygons
- Coal
- Placer
- Mineral
- Titles Held by Bombardier/Northstar

Topographic Layers

- **Islands**
- **Coast 1:20K (<1M)**
- **Lakes 1:50K (<300K)**
- **Rivers 1:50K (<300K)**
- **BC Ocean**

Raster Layers

- **DEM image hillshade (<300K)**



SCALE 1 : 250,000

5 0 5 10 15

KILOMETERS

N

Figure 3

Texada Project BC MINFILE

Mineral Inventory Layers

ARIS number label

Mineral Titles Layers

MTO Mineral Titles Online Polygons

Coal

Placer

Mineral

Titles Held by Bombardier/Northstar

Topographic Layers

Islands

Coast 1:20K (<1M)

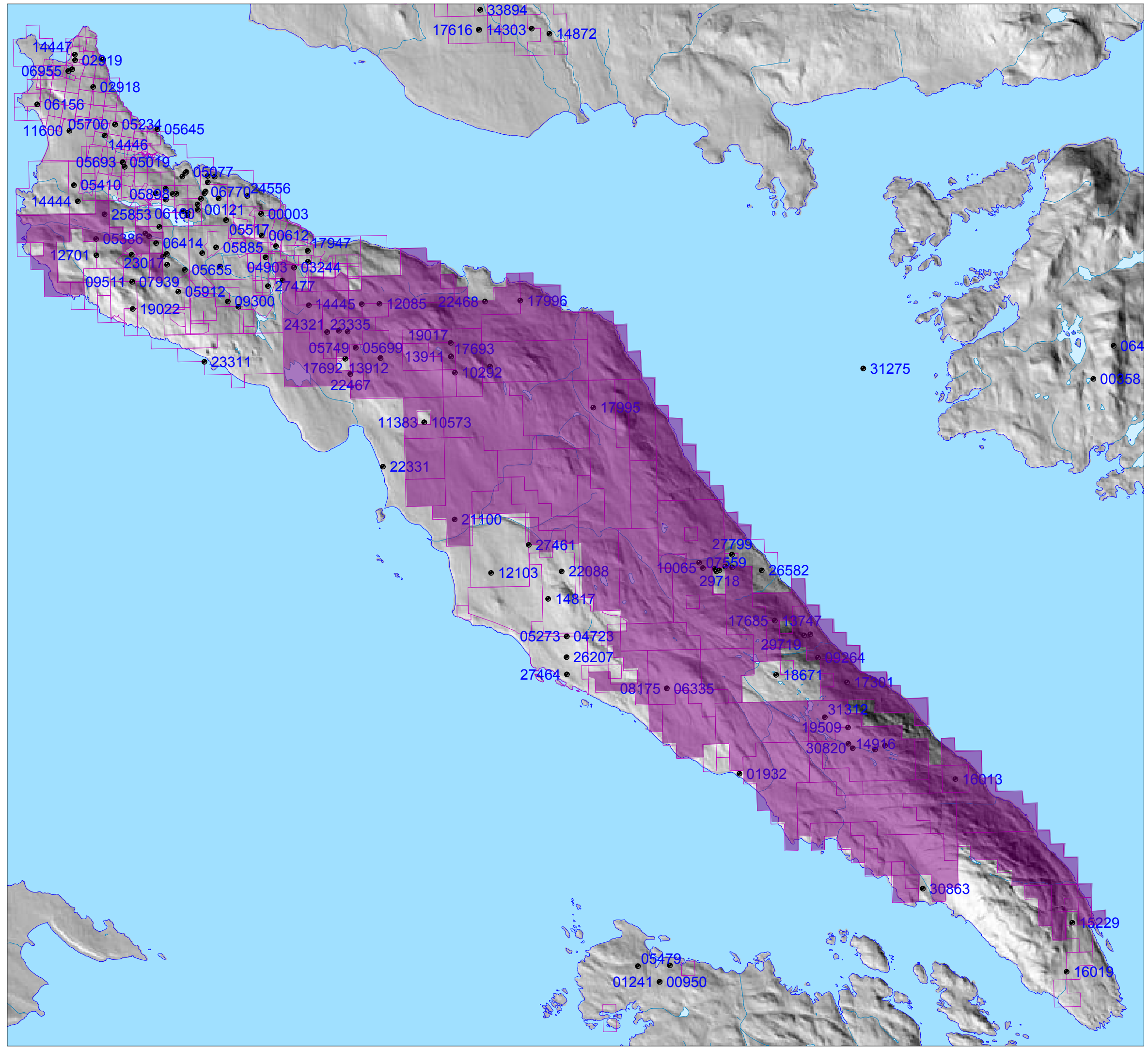
Lakes 1:50K (<300K)

Rivers 1:50K (<300K)

BC Ocean

Raster Layers

DEM image hillshade (<300K)



SCALE 1 : 250,000

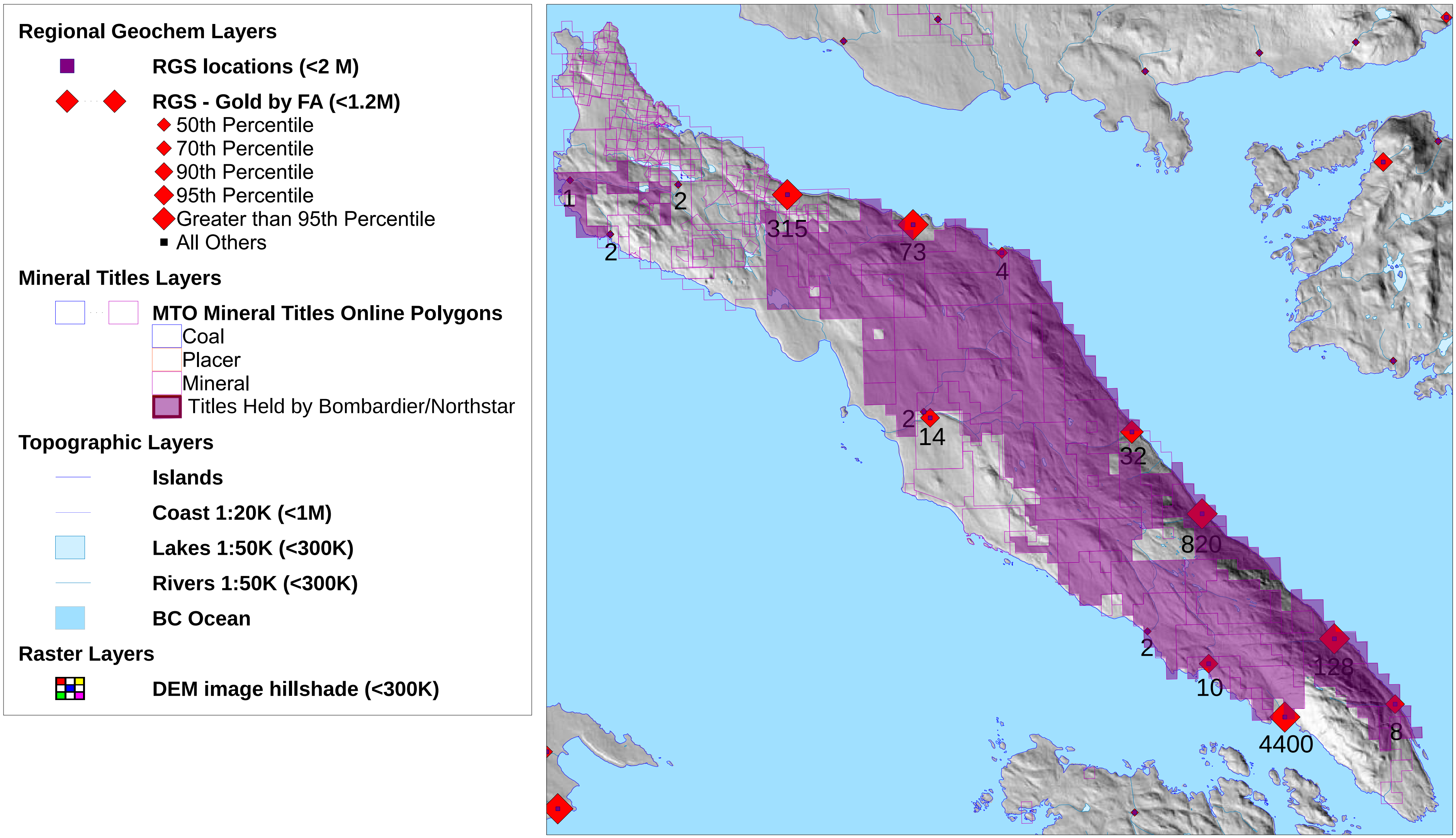
5 0 5 10 15

KILOMETERS

Figure 4

Texada Project BC ARIS

N



SCALE 1 : 250,000

5 0 5 10 15

KILOMETERS

N

Figure 5

Texada Project BC RGS Au ppb

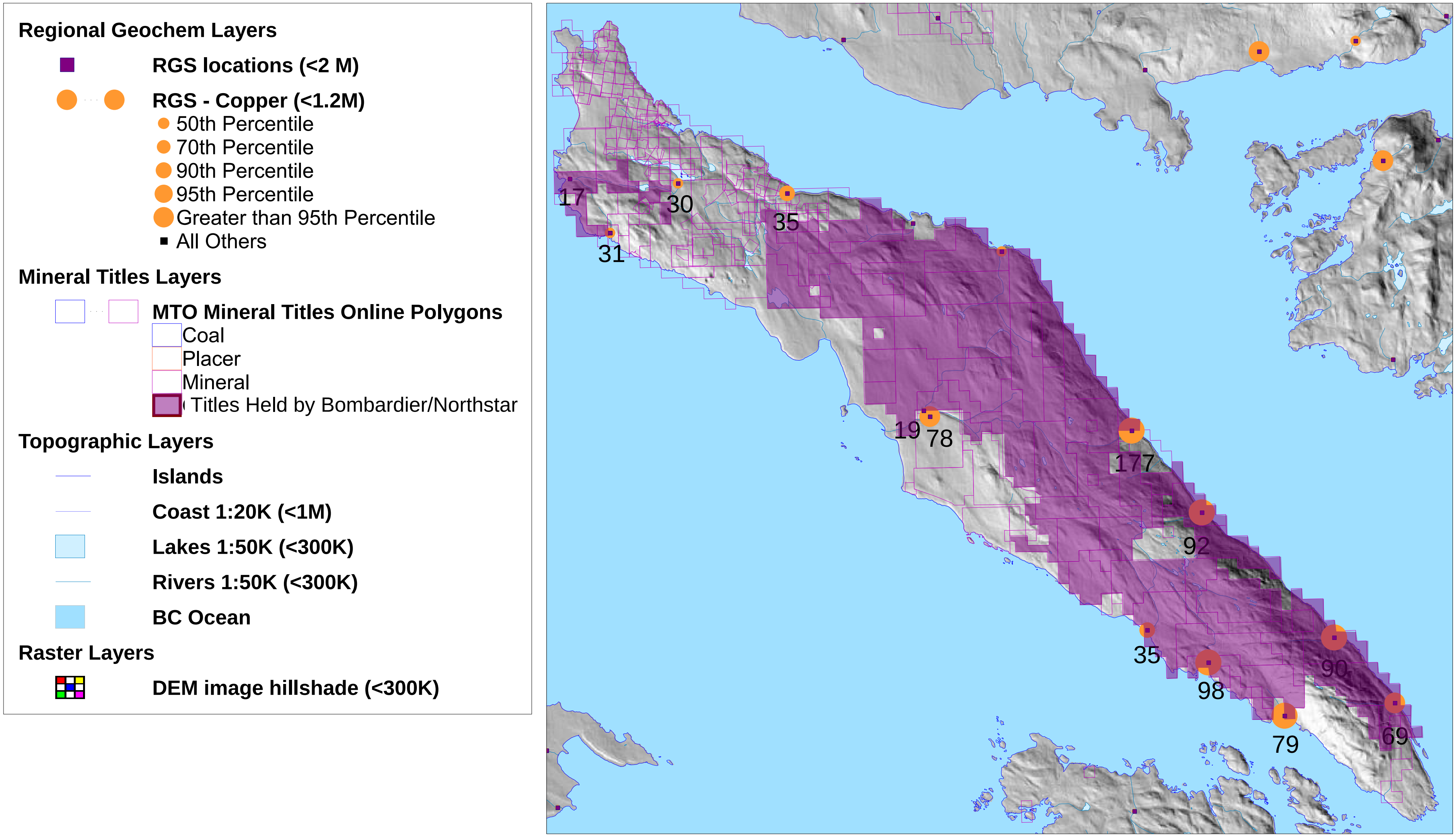
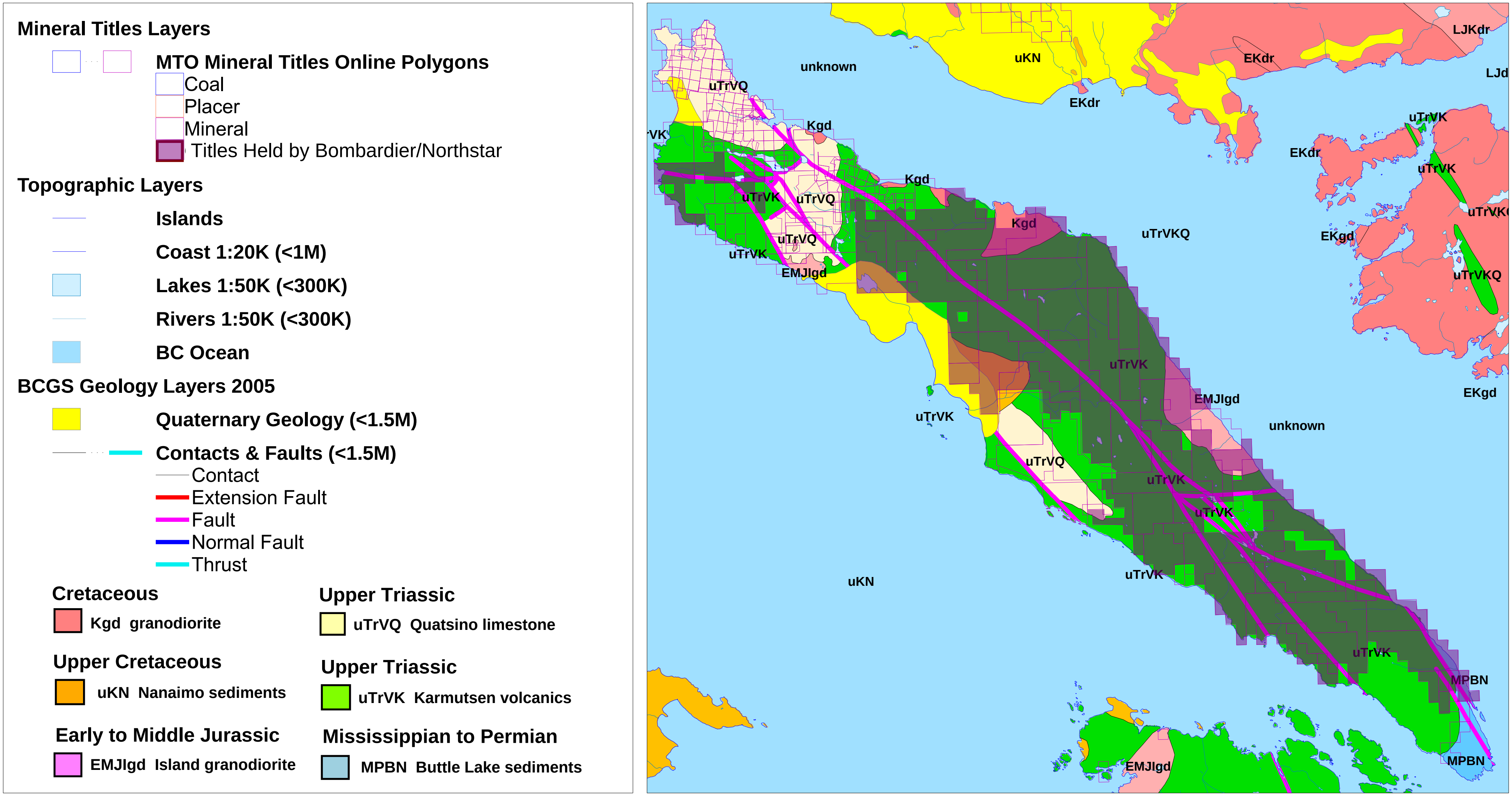


Figure 6

Texada Project BC RGS Cu ppm



SCALE 1 : 250,000

5 0 5 10 15

KILOMETERS

N

Figure 7

Texada Project BCGS 2005 Geology

Mineral Titles Layers

MTO Mineral Titles Online Polygons

Coal

Placer

Mineral

Titles Held by Bombardier/Northstar

Topographic Layers

Islands

Coast 1:20K (<1M)

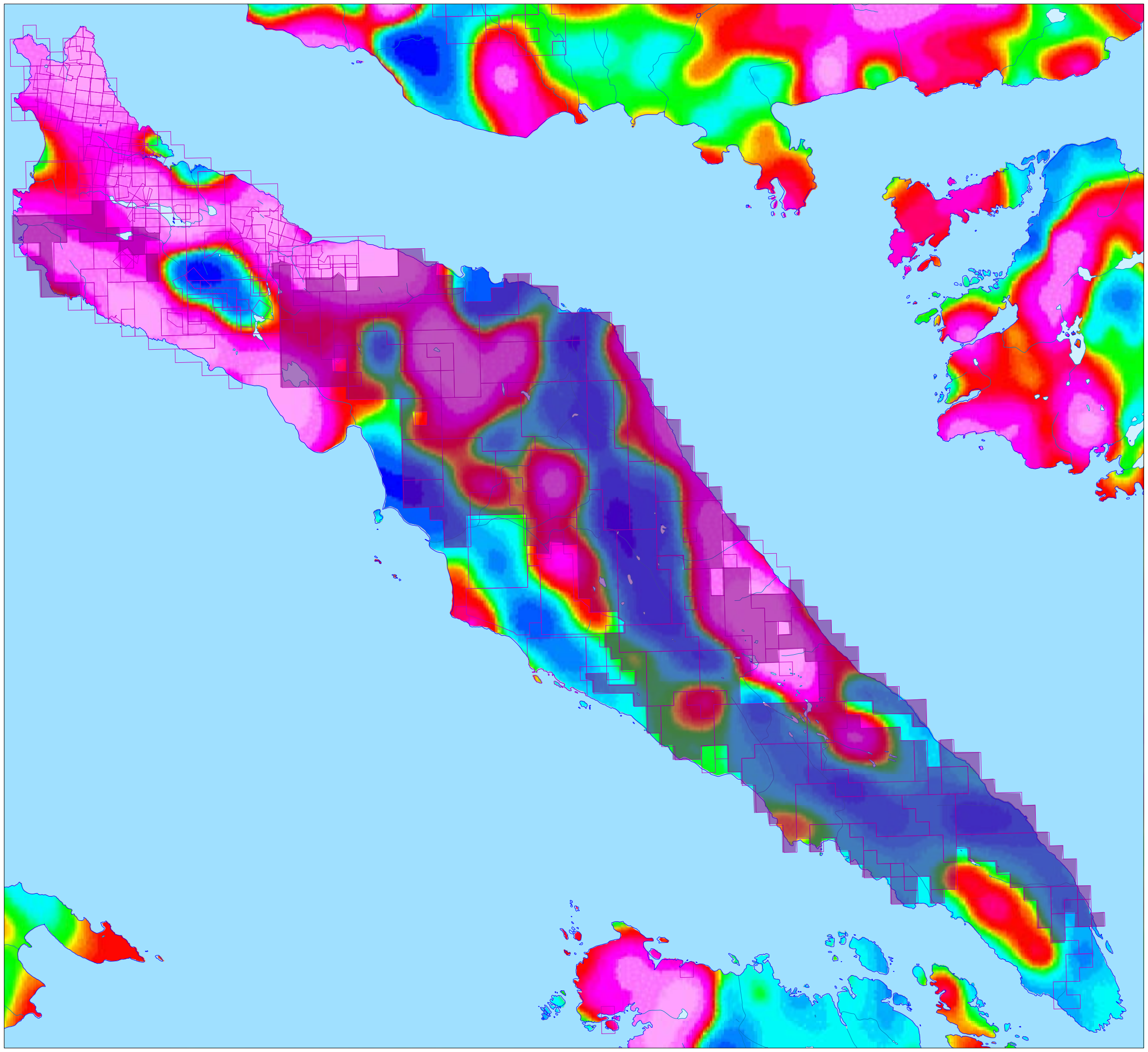
Lakes 1:50K (<300K)

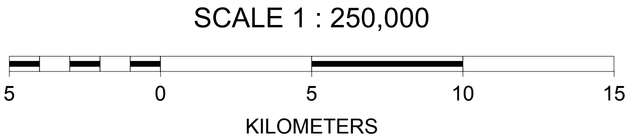
Rivers 1:50K (<300K)

BC Ocean

Geophysical Layers

1st Vertical Derivative Magnetic Field (<500K)





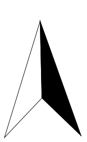


Figure 8

Texada Project
1st Vertical Derivative Aeromagnetics

Texada Island Group

Geological Targets
over Radarsat-1 Fine Beam Derivative

AURACLE Geospatial Science Inc.

Figure 9

Coast Minerals Corporation

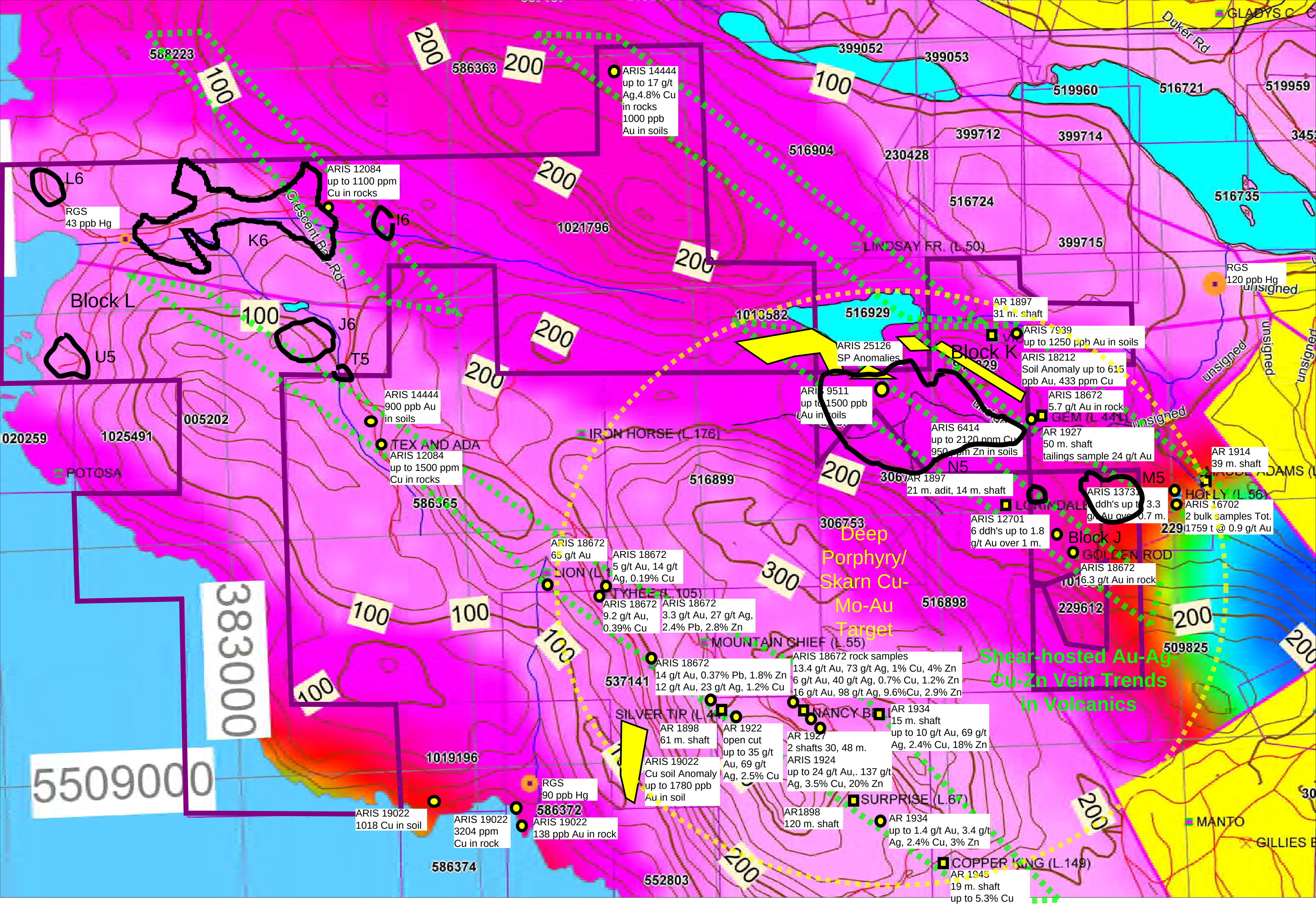


Figure 10

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

K6 ARIS 33841 Remote Sensing Target (Auracle)

Surprise Mountain Target North Texada Island

N

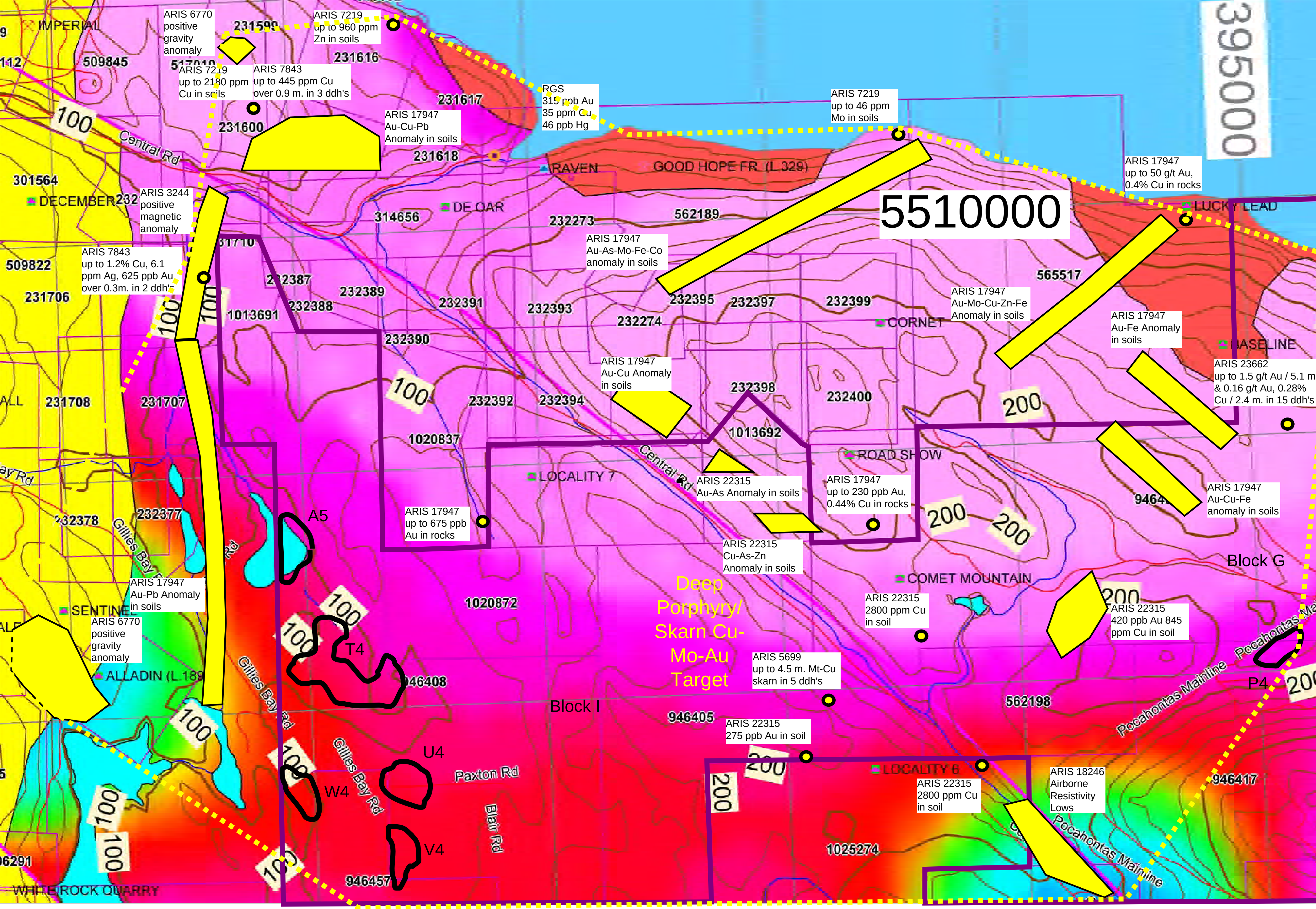


Figure 11

SCALE 1 : 20,000

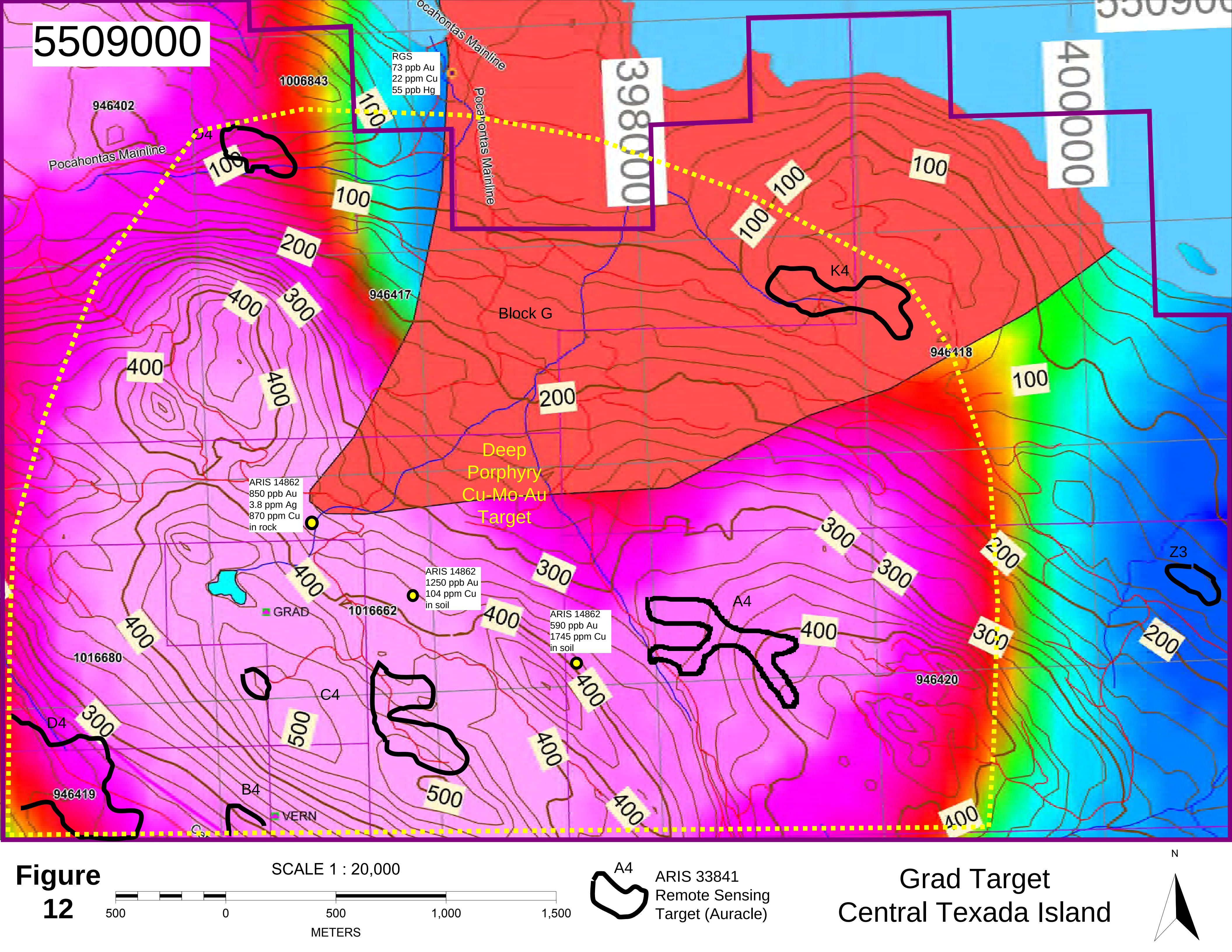
500 0 500 1,000 1,500

METERS

T4 ARIS 33841 Remote Sensing Target (Auracle)

N

Comet Mountain Target Central Texada Island



5509000
398000
400000
Pocahontas Mainline
RGS
73 ppb Au
22 ppm Cu
55 ppb Hg
1006843
946402
946417
946418
946419
946420
1016662
1016680
Block G
Deep
Porphyry
Cu-Mo-Au
Target
ARIS 14862
850 ppb Au
3.8 ppm Ag
870 ppm Cu
in rock
ARIS 14862
1250 ppb Au
104 ppm Cu
in soil
ARIS 14862
590 ppb Au
1745 ppm Cu
in soil
GRAD
VERN
K4
A4
C4
D4
B4
Z3
100
200
300
400
500
Figure
12
SCALE 1 : 20,000
500
0
500
1,000
1,500
METERS
A4
ARIS 33841
Remote Sensing
Target (Auracle)
Grad Target
Central Texada Island
N

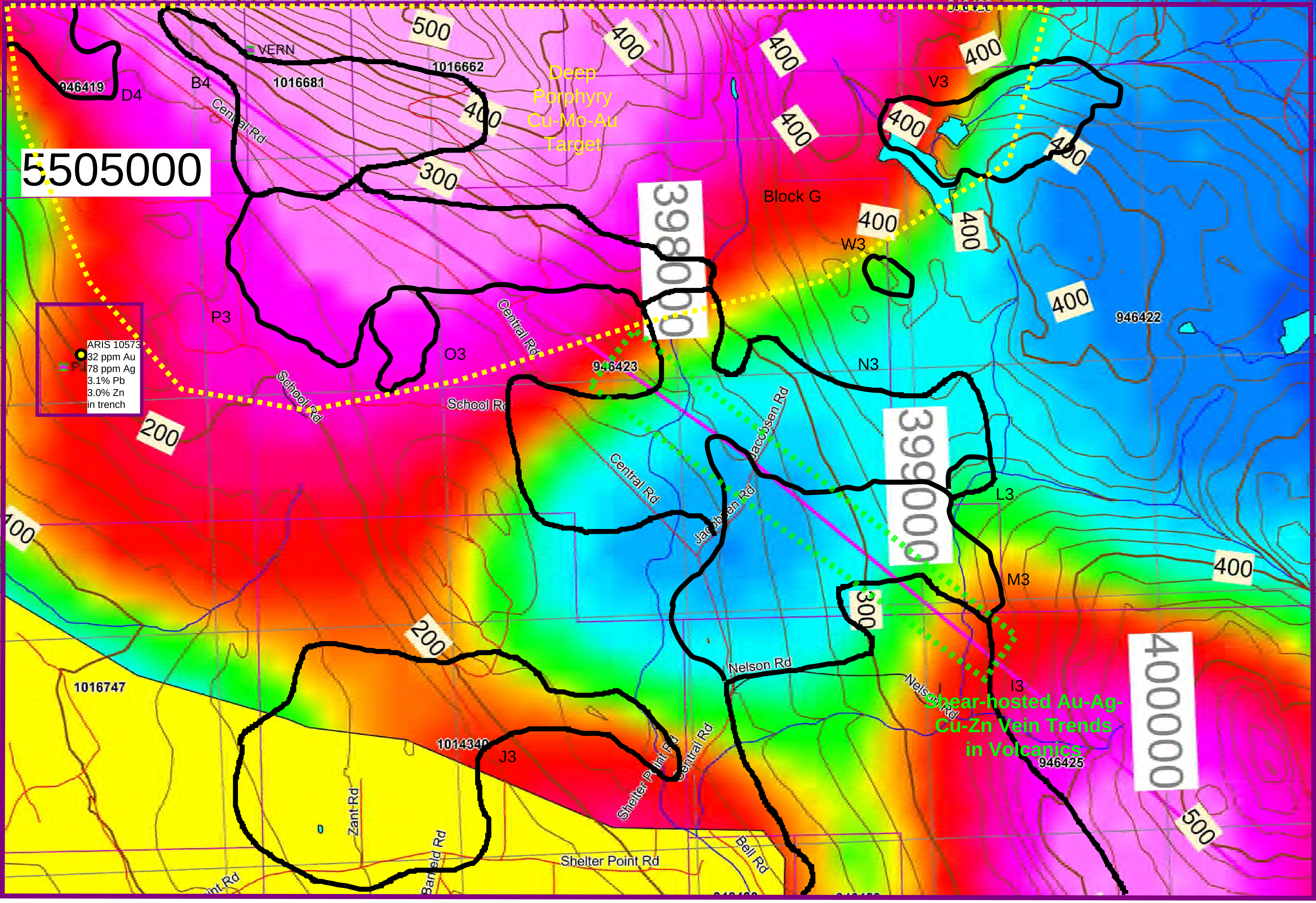


Figure 13

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

J3 ARIS 33841 Remote Sensing Target (Auracle)

PJ & Vern Target
Central Texada Island

N

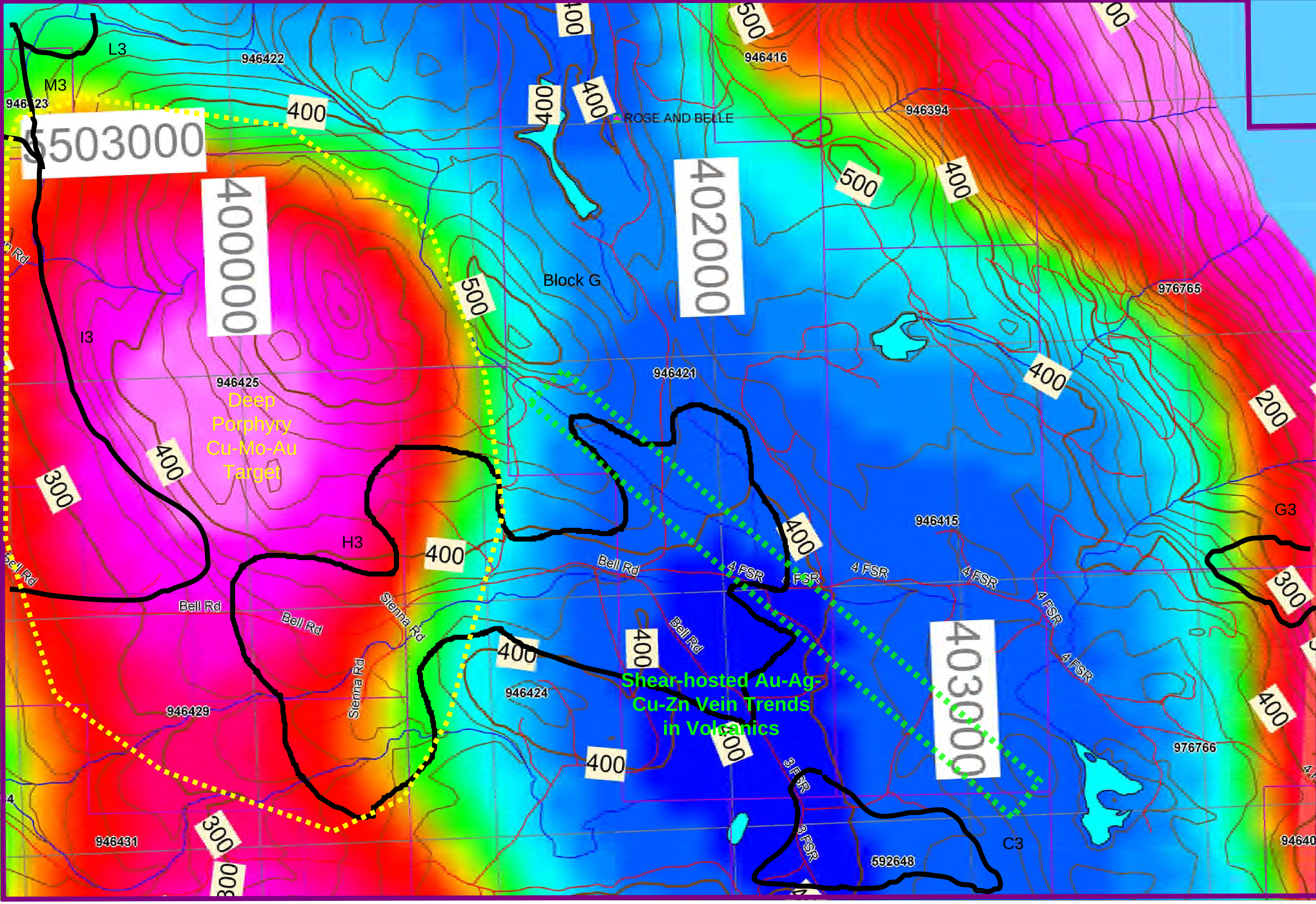


Figure 14

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

H3 ARIS 33841 Remote Sensing Target (Auracle)

Rose & Belle Target
Central Texada Island

N

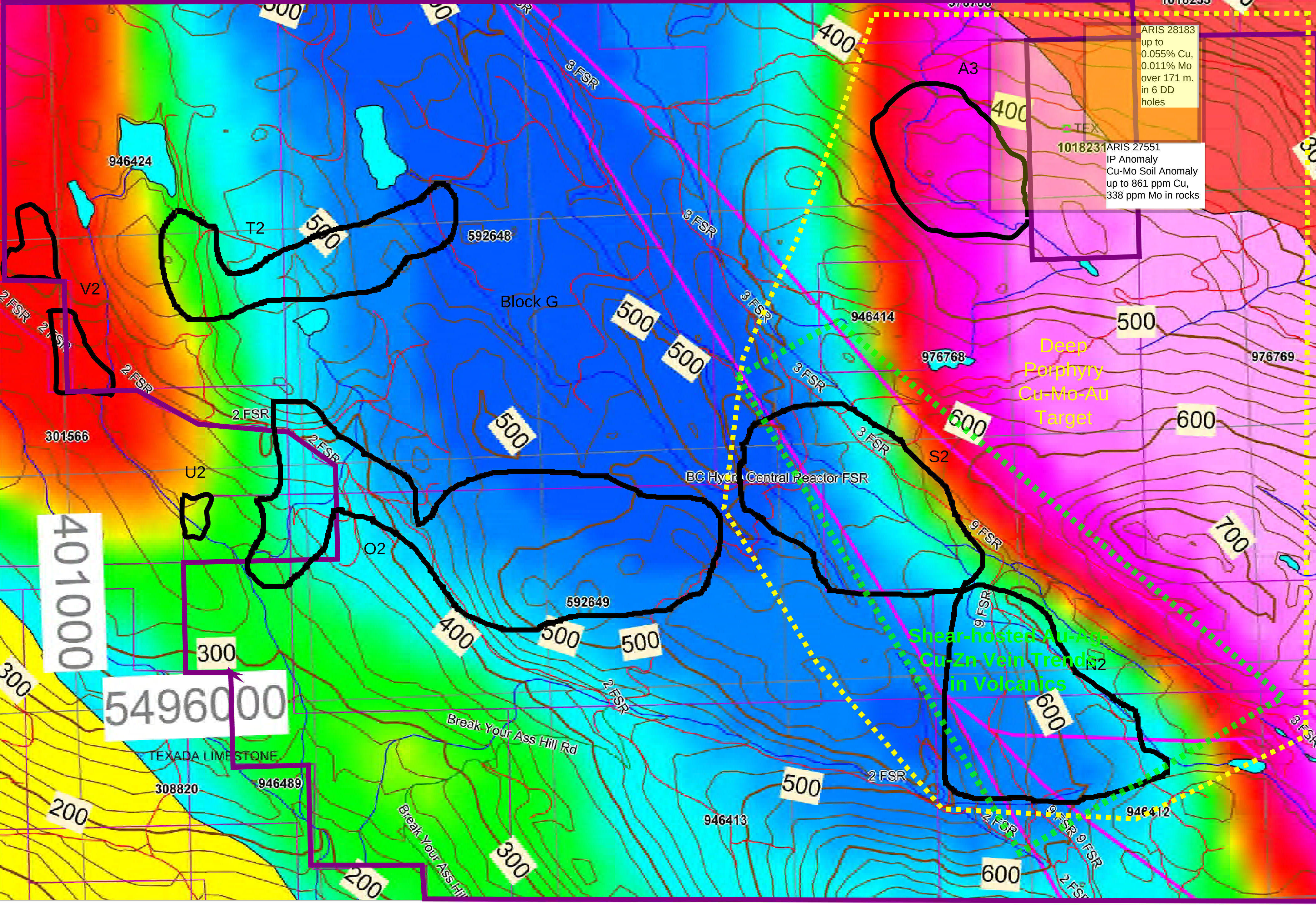


Figure 15

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

A3 ARIS 33841 Remote Sensing Target (Auracle)

N

Dude & Tex Target Central Texada Island

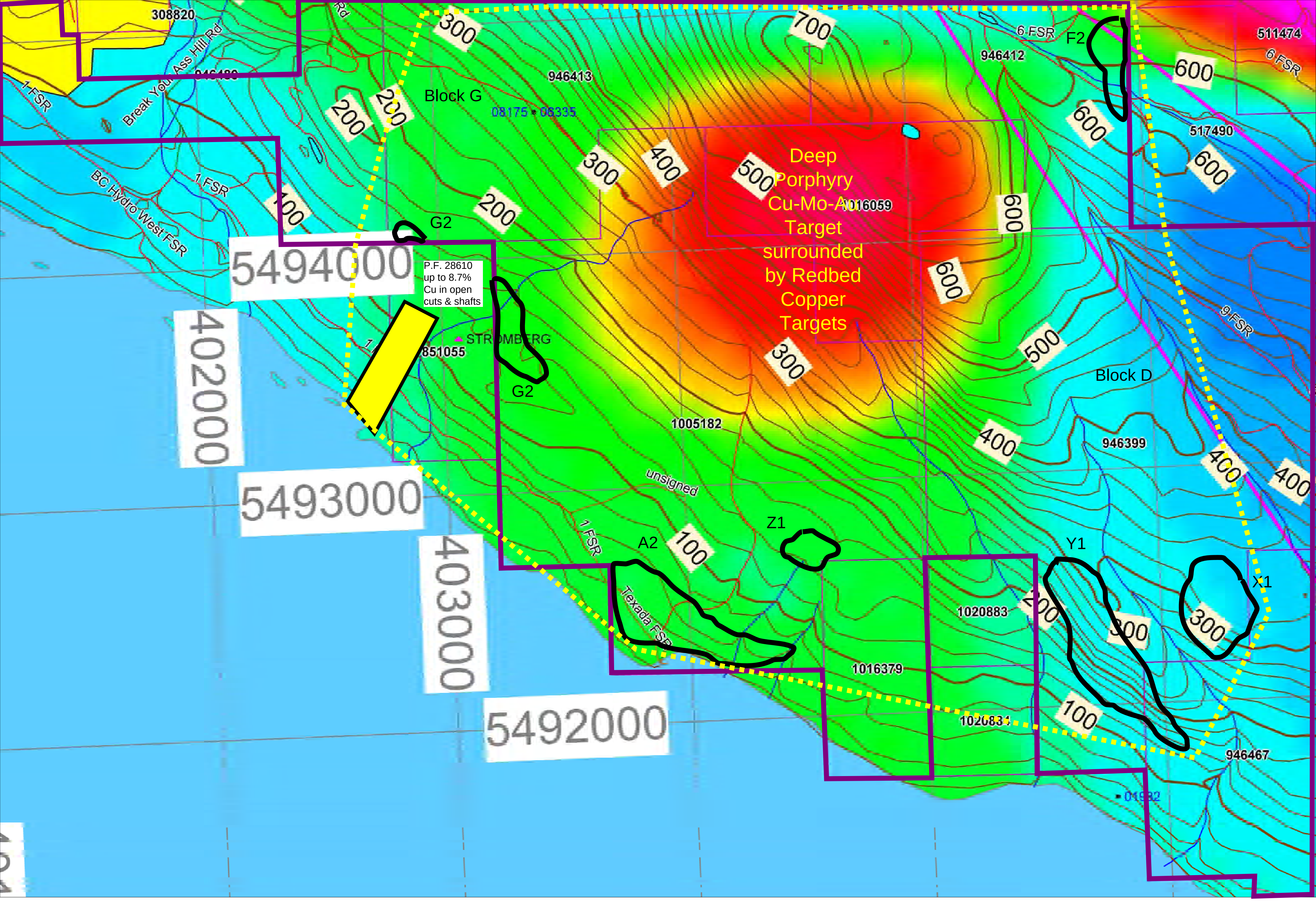


Figure 16

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

A2 ARIS 33841 Remote Sensing Target (Auracle)

Stromberg Target
Southern Texada Island

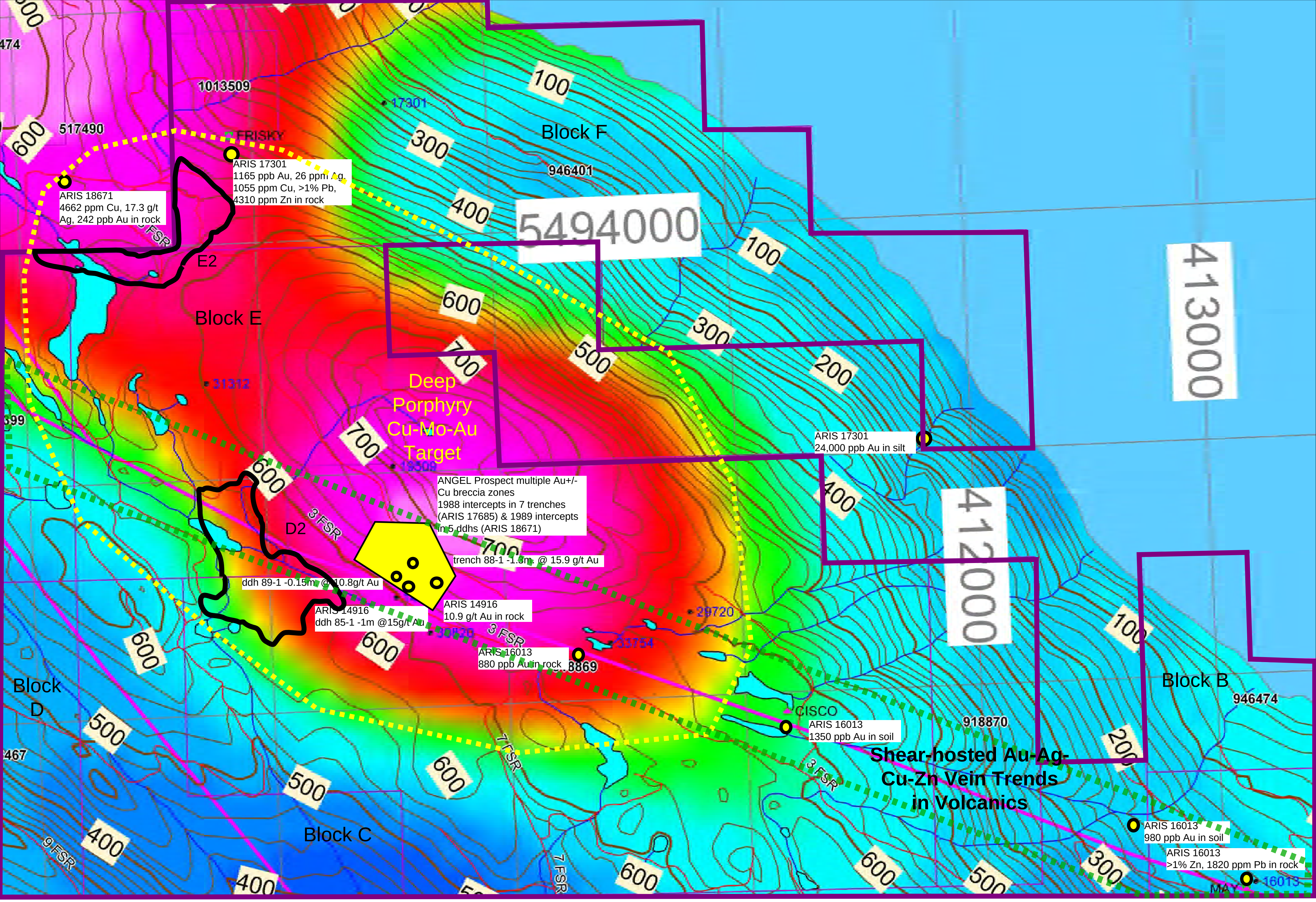


Figure 17

SCALE 1 : 20,000

500 0 500 1,000 1,500

METERS

D2 ARIS 33841 Remote Sensing Target (Auracle)

Angel & Cisco Target
Southern Texada Island

N

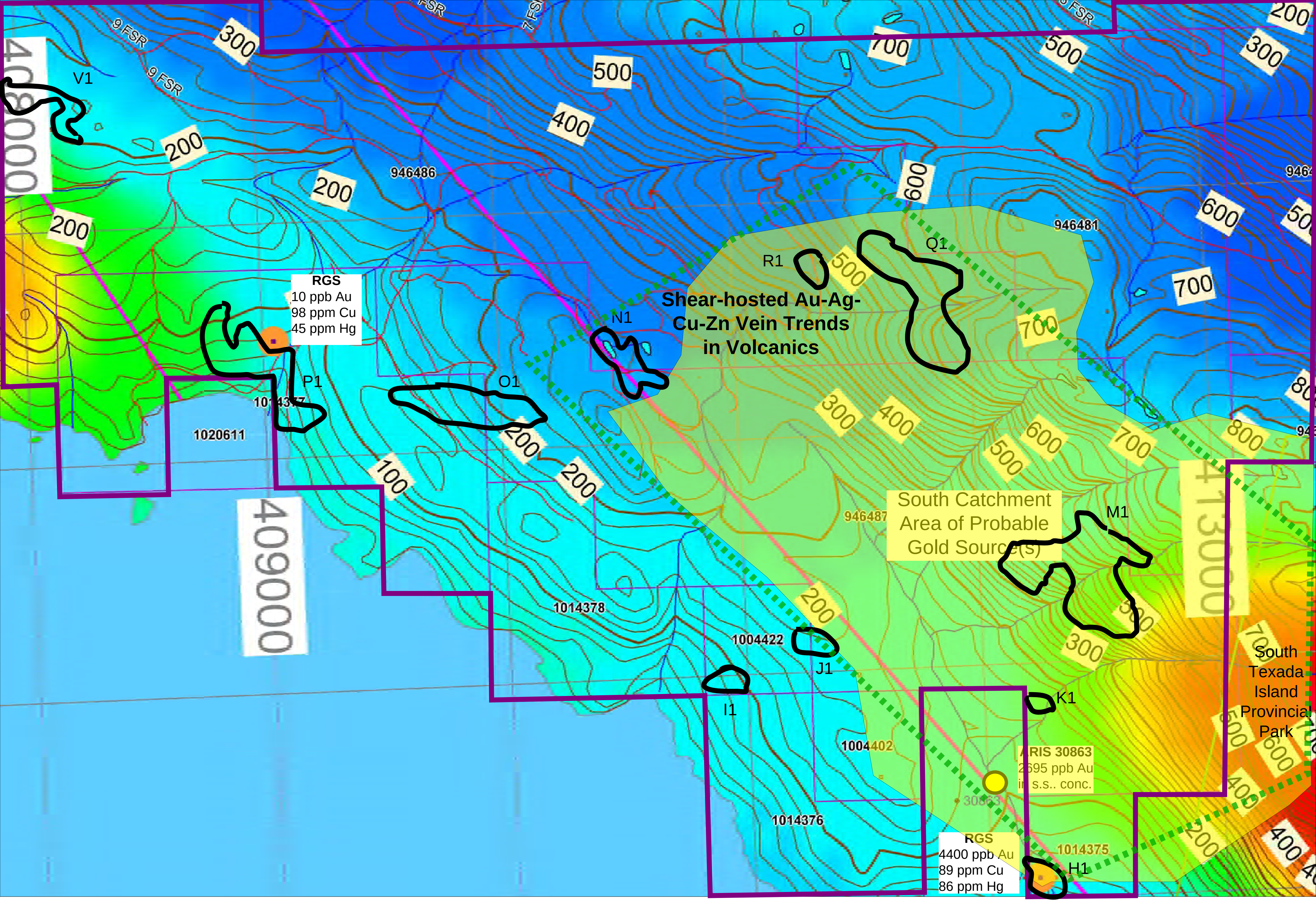


Figure 18

Cook Bay Target
Southern Texada Island

Appendix 1

June 5 2013 Memo from ARIS 33841

Jacques Houle, P.Eng.

Mineral Exploration Consulting

6552 Peregrine Road **ph. (250) 390-3930**

Nanaimo, B.C. V9V 1P8 **jhoule06@shaw.ca**

Memorandum

To: **David McLelland**

From: **Jacques Houle**

Date: **June 5, 2013**

Re. Analysis of Remote Sensing Survey for Coast Minerals Texada Island Project

The geological setting of Texada Island is very similar to that of the northern 90% of Vancouver Island from Duncan to Port Hardy. Layered rocks on Texada Island generally strike northwest and dip to the southwest, and exposures range in age from Devonian 375 million year old (ma) volcanics at the southeast end of the island to late Cretaceous 75 ma Nanaimo Group shales near Gillies Bay. This includes the intervening Permian 275 ma limestones exposed in the southeast, and the Triassic 225 ma Karmutsen volcanics exposed over most of the island, with two gently folded basins of conformably overlying Triassic Quatsino limestones: a major north-south basin at the north end of the island, and a smaller island-parallel basin in the south-central portion.

At least two different ages of granodiorite to diorite intrusive intrusions known to be related to metallic mineral deposits have pierced and extensively underlie the layered rocks of Texada Island. Jurassic 175 ma Island intrusives from Vancouver Island to the southwest, and early Cretaceous 120 ma Coast intrusions from the Sunshine Coast to the northeast. Significant steep faulting has been mapped in 2 main directions, NW-SE and E-W, throughout the island generally with left-lateral displacement of layered units, and unknown vertical displacements or relationships with intrusive units.

Metallic mineral deposits (excludes sedimentary limestone, shale or aggregate) of Texada Island consist of 4 main types:

1. Skarn (iron and/or copper, silver and gold) generally related to limestones at or near contacts with intrusions, found in northwest Texada Island
2. Porphyry (copper/gold and/or copper/molybdenum) closely related to intrusions, found in eastern Texada Island
3. Quartz Veins (gold, silver) related to shear and fault structures found throughout the island, and probably genetically related to intrusions
4. Redbed (copper, silver) hosted in volcanics in the south, and probably young in age resulting from weathering and secondary re-deposition of copper and silver

The area covered by the Texada Project excludes all historic metallic mineral past producers and developed prospects. Between 1896 and 1976, 13 skarn deposits located on northern Texada Island produced 21 million tonnes averaging 0.16 g/t gold, 1.9 g/t silver, 0.17% copper and 45% iron, according to BC MINFILE production records. In the BC MINFILE inventory records for developed prospects, iron is not documented and only 2 metallic occurrences host non-NI43-101 compliant inventories in gold-bearing copper skarns:

1. Little Billie MINFILE 092F105 - 181,420 tonnes averaging 11.65 g/t gold, 34.28 g/t silver and 2% copper
2. Yew MINFILE 092F516 – 102,329 tonnes averaging 13.66 g/t gold, 1.45% copper

Records of historic exploration and development work are very extensive and well documented in the BC Assessment Reports (ARIS) and BC Minister of Mines reports, with good work dating back to the late 1800's. The period of most significant modern exploration on Texada Island was from 1988 to 1991, by three major international mining companies: Freeport McMoRan Gold Corp., Echo Bay Mines Ltd. and BP Resources Canada Ltd. They targeted gold-bearing copper skarn, porphyry copper-gold and gold quartz vein deposits, and stopped exploring in B.C. in the early 1990's when most other companies also left B.C., but left excellent records in ARIS.

Dean Bombardier began acquiring cell mineral claims on Texada Island in February, 2012 on behalf of Coast Minerals Corporation. Coast Minerals directly or indirectly holds 78 partially contiguous mineral tenures covering 18,161 hectares on Texada Island, located 100 km northwest of Vancouver, B.C. These tenures cover about 75% of Texada Island, including many BC MINFILE occurrences, and areas of work programs documented in many BC ARIS reports. The Texada Island Project is the largest mineral claim property every assembled on Texada Island.

Both radar and spectral remote sensing data was compiled and fused by Auracle over the Texada Island Project area. Many structural features were identified in the radar data, including geological contacts and faults previously mapped and interpreted by BC government geologists, refinements of some of those known structures, and newly identified structures. Both metallic and alteration mineral classifications were reviewed and polygons were drawn around areas of unique mineral classifications. Eighty three (83) metallic mineral polygons were identified and labeled, and represent potential prospecting targets. Twenty eight (28) alteration mineral polygons were identified, but not labeled, and in some cases surround or link metallic mineral targets. Some of the structures identified also link or follow the boundaries of metallic mineral targets or MINFILE occurrences.

Additional work is required to integrate MINFILE, ARIS and other publicly available data with the remote sensing metallic mineral targets, followed by prioritization of those targets, and then systematic ground-truthing by prospecting, stream moss mat geochemistry and possible targeted field exploration programs.

Appendix 2

Selected BC Mineral Deposit Profiles

B.C. Home

Ministry of Energy, Mines and Petroleum Resources

Contact Information
Aggregate
Exploration
Geoscience

What's New in Geoscience
- Aggregates

ARIS Assessment Reports
- Bedrock Mapping
- Coal
- Educational Resources
- Exploration and Mines
- Geochemistry
- Geophysical Data
- Geoscience Agencies
- Geoscience Mailbox
- Hiring
- Industrial Minerals
- MapPlace

MINFILE Mineral Inventory
- Metallic Minerals
- Mineral Deposit Profiles
  - Introduction
  - List by Deposit Group
    - A – Organic
    - B - Residual/Surficial
    - C - Placer
    - D - Continental Sediments and Vocanics
    - E - Sediment-Hosted
    - F - Chemical Sediment

D - Continental Sediments and Volcanics

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
D01	Open-system zeolites	- -	25oa
D02	Closed-basin zeolites	- -	25ob
D03	Volcanic redbed Cu	Basaltic Cu	23
D04	Basal U	- -	- -
D05*	Sandstone U	Roll front U, Tabular U	30c
D06	Volcanic-hosted U	Epithermal U, Volcanogenic U	25f
D07	Iron oxide breccias & veins ±P±Cu±Au ±Ag±U	Olympic Dam type, Kiruna type	29b,25i

OPEN-SYSTEM ZEOLITES

D01

by R.A. Sheppard [1] and G.J. Simandl [2]

[1]United States Geological Survey, Federal Center, Denver, Colorado, USA

[2]British Columbia Geological Survey, Victoria, B.C., Canada

Sheppard, R.A. and Simandl, G.J. (1999): Open-system Zeolites; in Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals, G.J. Simandl, Z.D. Hora and D.V. Lefebure, Editors, British Columbia Ministry of Energy and Mines, 1999-10.

IDENTIFICATION

SYNONYM: In the field it may be practically impossible to distinguish these deposits from burial metamorphic zeolites.

COMMODITIES: Clinoptilolite, mordenite, chabazite, phillipsite, heulandite.

EXAMPLES: (**British Columbia (MINFILE #) - *Canada/ International***): Clinoptilolite, Asp Creek (092HSE164), Bromley Vale Zeolite (092HSE166), Tailings Tephra (092HSE167), Sunday Creek (092HSE168); *clinoptilolite, John Day Formation, (Oregon, USA), clinoptilolite and mordenite, Miocene Paintbrush Tuff, Calico Hills and Crater Flat Tuffs, Nye County (Nevada, USA), phillipsite and chabazite, Yellow tuffs near Naples (Italy), clinoptilolite, Death Valley Junction, (California, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Microcrystalline zeolites (clinoptilolite, chabazite, mordenite,

- G - Marine Volcanic Association
- H - Epithermal
- I - Vein, Breccia and Stockwork
- J - Manto
- K - Skarn
- L - Porphyry
- M - Ultramafic / Mafic
- N - Carbonatites
- O - Pegmatite
- P - Metamorphic-hosted
- Q - Gems and Semi-precious Stones
- R - Industrial Rocks
- S - Other
- Lithological Listing
- Listing by Commodity
- Published Index
- Guidelines to Authors
- Selected Profiles
- All Deposit Groups
- Ordering Publications
- Examples of Deposits
- Mineral Potential
- Partnerships
- Property File
- Publications Catalogue
- Surficial Geology and Hazards
- Terrain and Soil Maps
- Staff: Cordilleran Experts

Health and Safety

History of Mining in B.C.

Legislation

Mineral Statistics

Mineral Titles

phillipsite) hosted by relatively thick, generally non-marine, tephra sequences. The ore zones are 10s to 100s of metres thick and commonly exhibit a more or less vertical zonation of zeolites and associated silicate minerals within the host sequence. The zeolites crystallized in the post-depositional environment over periods ranging from thousands to millions of years.

TECTONIC SETTINGS: Active or unmetamorphosed, continental, arc-related or other insular volcanic complexes.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Non-marine and shallow marine basins in volcanic terrains. Depositional basins may be fault bound. Many deposits form in fluviatile and lacustrine volcanic sequences, but some are hosted by shallow marine or subaerial tuffaceous deposits. Typical regional depositional environments contain thick sequences of vitric tuffs affected by diagenesis or very low grade metamorphism.

AGE OF MINERALIZATION: Mesozoic to Holocene, but most are Cenozoic. Zeolite deposits in British Columbia are Cretaceous or Tertiary.

HOST/ASSOCIATED ROCK TYPES: The zeolite-bearing rocks are hosted by volcanic ash and tuff beds with minor intercalated flows. Silicic tuffs commonly were deposited as non-welded ash flows. Other rock types include fluviatile mudstone, sandstone, conglomerate and diatomite.

DEPOSIT FORM: Stratabound, stratiform or lens-shaped, mineral zonation may cross-cut the bedding. Thickness of the zeolitic tuffs in major deposits may range from 100's to 1000's of metres. Areal extent is commonly 100's to 1000's of square kilometres. Minor deposits and minable portions of above described zeolitic tuffs may be less than 30 metres in thickness.

TEXTURE/STRUCTURE: Finely crystalline, commonly bedded, similar to bedded diatomite or bentonite. The common local attribute is vertical zonation of authigenic silicate minerals. In silicic tuff sequences, the alkali-rich siliceous zeolites (clinoptilolite and mordenite) in the upper part of the deposit are commonly replaced at depth by analcime, potassium feldspar and/or albite. A similar sequence occurs in burial diagenetic deposits.

ORE MINERALOGY (Principal and *subordinate*): Clinoptilolite, chabazite, mordenite, phillipsite.

GANGUE MINERALOGY (Principal and *subordinate*): Authigenic smectite, mixed layer illite-smectite, opal - (cristobalite/tridymite), quartz, plagioclase, microcline, sanidine, biotite, muscovite, calcite; pyrogenic crystal fragments, volcanic rock fragments, unreacted vitric material.

ALTERATION MINERALOGY: Zeolitization is the ore forming process (see ore mineralogy). Early zeolite minerals are further modified during burial diagenesis. In silicic tuff sequences, the alkali-rich siliceous zeolites (clinoptilolite and mordenite) in the upper part of the deposit are commonly replaced at depth by analcime, potassium feldspar and/or albite. In some cases the zonation may be enhanced or overprinted by hydrothermal alteration related to intrusive activity.

WEATHERING: Zeolitic tuffs commonly resist weathering and may be ledge formers.

ORE CONTROLS: Grain size and permeability of host tuff; flow of meteoric water downward in an open hydrologic system; hydrolysis and solution of vitric material by the subsurface water in the upper part of the system raised the pH, activity of SiO_2 and content of dissolved solids to values where zeolites crystallized. These result in a vertical or near-vertical zonation of zeolites and other authigenic minerals. Composition of the vitric material and the characteristics of the solutions may have dictated which zeolite species precipitated. For example, clinoptilolite and mordenite are common in silicic tuffs, but chabazite and phillipsite are common in mafic or trachytic tuffs. In many cases the composition of the glassy protolith is believed to determine the mineralogy of the deposit. Trachyte to phonolite glassy protoliths with low Si/Al ratios (£ 3.0) may favour the formation of phillipsite and chabazite, while a more felsic protolith may favour formation of clinoptilolite. Chabazite forms within the systems characterized by low Na/K ratio, whereas phillipsite dominates where the protolith has a high Na/K ratio. Conversion of zeolite to an assemblage of alkali feldspar-quartz can occur at a later stage if the stability field of zeolites is exceeded.

ASSOCIATED DEPOSIT TYPES: Deposits that may occur in the same geographic area include pumice (R11), bentonite (E06), diatomaceous earth (F06), volcanic-hosted precious opal (Q11), peat (A01) and coal (A02 and possibly A03).

GENETIC MODELS: It is nearly universally accepted that zeolite formation is linked to syn- and post- depositional reaction of volcanic glass with relatively alkaline solutions. The zonation of the open-system type of zeolite deposit is in many cases similar to the upper zones of burial diagenesis (burial metamorphism) that affected thick sequences of silicic, vitric tuffs. Zeolitization temperatures are believed to be less than 100° C, but higher temperatures are estimated for some of the deposits. In many cases, there is controversy as to whether the fluids are "low temperature hydrothermal solutions", "diagenetic fluids" or "heated meteoritic waters". The genetic process probably varies from one deposit to an other. There may be some overlap between different fluid types in the same deposit and also in the terminology used by individual authors.

COMMENTS: In British Columbia, clinoptilolite is a major constituent of zeolite deposits.

Permitting and Reclamation

Regional Offices

Sustainability

EMPR

Minister of State for Mining

Electricity and Alternative Energy Division

Marketing, Aboriginal & Community Relations

Mineral Exploration and Mining

Oil & Gas

Titles

Library

Publications

Electricity Policy and Development

Ministry Contacts

Links and Related Organizations

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: None recognized. In most cases, zeolites can be detected and positively identified only by direct analytical techniques, such as x-ray diffraction. Lithogeochemistry may be a useful tool.

GEOPHYSICAL SIGNATURE: Possible use of color-composite imagery from airborne multispectral scanner data to distinguish zeolitic tuffs.

OTHER EXPLORATION GUIDES: Very low grade or unmetamorphosed volcaniclastic sequences typically containing large proportions of ignimbrites. Vertical zonation of zeolites and associated authigenic silicate minerals in thick (100s to 1000s of metres) tuffaceous sequences. This vertical zonation commonly is (from top to bottom) unaltered vitric material - smectite to clinoptilolite to mordenite to opal-(cristobalite-tridymite) to analcime to potassium feldspar to quartz and then to albite and quartz. This zonation may cut across bedding.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The value of zeolite deposits varies depending on the end product use and zeolite species present. Properties, such as cation exchange capacity for radionuclides, heavy metals or NH+4, are more meaningful than grade. This is because these properties are commonly different for the same zeolite species originating from two distinct deposits. The zeolite content of better deposits currently mined is estimated to have zeolite content above 60 %, but may reach over 80%. Deposits supplying materials to control the odor to local farms may have zeolite content well below 50%, but must be close to the market.

ECONOMIC LIMITATIONS: Virtually all mines are open pit. The cost of the transportation to the market is the most important non-technical parameter. The Si/Al ratio, cation exchange capacity and adsorption capacity for various gases are important technical parameters. Hardness and attrition resistance of zeolitic tuff (commonly affected by abundance of opal-cristobalite-tridymite or quartz) are important in processing and end use. Crystal size of the zeolite is < 2m m to 30m m and can affect the adsorption of gases and the extent and rapidity of cation exchange. Color (due to iron staining) and the abundance of non-zeolitic minerals may limit use. Environmental regulations vary from one jurisdiction to another. Some of the zeolite minerals such as erionite and mordenite may be classified as asbestiform. Free silica occurs commonly in the zeolite ores. Excessive concentrations of asbestiform particles or free silica in the ground product may limit its marketability.

END USES: Natural zeolites are used for effluent treatment, mine waste management, pet litter, barn deodorizers, soil conditioners, aquaculture, animal feed additive and construction materials, including pozzolan materials. Higher-priced synthetic zeolites dominate in manufacturing, oil industry / chemical applications and detergent industry. Natural zeolites are used in ion-exchange and adsorption applications, for example, clinoptilolite to remove NH4+ in tertiary sewage treatment and phillipsite to remove Cs and Sr from radioactive materials. Removal of heavy metals from industrial and mine drainage, currently achieved by direct addition of lime or soda, may be done in the future by zeolites. Heavy metal removal, particularly in acid mine drainage, has potential for a growing market.

IMPORTANCE: Important sources of natural clinoptilolite and mordenite. Bentonite, attapulgite and other materials known for their high absorbency may be cost effective alternatives to zeolites for specific ion exchange applications.

REFERENCES

Broxton, D.E., Bish, D.L. and Waren, R.G. (1987): Distribution and Chemistry of Diagenetic Minerals at Yucca Mountain, Nye County, Nevada; Clays and Clay Minerals, Volume 35, pages 89-110.
Colella, C. (1996): Ion Exchange Equilibria in Zeolite Minerals; Mineralium Deposita, Volume 31, pages 554-562.
de'Gennarro, M. and Langella, A. (1996): Italian Zeolitized Rocks of Technological Interest; Mineralium Deposita, Volume 31, pages 452-472.
Ghiara, M.R., Franco, E., Luxoro, S., Gnazzo, L. (1995): Diagenetic Clinoptilolite from Pyroclastic Flows of Northern Sardinia; in Proceedings III, Convegno Nazionale di Scienza e Tecnologia delle zeoliti, Cetraro, Sept. 1995: De Rose Montalto, Cosenza; Editor R. Aiello, pages 349-353.
Gottardi, G. and Obradovic, J. (1978): Sedimentary Zeolites in Europe; Fortschritte der Mineralogie, Volume 56, pages 316-366.
Hay, R.L. (1963): Stratigraphy and Zeolitic Diagenesis of the John Day Formation of Oregon; Berkley, University of California Publications in Geological Sciences, Volume 42, pages 1999-262.
Hay, R.L., and Sheppard, R.A. (1981): Zeolites in Open Hydrologic Systems; in Mineralogy and Geology of Natural Zeolites, F.A. Mumpton, Editor, Mineralogical Society of America Reviews in Mineralogy, Volume 4, pages 93-102.
Holmes, D.A. (1994): Zeolites; in Industrial Minerals and Rocks, 6th edition , D.D. Carr, Senior Editor, Society for Mining, Metallurgy and Exploration, Inc., Littleton, Colorado, pages 1129-1158.
Mumpton, F.A. (1983): Commercial Utilization of Natural Zeolites; in; Industrial Minerals and Rocks, S.J. Lefond, Chief Editor, American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, pages 1418-1431.
Pansini, M. (1996): Natural Zeolites as Cation Exchangers for Environmental Protection; Mineralium Deposita, Volume 31, pages 563-575.
Sheppard, R.A. (1991): Descriptive Model of Sedimentary Zeolites - Deposit Subtype: Zeolites in Tuffs of Open Hydrologic Systems; in Some Industrial Mineral Deposit Models: Descriptive

Deposit Models, G.J. Orris and J.D. Bliss, Editors, U.S. Geological Survey, Open-File Report 91-11A, pages 13-15.
Sheppard, R.A. (1985): Death Valley Junction - Ash Meadows Zeolite Deposit, California and Nevada: 1985 International Clay Conference, Field Trip Guidebook, pages 51-55.
Stamatakis, M.G., Hall, A., and Hein, J.R. (1996): The Zeolite deposits of Greece; Mineralium Deposita, Volume 31, pages 473-481.
Temel, A. and Gundogdu, M.N. (1996): Zeolite Occurrences and the Erionite-mesothelioma Relationship in Cappadocia, Central Anatolia, Turkey; Mineralium Deposita, Volume 31, pages 539-547.

[Back to top]

CLOSED-BASIN ZEOLITES

D02

by R.A. Sheppard [1] and G.J. Simandl [2]
[1]United States Geological Survey, Federal Center, Denver, Colorado, USA
[2]British Columbia Geological Survey, Victoria, B.C., Canada

Sheppard, R.A. and Simandl, G.J. (1999): Closed-basin Zeolites; in Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals, G.J. Simandl, Z.D. Hora and D.V. Lefebure, Editors, British Columbia Ministry of Energy and Mines, Open File 1999-10.

IDENTIFICATION

SYNONYMS: "Closed-system" zeolite deposits.

COMMODITIES: Analcime, chabazite, clinoptilolite, erionite, mordenite, phillipsite.

EXAMPLES: (**British Columbia (MINFILE #) - *Canada/International***): *Lake Tecopa (California, USA), Bowie Deposit (Arizona, USA), Jersey Valley Deposit (Nevada, USA), Lake Magadi (Kenya).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Microcrystalline zeolite-bearing vitric tuff that consists chiefly of analcime, chabazite, clinoptilolite, mordenite, phillipsite and sometimes erionite. Deposit may consist of one or several stacked zeolite layers separated by sub-economic or barren beds.

TECTONIC SETTINGS: Varied tectonic settings. Closed hydrographic basins in either block-faulted terrains (such as the Basin and Range province), trough valleys associated with rifting (such as the Eastern Rift Valley of Kenya) or as Tibet-type grabens formed in a compression environment (such as Emet and Kirka basins, Turkey).

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: These deposits form in lacustrine basins that receive silica-rich, vitric, volcanic material. The saline lake water is commonly of sodium carbonate-bicarbonate variety, with a pH of 9 or greater. These lakes are common in arid and semi-arid regions where annual evaporation exceeds rainfall.

AGE OF MINERALIZATION: Late Paleozoic to Holocene; most deposits are Cenozoic.

HOST/ASSOCIATED ROCK TYPES: Most favourable hostrocks are rhyolitic to dacitic, vitric tuffs, especially those that are alkali-rich. Associated rocks are bedded evaporites (trona, halite, borates), mudstone, diatomite, bedded or nodular Magadi-type chert, oil shale, conglomerates and sandstones.

DEPOSIT FORM: Stratabound; several distinct, overlying beds may be zeolitized. The thickness of the zeolitic tuffs commonly ranges from 10 cm to 10 m. Areal extent is commonly tens to hundreds of square kilometres.

TEXTURE/STRUCTURE: Finely crystalline individual tuff beds show lateral zonation from unaltered glass near the shore, to zeolites and then to potassium feldspar in the center of the paleobasin.

ORE MINERALOGY (Principal and *subordinate*): Analcime, chabazite, clinoptilolite, erionite, mordenite, phillipsite. Several of these ore minerals commonly coexist within a given deposit.

GANGUE MINERALOGY (Principal and *subordinate*): Authigenic smectite, mixed layer illite/smectite, silica (opal, cristobalite/tridymite), quartz, searlesite, dawsonite, potassium feldspar, ± calcite, ± dolomite, biotite, sanidine, sodic plagioclase, hornblende, volcanic glass.

ALTERATION MINERALOGY: In certain highly alkaline and saline lacustrine deposits, siliceous and alkalic zeolites have been replaced during late burial diagenesis by analcime or potassium

feldspar in the central part of the basin.
WEATHERING: Zeolitic tuffs resist weathering and are ledge formers in the lacustrine sequence. Local yellow to brown stains related to hydrous iron oxides.

ORE CONTROLS: Chemical composition of the protolith glass and grain size and permeability of the host vitric tuff are the key parameters. Salinity, pH, and ratios of alkali and alkaline-earth ions in the pore water are other important factors. Zeolite deposits are not preserved in rocks where metamorphism exceeded zeolite facies conditions.

ASSOCIATED DEPOSIT TYPES: Continental-basin bedded evaporites (trona, halite, borates), diatomite (F06), and finely crystalline, disseminated fluorite in lacustrine rocks. Li-rich trioctahedral smectites (hectorite, saponite and stevensite) may be closely associated with borates.

GENETIC MODELS: Microcrystalline zeolites form during early diagenesis of silicic, vitric tuffs deposited in closed hydrographic basins. The zeolites crystallize in the post-depositional environment over thousands to hundreds of thousands of years by reaction of the vitric material with saline, alkaline pore water trapped during lacustrine sedimentation. Locally, zeolites also form from detrital clays, feldspar, and feldspathoids and from chemically precipitated aluminosilicate gels in the same depositional environment.

COMMENTS: There are zeolite-bearing tuffs in British Columbia, however, no associated evaporite minerals, no boron enrichment, and no lateral zonation characteristic of closed-basin zeolites are reported.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: The lacustrine environment of sodium carbonate-bicarbonate type that is favourable for closed basin zeolites may also be enriched in boron and lithium.

GEOPHYSICAL SIGNATURE: Possible use of color-composite imagery from airborne multispectral scanner data to distinguish zeolitic alteration.

OTHER EXPLORATION GUIDES: Unmetamorphosed or very low metamorphic-grade environments. Molds of evaporitic minerals, associated dolomitic mudstone, occurrence of Magadi-type chert. Concentric zonation and lateral gradation in a basinward direction of unaltered volcanic glass to alkali-rich, silicic zeolites to analcime and then to potassium feldspar in the central part of the depositional basin. Zeolites are finely crystalline and resemble bedded diatomite, feldspar or bentonite in outcrop. Combination of X-Ray diffraction and ammonia cation exchange capacity (CEC) are essential in the early screening of zeolite prospects.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The cutoff grade varies greatly. For example, a 10 to 20 centimetre thick ore bed at Bowie contains 60 to 80% chabasite. Obviously, this zone would not have been economic if the main ore mineral was clinoptilolite. Most of the commercial clinoptilolite deposits contain between 50% and 90% zeolite.

ECONOMIC LIMITATIONS: Distance to the market is an important limitation for materials used in agricultural and construction applications. High-value specialty zeolites are international travelers. Production is typically from open pits with as much as 30 m of overburden. Mining costs reported by Holmes (1994) vary from US$ 3 to 6 per ton. Ground natural zeolites are selling for US$30 to 120 for low-value industrial use, but small tonnages of specialty products for the radioactive waste market can sell for more than $US 1000.00 per ton. Environmental regulations vary from one jurisdiction to an other. Some of the zeolite minerals, such as erionite and mordenite, may be classified as asbestiform, a designation that reduces the market for the product. Free silica occurs commonly in the zeolite ores. Excessive concentrations of free silica or fibrous particles in the ground product may severely limit its marketability.

END USES: Zeolites have many agricultural uses, for example as preservative agents (desiccants), soil conditioners, fertilizer extenders, herbicides, pesticide and fungicide carriers, animal food additives and odor controllers. They are used in aquaculture for ammonia removal. Other uses are as dimension stone, light weight aggregate, pozzolan and for treatment processes, such as natural gas purification, nuclear waste treatment and disposal, and oil spill, sewage and effluent cleanup. Chabazite and clinoptilolite are used in heat exchange systems. Most of the non-construction uses are based on the ion-exchange and adsorption properties of zeolites. Cation exchange capacity and adsorption capacity for various gases are important. For example, chabazite is used to remove CO_2 and H_2S from sour natural gas while clinoptilolite can remove NH4+ in tertiary sewage treatment and in pet-litter and base metals from effluents. The Si/Al ratio and exchangeable cation ratios of the zeolites affect certain uses. Crystallite size of the zeolite is < 2 m m to 30 m m and can affect the adsorption of gases and the extent and rapidity of cation exchange.

IMPORTANCE: This deposit type contains the largest variety of zeolite species and it is an important source of chabazite, erionite, and phillipsite. Naturally occuring zeolites are substantially less expensive than synthetic zeolites; however, the latter are preferred in many applications because they are monomineralic, have less variability in product properties, or have useful properties that can not be matched by natural products. Bentonite, attapulgite, activated carbon, silica gel are viable substitutes for zeolite in a number of applications.

REFERENCES

Colella, C. (1996): Ion Exchange Equilibria in Zeolite Minerals; Mineralium Deposita, Volume 31, pages 554-562.
Gündogdu, M.N., Yalçin, H., Temel, A. and Claue, N. (1996): Geological, Mineralogical and Geochemical Characteristics of Zeolite Deposits Associated with Borates in the Bigadiç, Emet and Kirka Neogene Lacustrine Basins, Western Turkey; Mineralium Deposita, Volume 31, pages 492-513.
Gottardi, G. and Obradovic, J. (1978): Sedimentary Zeolites in Europe; Fortschritte der Mineralogie, Volume 56, pages 316-366.
Holmes, D.A. (1994): Zeolites; in Industrial Minerals and Rocks, 6th edition , D.D. Carr, Senior Editor, Society for Mining, Metallurgy and Exploration, Inc., Littleton, Colorado, pages 1129-1158.
Ibrahim, K. and Hall, A. (1996): The Authigenic Zeolites of the Aritayn Volcanic Formation, Northeast Jordan; Mineralium Deposita, Volume 31, pages 514-522.
Mumpton, F.A. (1983): Commercial Utilization of Natural Zeolites; in; Industrial Minerals and Rocks, S.J. Lefond, Chief Editor, American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, pages 1418-1431.
Pansini, M. (1996): Natural Zeolites as Cation Exchangers for Environmental Protection; Mineralium Deposita, Volume 31, pages 563-575.
Sheppard, R.A. (1991): Zeolitic Diagenesis of Tuffs in the Miocene Chalk Hills Formation, Western Snake River Plain, Idaho; U.S. Geological Survey, Professional Paper 1963, 27 pages.
Sheppard, R.A. (1982): Model for Zeolites in Alkaline-Lake Deposits; Characteristics of Mineral Deposit Occurrences, compiled by R.L. Erickson, U.S. Geological Survey, Open-File Report 82-795, pages 241-243.
Sheppard, R.A. and Gude, A.J., 3rd (1968): Distribution and Genesis of Authigenic Silicate Minerals in Tuffs of Pleistocene Lake Tecopa, Inyo Country, California; U.S. Geological Survey, Professional Paper 547, 38 pages.
Sheppard, R.A. and Gude, A.J., 3rd (1973): Zeolites and associated Authigenic Silicate Minerals in Tuffaceous Rocks of the Big Sandy Formation, Mohave County, Arizona; US. Geological Survey, Professional Paper 830, 36 pages.
Surdam, R.C. and Sheppard, R.A. (1978): Zeolites in Saline, Alkaline-Lake Deposits; in: Natural Zeolites: Occurrences, Properties, Use, L.B. Sand and F.A. Mumpton, Editors, Pergamon Press, New York, pages 145-174.
Temel, A. and Gundogdu, M.N. (1996): Zeolite Occurrences and the Erionite-mesothelioma Relationship in Cappadocia, Central Anatolia, Turkey; Mineralium Deposita, Volume 31, pages 539-547.

[Back to top]

VOLCANIC REDBED Cu

D03

by D.V. Lefebure and B.N. Church
British Columbia Geological Survey

Lefebure, D.V. and Church, B.N. (1996): Volcanic Redbed Cu, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallic Deposits, Lefebure, D.V. and Hõy, T, Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 5-7.

IDENTIFICATION

SYNONYMS: Basaltic Cu, volcanic-hosted copper, copper mantos.

COMMODITIES (*BYPRODUCTS*): Cu (Ag)

EXAMPLES (**British Columbia - *Canada/International***): Sustut Copper (094D 063), Shamrock (092HNE092), NH (093L 082), North Star (094D 032); *White River (Yukon, Canada), 47 Zone and June, Coppermine River area (Northwest Territories, Canada) Mountain Grill and Radovan (Alaska, USA), Calumet-Hecla and Kearsarga, Keweenaw Peninsula (Michigan, USA), Mantos Blancos, Ivan and Altamira (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Chalcocite, bornite and/or native copper occur in mafic to felsic volcanic flows, tuff and breccia and related sedimentary rocks as disseminations, veins and infilling amygdules, fractures and flowtop breccias. Some deposits are tabular, stratabound zones, while others are controlled by structures and crosscut stratigraphy.

TECTONIC SETTINGS: These deposits occur in intracontinental rifts with subaerial flood basalt sequences and near plate margins with island-arc and continental-arc volcanics.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Continental to shallow-marine volcanic settings which formed in “low to intermediate latitudes” with arid to semi-arid environments. The metamorphic grade is sub-greenschist.

AGE OF MINERALIZATION: Proterozoic to Tertiary.

HOST/ASSOCIATED ROCK TYPES: Amygdaloidal basaltic lavas, breccias and coarse volcaniclastic beds with associated volcanic tuffs, siltstone, sandstone and conglomerate are the most common rock types. The volcanics may cover the spectrum from basalt to rhyolite composition. Redbed sedimentary rocks are common and often exhibit shallow water sedimentary structures (small-scale crossbedding, mud cracks, algal mats). Any of these units may host the deposits, although typically it is the mafic volcanics that have widespread elevated background values of copper due to the presence of native copper or chalcocite in amygdules, flow breccias or minor fractures.

DEPOSIT FORM: Many deposits are tabular lenses from a few to several tens of metres thick which are roughly concordant with the host strata over several hundred metres. Other deposits are strongly influenced by structural controls and crosscut the stratigraphy as veins, veinlets, fault breccias and disseminated zones.

TEXTURE/STRUCTURE: Disseminations, open-space fillings, veins and some replacement textures. Open spaces may be amygdules, cavities in flowtop breccias or fractures. Mineralization is commonly fine-grained, although spectacular examples of copper "nuggets" are known.

ORE MINERALOGY (Principal and *subordinate*): Chalcocite, bornite, native copper, digenite, djurleite, chalcopyrite, covellite, native silver and greenockite. Iron sulphides, including pyrite, typically peripheral to the ore. Some deposits are zoned from chalcocite through bornite and chalcopyite to fringing pyrite. Copper-arsenic minerals, such as domeykite, algodonite and whitneyite, occur in fissure veins in the Keewenaw Peninsula.

GANGUE MINERALOGY (Principal and *subordinate*): Typically minor gangue; hematite, magnetite, calcite, quartz, epidote, chlorite and zeolite minerals.

ALTERATION MINERALOGY: Generally no associated alteration, although many deposits occur in prehnite-pumpellyite grade regionally metamorphosed volcanic rocks with minerals such as calcite, zeolites, epidote, albite, prehnite, pumpellyite, laumontite and chlorite.

WEATHERING: These deposits commonly have no associated gossans or alteration; locally minor malachite or azurite staining.

ORE CONTROLS: Deposits appear to be confined to subaerial to shallow-marine volcanic sequences commonly with intercalated redbeds. One of the major ore controls is zones of high permeability due to volcaniclastics, breccias, amygdules and fractures.

ASSOCIATED DEPOSIT TYPES: Sediment-hosted copper deposits (E04) often occur in the same stratigraphic sequences. The carbonate-hosted copper deposits at Kennicott, Alaska are associated with basaltic Cu deposits in the Nikolai greenstone.

GENETIC MODELS: Most authors have favoured metamorphism of copper-rich, mafic volcanic rocks at greater depth for the source of the metal-bearing fluids, and subsequent deposition higher in the stratigraphic sequence, in oxidized subaerial hostrocks at lower metamorphic grade. More recently analogies have been drawn to diagenetic models for sediment-hosted Cu deposits which predate the metamorphism. Low-temperature fluids migrating updip along permeable strata to the margins of basins, or along structures, deposit copper upon encountering oxidized rocks. These rocks are typically shallow-marine to subaerial volcanic rocks which formed in arid and semi-arid environments. Both models require oxidized rocks as traps, which requires the presence of an oxygen-rich atmosphere; therefore, all deposits must be younger than ~2.4 Ga.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Simple ore mineralogy produces a very specific geochemical signature for Cu and usually Ag. Lithogeochemical and stream sediment samples may return high values of CuñAg, typically high Cu/Zn ratios and low gold values.

GEOPHYSICAL SIGNATURE: Induced polarization surveys can be used to delineate mineralized lenses and areas of more intense veining.

OTHER EXPLORATION GUIDES: Malachite-staining. A red liverwort-like organism (Tentopholia iolithus) is often found in abundance on the surface of outcrops with copper mineralization in northern British Columbia.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The deposits range in size from hundreds of thousands to hundreds of millions of tonnes grading from less than 1% Cu to more than 4% Cu. Silver values are only reported for some deposits and vary between 6 and 80 g/t Ag. Sustut contains 43.5 Mt grading 0.82% Cu. The Calumet conglomerate produced 72.4 Mt grading 2.64% Cu.

ECONOMIC LIMITATIONS: Only a few deposits have been high enough grade to support underground mines and the majority of occurrences are too small to be economic as open pit operations.

IMPORTANCE: The Keweenaw Peninsula deposits in Michigan produced 5 Mt of copper between 1845 and 1968. Otherwise production from basaltic copper deposits has been limited; the only currently operating mines producing significant copper are in Chile. However, there are numerous deposits of this type in British Columbia which underlines the potential to find significant copper producers.

REFERENCES

Butler, B.S. and Burbank, W.S. (1929): The Copper Deposits of Michigan; U.S.Geological Survey, Professional Paper 144, 238 pages.
Cox, D.P. (1986): Descriptive Model of Basaltic Cu; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 130.
Kindle, E.D. (1972): Classification and Description of Copper Deposits, Coppermine River; Geological Survey of Canada, Bulletin 214, 109 pages.
Kirkham, R.K. (1984): Volcanic Redbed Copper; in Canadian Mineral Deposit Types, A Geological Synopsis, Eckstrand, O.R., Editor, Geological Survey of Canada, Economic Geology Report 36, page 37.
Kirkham, R.K. (in press): Volcanic Redbed Copper; in Geology of Canadian Mineral Deposit Types, Eckstrand, O.R., Sinclair, W.D. and Thorpe, R.I., Editors, Geological Survey of Canada, Geology of Canada, Number 8, pages 243-254.
Lortie, R.H. and Clark, A.H. (1987): Strata-bound Cupriferous Sulphide Mineralization associated with Continental Rhyolitic Volcanic Rocks, Northern Chile: I. The Jardin Silver Copper-Silver Deposit; Economic Geology, Volume 82, pages 546-570.
Sato, T. (1984): Manto Type Copper Deposits in Chile; Bulletin of the Geological Society of Japan, Volume 35, pages 565-582.
Sood, M.K., Wagner, R.J. and Markazi, H.D. (1986): Stratabound Copper Deposits in East South-central Alaska: Their Characteristics and Origin; in Geology and Metallogeny of Copper Deposits, Friedrich, G.H. et al., Editors, Springer- Verlag, Berlin, pages 422-442.
White, W.S. (1968): The Native-Copper Deposits of Northern Michigan; in Ore Deposits of the United States, 1933-1967; The Graton-Sales Voume, Ridge, J.D., Editor, American Institute of Mining, Metallurgy and Petroleum Engineers, Inc., New York, pages 303-325.
Wilton, D.H.C. and Sinclair, A.J. (1988): The Geology and Genesis of a Strata-bound Disseminated Copper Deposit at Sustut, British Columbia, Economic Geology, Volume 83, pages 30-45.

[Back to top]

IRON OXIDE BRECCIAS AND VEINS P-Cu-Au-Ag-U

D07

by David V. Lefebure
British Columbia Geological Survey

Lefebure, D.V. (1995): Iron Oxide Breccias and Veins P-Cu-Au-Ag-U, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 33-36.

IDENTIFICATION

SYNONYMS: Olympic Dam type, Kiruna type, apatite iron ore, porphyrite iron (Yangtze Valley), iron oxide rich deposits, Proterozoic iron oxide (Cu-U-Au-REE), volcanic-hosted magnetite.

COMMODITIES (*BYPRODUCTS*): Fe, P, Cu, Au, Ag, U (potential for REE, Ba, F).

EXAMPLES (British Columbia - *Canada/International*): Iron Range (082FSE014; 082FSE015; 082FSE016; 082FSE017; 082FSE018; 082FSE019; 082FSE020; 082FSE021; 082FSE022; 082FSE023; 082FSE024; 082FSE025; 082FSE026; 082FSE027; 082FSE028); *Sue-Dianne (Northwest Territories, Canada); Wernecke breccias (Yukon, Canada), Kiruna district(Sweden),* *Olympic Dam (Australia), Pea Ridge and Boss-Bixby (Missouri, USA), El Romeral (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite and/or hematite breccia zones and veins which form pipes and tabular bodies hosted by continental volcanics and sediments and intrusive rocks. The deposits exhibit a wide range in their nonferrous metal contents. They vary from Kiruna type monometallic (Fe ± P) to Olympic Dam type polymetallic (Fe ± Cu ± U ± Au ± REE).

TECTONIC SETTING: Associated with stable cratons, typically associated with grabens related to rifting. Intracratonic extensional tectonics coeval with hostrock deposition. Upper crustal igneous or sedimentary rocks.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Found crosscutting a wide variety of sedimentary and igneous rocks; magnetite-apatite deposits show an affinity for volcanics and associated hypabyssal rocks.

AGE OF MINERALIZATION: Proterozoic to Tertiary and believed to be virtually contemporaneous with associated suite of intrusive and/or volcanic rocks. Polymetallic Fe oxide deposits are commonly mid-Proterozoic age varying from 1.2 to 1.9 Ga.

HOST / ASSOCIATED ROCK TYPES: Veins and breccias crosscut, or are conformable with, a wide variety of continental sedimentary and volcanic rocks and intrusive stocks, including felsic volcanic breccia, tuff, clastic sedimentary rocks and granites. There may be a special association with a felsic alkalic rock suite ranging from “red” granite, and rapakivi granite to mangerite and charnockite and various volcanic equivalents. Fe oxides have been reported as common accessories in the associated igneous rocks. In some deposits the Fe oxide forms the matrix to heterolithic breccias which are composed of lithic and oxide clasts (usually hematite fragments), hematite-quartz microbreccia and fine-grained massive breccia. Some deposits have associated hematite-rich breccias, bedded Fe oxides and Fe oxide-bearing volcanic rocks which are conformable with associated volcanic rocks. Magnetite lavas and feeder dikes exist on the El Laco volcano in Chile. . DEPOSIT FORM: Discordant pod-like zones, veins (dike-like), tabular bodies and stockworks; in some deposits dikes are overlain by Fe oxide tuffs and flows. The veins and tabular zones extend horizontally and vertically for kilometres with widths of metres to hundreds of metres.

TEXTURE / STRUCTURE: Cu-U-Au mineralization is typically hosted in the Fe oxide matrix as disseminations with associated microveinlets and sometimes rare mineralized clasts. Textures indicating replacement and microcavity filling are common. Intergrowths between minerals are common. Hematite and magnetite may display well developed crystal forms, such as interlocking mosaic, tabular or bladed textures. Some of the deposits (typically hematite rich) are characterized by breccias at all scales with Fe oxide and hostrock fragments which grade from weakly fractured hostrock on the outside to matrix-supported breccia (sometimes heterolithic) with zones of 100% Fe oxide in the core. Breccias may be subtle in hand sample as the same Fe oxide phase may comprise both the fragments and matrix. Breccia fragments are generally angular and have been reported to range up to more than 10 m in size, although they arefrequently measured in centimetres. Contacts with hostrocks are frequently gradational over scale of centimetres to metres. Hematite breccias may display a diffuse wavy to streaky layered texture of red and black hematite.

ORE MINERALOGY (Principal and *subordinate*): The deposits vary between magnetite-apatite deposits with actinolite or pyroxene (Kiruna type) and hematite-magnetite deposits with varying amounts of Cu sulphides, Au, Ag, uranium minerals and REE (Olympic Dam type). Hematite (variety of forms), specularite, magnetite, bornite, chalcopyrite, chalcocite, pyrite; digenite, covellite, native copper, carrolite, cobaltite, Cu-Ni-Co arsenates, pitchblende, coffinite, brannerite, bastnaesite, monazite, xenotime, florencite, native silver and gold and silver tellurides. At Olympic Dam, Cu is zoned from a predominantly hematite core (minor chalcocite-bornite) to chalcocite-bornite zone then bornite-chalcopyrite to chalcopyrite-pyrite in the outermost breccia. Uraninite and coffinite occur as fine-grained disseminations with sulphides; native gold forms fine grains disseminated in matrix and inclusions in sulphides. Bastnaesite and florencite are very fine grained and occur in matrix as grains, crystals and crystal aggregates.

GANGUE MINERALOGY (Principal and *subordinate*): Gangue occurs intergrown with ore minerals, as veins or as clasts in breccias. Sericite, carbonate, chlorite, quartz, fluorite, barite, and sometimes minor rutile and epidote. Apatite and actinolite or pyroxene with magnetite ores (Kiruna type). Hematite breccias are frequently cut by 1 to 10 cm veins with fluorite, barite, siderite, hematite and sulphides.

ALTERATION MINERALOGY (Principal and *subordinate*): A variety of alteration assemblages with differing levels of intensity are associated with these deposits, often with broad lateral extent. Olympic Dam type: Intense sericite and hematite alteration with increasing hematite towards the centre of the breccia bodies at higher levels. Close to the deposit the sericitized feldspars are rimmed by hematite and cut by hematite veinlets. Adjacent to hematite breccias the feldspar, rock flour and sericite are totally replaced by hematite. Chlorite or k-feldspar alteration predominates at depth. Kiruna type: Scapolite and albite?; there may also be actinolite-epidote alteration in mafic wallrocks. With both types of deposits quartz, fluorite, barite, carbonate, rutile, orthoclase ± epidote and garnet alteration are also reported.

WEATHERING: Supergene enrichment of Cu and U, for example, the pitchblende veins in the Great Bear magmatic zone.

ORE CONTROLS: Strong structural control with emplacement along faults or contacts, particularly narrow grabens. Mid-Proterozoic rocks particularly favourable hosts. Hydrothermal activity on faults with extensive brecciation. May be associated with felsic volcanic and alkalic igneous rocks. In some deposits calderas and maars have been identified or postulated. Deposits may form linear arrays more than 100 km long and 40 km wide with known deposits spaced 10-30 km along trend.

ASSOCIATED DEPOSIT TYPES: Volcanic-hosted U (D06); alkaline porphyry Cu-Au deposits (L03); supergene uranium veins.

COMMENTS: Hitzman et al. (1992) emphasize that these are low-Ti iron deposits, generally less than 0.5% TiO_2 and rarely above 2% TiO_2 which allows distinction from Fe oxides associated with anorthosites, gabbros and layered mafic intrusions. Fe and Cu sulphides may be more common with hematite Fe oxides.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalously high values for Cu, U, Au, Ag, Ce, La, Co, ± P, ± F, and ± Ba in associated rocks and in stream sediments.

GEOPHYSICAL SIGNATURE: Large positive gravity anomalies because of Fe oxides. Regional aeromagnetic anomalies related to magnetite and/or coeval igneous rocks. Radiometric anomaly (such as airborne gamma-ray spectrometer survey) expected with polymetallic deposits containing uranium.

OTHER EXPLORATION GUIDES: Proterozoic faulting with associated Fe oxides (particularly breccias), possibly related to intracratonic rifting. Widespread hematite, sericite or chlorite alteration related to faults. Possibly form linear arrays 100 or more kilometres long and up to tens of kilometres wide.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Deposits may exceed 1000 Mt grading greater than 20 % Fe and frequently are in 100 to 500 Mt range. Olympic Dam deposit has estimated reserves of 2000 Mt grading 1.6% Cu, 0.06% U_3O_8, 3.5 g/t Ag and 0.6 g/t Au with a measured and indicated resource in a large number of different ore zones of 450 Mt grading 2.5% Cu, 0.08 % U_3O_8, 6 g/t Ag and 0.6 g/t Au with ~5,000 g/t REE. The Ernest Henry deposit in Australia contains 100 Mt at 1.6% Cu and 0.8 g/t Au. Sue-Dianne deposit in the Northwest Territories contains 8 Mt averaging 0.8% Cu and 1000 g/t U and locally significant gold. The Kiruna district contains more than 3000 Mt of Fe oxide apatite ore grading 50-60% Fe and 0.5 -5 % P. The largest orebody at Bayan Obo deposit in Inner Mongolia, China contains 20 Mt of 35 % Fe and 6.19% REE.

ECONOMIC LIMITATIONS: Larger Fe oxide deposits may be mined for Fe only; however, polymetallic deposits are more attractive.

IMPORTANCE: These deposits continue to be significant producers of Fe and represent an important deposit type for producing Cu, U and possibly REE.

REFERENCES

ACKNOWLEDGEMENTS: This deposit profile represents the results of a literature review. The only "ground truthing" is thanks to instructive conversations with Sunil Gandhi of the Geological Survey of Canada and Tom Setterfield of Westminer Canada Ltd.

Cox, D.P. (1986): Descriptive Model of Olympic Dam Cu-U-Au; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, 379 pages.
Einaudi, M.T. and Oreskes, N. (1990): Progress Toward an Occurrence Model for Proterozoic Iron Oxide Deposits - A Comparison Between the Ore Provinces of South Australia and Southeast Missouri; in The Midcontinent of the United States - Permissive Terrane for an Olympic Dam Deposit?, Pratt, W.P. and Sims, P.K. Editors, U. S. Geological Survey, Bulletin 1392, pages 589-69.
Gandhi, S.S. (1994): Geological Setting and Genetic Aspects of Mineral Occurrences in the Southern Great Bear Magmatic Zone, Northwest Territories; in Studies of Rare- metal Deposits in the Northwest Territories, Sinclair, W.D. and Richardson, D.G, Editors, Geological Survey of Canada, Bulletin 475, pages 63-96.
Gandhi, S.S. and Bell, R.T. (1993): Metallogenetic Concepts to Aid in Exploration for the Giant Olympic Dam Type Deposits and their Derivatives; Proceedings of the Eighth Quadrennial IAGOD Symposium, in Ottawa, Ontario, August 12-18, 1990, International Asssociation on the Genesis of Ore Deposits, Maurice, Y.T., Editor, Schweizerbar'sche Verlagsbuchhandlung, Stutggart, pages 787-802.
Hauck, S.A. (1990): Petrogenesis and Tectonic Setting of Middle Proterozoic Iron Oxide- rich Ore Deposits; An Ore Deposit Model for Olympic Dam Type Mineralization; in The Midcontinent of the United States - Permissive Terrane for an Olympic Dam Deposit?, Pratt, W.P. and Sims, P.K. Editors, U. S. Geological Survey, Bulletin 1932, pages 4-39.
Hildebrand, R.S. (1986): Kiruna-type Deposits: Their Origin and Relationship to Intermediate Subvolcanic Plutons in the Great Bear Magmatic Zone, Northwest Canada; Economic Geology, Volume 81, pages 640-659.
Hitzman, M. W., Oreskes, N. and Einaudi, M. T. (1992): Geological Characteristics and Tectonic Setting of Proterozoic Iron Oxide (Cu-U-Au-REE) Deposits; Precambrian Research, Volume 58, pages 241-287.
Laznicka, P. and Gaboury, D. (1988): Wernecke Breccias and Fe, Cu, U Mineralization: Quartet Mountain-Igor Area (NTS 106E); in Yukon Exploration and Geology, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, pages 42-50.
Oreskes, N. and Einaudi, M.T. (1990): Origin of Rare Earth-enriched Hematite Breccias at the Olympic Dam Deposit, Roxby Downs, South Australia; Economic Geology, Volume 85, pages 1-28.
Parak, T. (1975): Kiruna Iron Ores are not "Intrusive-magmatic Ores of the Kiruna Type"; Economic Geology, Volume 68, pages 210 -221.
Reeve, J.S., Cross, K.C., Smith, R.N. and Oreskes, N. (1990): Olympic Dam Copper- Uranium-Gold-Silver Deposit; in Geology of

the Mineral Deposits of Australia and Papua New Guinea, Hughes, F.E., Editor, The Australasian Institute of Mining and Metallurgy, pages 1009-1035.
Research Group of Porphyrite Iron Ore of the Middle-Lower Yangtze Valley (1977): Porphyrite Iron Ore - A Genetic Model of a Group of Iron Ore Deposits in Andesitic Volcanic Area; Acta Geological Sinica, Volume 51, No. 1, pages 1-18.
Roberts, D.E. and Hudson, G.R.T. (1983): The Olympic Dam Copper-Uranium-Gold Deposit, Roxby Downs, South Australia; Economic Geology, Volume 78, pages 799-822.

** Note: All BC deposit profile #s with an asterisk have no completed deposit profile. USGS deposit model #s with an asterisk had no published model in the late 1990s.*

Examples of Continental and Volcanic Deposits

BC Profile #	Global Examples	B.C. Examples
D01	Ash Meadows (California), John Day Formation (Oregon)	Princeton Basin, Cache Creek area
D02	Bowie (Arizona), Lake Magadi (Kenya)	
D03	Keewenaw (Michigan), Coppermine (Northwest Territories)	Sustut Copper, Shamrock, NH
D04	Sherwood (Washington)	Blizzard, Tyee
D05*	Colorado Plateau, Grants (New Mexico)	- -
D06	Marysvale (Utah), Aurora (Oregon)	Rexspar, Bullion (Birch Island)
D07	El Romeral (Chile), Sue-Dianne (Northwest Territories)	Iron Range

Top

BRITISH COLUMBIA
The Best Place on Earth

Search [ ] Go
All B.C. Government Ministry of Energy, Mines and Petroleum Resources

Advanced Search | Help | Contact Us Text Size A A

News | The Premier Online | Ministries & Organizations | Job Opportunities | Main Index

B.C.Home » Ministry Home » Mineral Exploration a ... » Geoscience » Mineral Deposit Profiles » List by Deposit Group » H - Epithermal Printer Version

B.C. Home

Ministry of Energy, Mines and Petroleum Resources

- Contact Information
- Aggregate
- Exploration
- Geoscience
- What's New in Geoscience
- Aggregates
- ARIS Assessment Reports
- Bedrock Mapping
- Coal
- Educational Resources
- Exploration and Mines
- Geochemistry
- Geophysical Data
- Geoscience Agencies
- Geoscience Mailbox
- Hiring
- Industrial Minerals
- MapPlace
- MINFILE Mineral Inventory
- Metallic Minerals
- Mineral Deposit Profiles
  - Introduction
  - List by Deposit Group
    - A – Organic
    - B - Residual/Surficial
    - C - Placer
    - D - Continental Sediments and Vocanics
    - E - Sediment-Hosted
    - F - Chemical Sediment
    - G - Marine Volcanic Association
    - H - Epithermal
    - I - Vein, Breccia and Stockwork
    - J - Manto
    - K - Skarn
    - L - Porphyry
    - M - Ultramafic / Mafic

H - Epithermal

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
H01	Travertine	Tufa	35d*
H02	Hot spring Hg	- -	27a
H03	Hot spring Au-Ag	- -	25a
H04	Epithermal Au-Ag-Cu; high sulphidation	Acid-sulphate, qtz-alunite Au, Nansatsu-type	25d
H05	Epithermal Au-Ag; low sulphidation	Adularia-sericite epithermal	25c
H06*	Epithermal Mn	- -	25g
H07	Sn-Ag veins	Polymetallic Sn veins	25h, 20b
H08	Alkalic intrusion-associated Au	Alkalic intrusion-related Au, Au-Ag-Te veins	22b
H09	Hydrothermal alteration clays-Al-Si	Kaolin, Alunite, Siliceous cap, Pyrophyllite	25lb*

TRAVERTINE

H01

by Z.D. Hora
British Columbia Geological Survey

Hora, Z.D. (1996): Travertine, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 29-30.

IDENTIFICATION

SYNONYMS: Tufa, calcareous sinter; certain varieties also referred to as onyx marble or Mexican onyx.

COMMODITIES (*BYPRODUCTS*): Decorative stone, building stone products, soil conditioner, agriculture lime; onyx marble.

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Clinton (092P 079), Slocan (082KSW074, 075), Wishing Well (Deep River, 094N 001); *Gardiner (Montana, USA), Salida (Colorado, USA), Bridgeport (California, USA); Lazio, Tuscany (Italy); Pamukkale (Turkey); Mexico, Spain, Iran.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Mounds, sheets, sometimes terraced, shallow lake in-fills, valley in-fill.

TECTONIC SETTING: Young orogenic belts with carbonate sediments in the subsurface; thrusts and faults with deep water circulation. Also intercontinental rift zones with strike-slip faulting, with or without associated volcanic activity.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Subaerial precipitation of calcium carbonate from mineral springs; also in shallow lacustrine basins with influx of mineralized CO2-rich water. Hotspring waters which give rise to travertine deposits usually do not originate at temperatures in excess of 100oC. Circulating ground waters are channeled by thrusts, faults and fractured rocks and mineralized by dissolution of subsurface carbonate rocks.

AGE OF MINERALIZATION: Tertiary to recent.

HOST/ASSOCIATED ROCK TYPES: Carbonate rocks in the subsurface; hydrothermal breccia and siliceous sinters, lacustrine sediments, carbonate veins (usually aragonite) in form of "Mexican onyx".

DEPOSIT FORM: Conical mounds, sheets, basin in-fills. As it is deposited by precipitation from warm spring waters, it shows successive layers with sometimes different colours and textures.

May be elongated above underlying feeder zones following faults and breccia zones.

TEXTURE: Banded, porous, brecciated; may be pisolitic. Generally fine-grained carbonate matrix with numerous irregular cavities ranging in size from a pin head to 1 cm or more across. The cavities are usually oriented in lines giving the rock parallel texture. Lacustrine varieties are more massive. The mounds may be criss-crossed by veins of "Mexican onyx", a varicoloured banded aragonite.

ORE MINERALOGY (Principal and *subordinate*): Calcite, aragonite, silica, fluorspar, barite, native sulphur.

WEATHERING: Clay/iron stains filling the voids, joints and bedding planes.

ORE CONTROLS: Commonly developed along high-angle faults and shear zones in young orogenic belts.

GENETIC MODEL: Travertine forms as surface deposits from geothermal systems of generally less than 100oC in temperature. The carbonate deposition results from the loss of some of the carbon dioxide by cooling, evaporation or presence of algae.

ASSOCIATED DEPOSIT TYPES: Hotsprings Au-Ag (H03), Hotspring Hg (H02), marl, solfatara sulphur, geyserite silica.

COMMENTS: To be economically of interest, the size must be suitable to open a quarry face, the carbonate must be recrystallized and cemented to be strong and hard for ornamental stone applications. Sediments of similar texture and composition may occur in karst regions, where the carbonate precipitated from cold water.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Mineral springs with carbon dioxide.

OTHER EXPLORATION GUIDES: Precipitation of tufa from small streams on moss and other organic matter, presence of thermal spring and solfatara exhalations.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Large deposits may reach 1-2 Mt, but even the small deposits of several tens to a hundred thousand tonnes may be of importance for local and custom type work. The travertine has to meet the minimum physical test requirements for intended use.

END USES: Interior and exterior facing, tile, ashlar, custom-made shapes as steps and sills, lapidary work and precious stone applications.

ECONOMIC LIMITATIONS: Even small occurrences can be exploited for local and custom markets.

IMPORTANCE: Locally important facing stone, however the usage does not match marble or granite. Mexican onyx is an important decorative stone.

REFERENCES

Carr, D.D. (1994): Industrial Minerals and Rocks; Society for Mining, Metallurgy, and Exploration, Littleton, Colorado, 1196 pages.
Harben, P.W. and Bates, R.L. (1990): Industrial Minerals Geology and World Deposits; Metal Bulletin, London, 135 pages.
Kuzvart, M. (1984): Deposits of Industrial Minerals; Academia, Prague, 440 pages.
Robbins, J. (198): Italy's Industrial Minerals; Industrial Minerals, No. 255, pages 19- 45.

[Back to top]

HOT SPRING Hg

H02

by A. Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1996): Hot-spring Hg, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 31-32.

IDENTIFICATION

SYNONYMS: (Epithermal) hotspring, subaerial siliceous sinter.

COMMODITIES (*BYPRODUCTS*): Hg, (Au).

EXAMPLES (British Columbia - *Canada/International*): Ucluelet; *Knoxville district, Sulphur Bank (California, USA), McDermitt and Steamboat Springs (Nevada, USA), Abuta mine(Japan).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Uppermost portions of epithermal systems develop clay altered zones and siliceous caps a few metres to hundreds of metres below surface and silica sinter deposits above the groundwater table as hotspring deposits. Travertine ledges and other silica-carbonate accumulations may be present nearby as peripheral or deeper deposits.

TECTONIC SETTING: Continental margin rifting and strike-slip faulting associated with small volume mafic to intermediate volcanism.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Modern and fossil hotspring

Ministry Contacts

Links and Related Organizations

settings with silica and silica-carbonate deposition near the paleo groundwater table and as subaerial silica sinter precipitates.

AGE OF MINERALIZATION: Tertiary and younger; some currently active hotsprings.

HOST/ASSOCIATED ROCK TYPES: Intermediate to basic volcanic flows, tuffs and breccias, minor diabasic dykes; hydrothermal breccias, travertine and siliceous sinters, lacustrine sediments. Country rocks commonly include greywacke, shale and fault-related serpentinized ultramafic bodies.

DEPOSIT FORM: Lensoid hotspring deposits and tabular lithologic replacement zones; commonly with cone- or wedge-like underlying feeder zones centered on regional- scale fault and fracture zones. Commonly less than 300 metres in vertical extent from paleosurface. Locally phreatic explosion pits.

TEXTURE: Disseminated sulphides in country rocks and hydrothermal breccias, quartz stockworks of banded to vuggy, multiple-generation quartz-chalcedony veins. Hydrofracturing textures are common. Less frequently cinnabar occurs as grains, lenses and fracture coatings in opaline silica sinter deposits. In some deposits cinnabar is concentrated on surfaces of wood and other organic matter.

ORE MINERALOGY (Principal and *subordinate*): Cinnabar, pyrite, native sulphur and mercury, stibnite, gold, marcasite.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, chalcedony; opal, carbonate, iron oxides, manganese oxides.

ALTERATION MINERALOGY (Principal and *subordinate*): Kaolinite, alunite, Fe-Mn oxides and sulphur above water table (minor amounts of cinnabar). Opaline quartz deposited at the water table, with cinnabar. Quartz, pyrite, zeolites, chlorite and minor adularia below the water table; silica-carbonate ñ magnesite assemblages in mafic, commonly serpentinized, rocks.

GENETIC MODEL: Deposits form in geothermal systems from near surface hot waters at less than 150§C, and generally cooler. Organic materials in solution and high CO2 vapour concentration may be important in the transporting of elevated amounts of Hg.

ORE CONTROLS: Located just below the paleo groundwater table within hotspring systems. Commonly developed along high-angle faults and generally in young volcanic terranes.

ASSOCIATED DEPOSIT TYPES: Hotspring Au-Ag (H03), epithermal Au-Ag (H04, H05), placer Au (C01, C02).

COMMENTS: There has been little work in recent years on this deposit type other than to examine their potential for related gold deposits, for example, McLaughlin mine in California (Gustafson, 1991). The significant Hg deposits typically contain no other recoverable constituents.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Hg, Sb, As. Generally <5 ppb Au but rare deposits with elevated gold are known.

GEOPHYSICAL SIGNATURE: VLF to identify favourable structures; magnetic lows in mafic volcanic hosts due to alteration envelope.

OTHER EXPLORATION GUIDES: Can be overlain by native sulphur occurrences or hot spring deposits with siliceous sinters and clay-altered rocks. Recent deposits are commonly associated with modern hot springs or geothermal fields. Silica- carbonate alteration with distinctive orange-coloured, amorphous limonite in weathered zones, typically in mafic and serpentized hostrocks.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Commercially exploited deposits tend to be very small; the largest deposits rarely exceed 1 mt in size. The median production from 20 Cordilleran USA mines is <1000 tonnes with 0.35% Hg. Typical mineable reserves contain ores ranging from 0.2 to 0.6% Hg. Productive deposits are Sulphur Bank and 5 small mines in the Knoxville District in California which produced 4, 700 tonnes of Hg and ~5,520 tonnes Hg respectively.

ECONOMIC LIMITATIONS: There probably is no operating mine of this type in the world today.

IMPORTANCE: These are relatively small deposits from near surface geological environments that are easily eroded and therefore rarely preserved. They currently are not important sources of mercury but can be associated with auriferous epithermal deposits.

REFERENCES

Berger, B. (1985): Geologic-Geochemical features of hot-spring precious metal deposits: U.S. Geological Survey, Bulletin 1646, pages 47-53.
Gustafson, D.L. (1991): Anatomy of a Discovery: The McLaughlin Gold Mine, Napa, Yolo, and Lake Counties, California: Economic Geology, Monograph 8, pages 350-359.
Rytuba, J.J. (1986): Descriptive Model of Hot-spring Hg; in Mineral Deposit Models, U.S. Geological Survey, Bulletin 1693, pages 178, 179.
Sherlock, R.L. and Logan, M.A.V. (in press): Silica-Carbonate Alteration of Serpentinite: Implications for the Association of Mercury and Gold Mineralization in Northern California; Exploration and Minining Geology, Canadian Institute of Mining and Metallurgy, in press.
White, D. (1981): Active Geothermal Systems and Hydrothermal Ore Deposits; Economic Geology, 75th Anniversary Volume, pages 392-423.

[Back to top]

HOT-SPRING Au-Ag

H03
by A. Panteleyev

British Columbia Geological Survey

Panteleyev, A.(1996): Hot-spring Au-Ag, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy,T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 33-36.

IDENTIFICATION

SYNONYMS: (Epithermal) hotspring, subaerial siliceous sinter.
COMMODITIES (BYPRODUCTS): Au, (Ag, Hg).

EXAMPLES (British Columbia (MINFILE #) - Canada/International): Cinola (uppermost part, 103F 034), Clisbako (093C 016), Wolf? (093F 045), Trout? (093F 044); McLaughlin (California, USA), Round Mountain (Nevada, USA).

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Auriferous chalcedonic or opaline silica and fine-grained quartz form veins, stockworks and matrix filling in breccias hosted by volcanic and, less commonly, sedimentary rocks. These are the uppermost parts of epithermal systems which develop mineralized siliceous caps a few metres to hundreds of metres below surface with subaerial siliceous sinter deposits at the water table and explosion breccias above.

TECTONIC SETTINGS: Continental margin rifting and district-scale fracture systems with associated bimodal or low volume mafic to intermediate volcanism. Commonly in regions of strike-slip faulting with transform faults and transtensional basin margins. Also extensional tectonism with related caldera development and resurgence, flow-dome complexes and high-level subvolcanic intrusive activity.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Shallow parts of fossil geothermal systems. Hotsprings deposit silica near the paleo groundwater table and as subaerial, ponded precipitates. Deeper fluids are channeled by permeable stratigraphic units, hydrothermal breccia bodies and faulted/fractured rocks. Subaerial volcanic centres including flow-dome or caldera complexes and related radial and ring fracture systems.

AGE OF MINERALIZATION: Tertiary and Quaternary are most common; some currently active hotsprings. Hotspring sinters as old as Late Devonian have been described (Cunneen and Sillitoe, 1989).

HOST/ASSOCIATED ROCK TYPES: Intermediate or bimodal basaltic-rhyolitic volcanics including volcanic flows, flow domes, tuffs and breccias; hydrothermal breccias and siliceous sinters. Any type of permeable or structurally prepared country rock can be mineralized, most commonly ash flow units and caldera-fill sediments. In some cases, serpentinized ultramafic and mafic rocks in major fault zones in areas of post-faulting volcanic activity are mineralized. Sedimentary rocks occur at Cinola and many other deposits.

DEPOSIT FORM: Near-surface, lensoid hotspring deposits and planar lithologic replacement zones. Individual zones are up to hundreds of metres in two dimensions and tens of metres in the third. Underlying these are cone or wedge-like hydrothermal feeder systems with quartz stockworks and veins centred on regional-scale fault and fracture zones, or their splays. Locally phreatic and phreatomagmatic explosion pits formed at the paleosurface.

TEXTURE/STRUCTURE: Generally very fine grained disseminated sulphides in silicified (opalized and chalcedonic) country rocks and silica sinter; hydrothermal breccias, quartz stockworks and banded to vuggy, sheeted, multiple-generation quartz- chalcedony veins. Hydrofracturing textures are common.

ORE MINERALOGY (Principal and subordinate): Pyrite, marcasite, gold, electrum; stibnite, sulphosalt minerals, realgar, cinnabar (cinnibar only near tops of deposits).

GANGUE MINERALOGY (Principal and subordinate): Quartz, chalcedony; opal, calcite, dolomite, barite. Strong silicification with quartz, chalcedony and opal in crustified, banded veins, sheeted veins and stockworks is characteristic in ores. Silica in some deposits contains abundant hydrocarbons that impart a characteristic brownish colour to the quartz.

ALTERATION MINERALOGY (Principal and subordinate): Multiple episodes of silicification to form veins and stockworks, and pervasive silicified hostrocks adjacent to them, is typical. Country rocks containing the silicified zones have argillic and, less commonly, advanced argillic assemblages with quartz-kaolinite and rarely alunite. They are flanked, or underlain, by propylitic rocks with chlorite, Fe oxides, zeolites and minor adularia. Selenite, alunite and other sulphate minerals and native sulphur can be abundant locally near surface.

WEATHERING: Limonite (jarosite, hematite, goethite) is locally prominent near surface in strongly oxidized deposits.

ORE CONTROLS: A key element at the McLaughlin deposit was the superposition of multiple generations of auriferous veinlets each carrying a small amount of gold (Lehrman, 1986).

GENETIC MODEL: Hydrothermal breccias and multiple generations of veins with calcite replacement by silica attest to boiling of hydrothermal fluids as an important ore-depositing mechanism. The boiling levels are related to the paleosurface and commonly have a surficial expression as active or paleo-hotsprings. The deeper hydrothermal fluid systems, generaly within 500 m of surface (paleosurface for older deposits), can be developed along active, regional high-angle faults and other volcanic and subvolcanic intrusion-related structures. The structures commonly cut or flank domes in flow-dome complexes.

ASSOCIATED DEPOSIT TYPES: Hotspring Hg (H02), solfatara sulphur; epithermal Au-Ag (H04, H05), placer Au (C01, C02).

COMMENTS: Many deposits currently being exploited throughout the world have grades between 1 and 2 g/t Au and range from a few to tens of millions of tonnes in size. They are viable generally because the rocks are commonly strongly oxidized and the gold can be recovered by heap leaching methods. The siliceous sinters formed at or very near to the surface rarely contain economic mineralization These deposits have a greater depth extent then hotspring mercury deposits. In their deeper parts they may grade into precious metal bearing and base metal epithermal veins.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, Sb, As, Hg, Tl near surface, increasing Ag, Ba at depth; locally Ni, B, Li and W. The Ag/Au ratio varies from 1:1 at surface to 30:1 at a depth of a few hundred metres. Mineralized rocks can be strongly leached at surface. Notably absent are: Se, Te, F, Mo, Sn and Mn. Base metal content is relatively low, for example, common amounts are Cu <60 ppm, Pb <5 ppm and Zn <450 ppm.

GEOPHYSICAL SIGNATURE: Resistivity, VLF to identify faults.

OTHER EXPLORATION GUIDES: Siliceous sinter can be used to identify the paleosurface; Hg mineralization may overlie deeper gold ores.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Mineralization tends to be low grade. Economically attractive bulk-mineable deposits contain >10 Mt of 1 to 2 g/t Au, or greater. High-grade veins and stockworks within the larger mineralized zones can be exploited by underground methods. The McLaughlin deposit, a superior discovery, contained initial reserves of 17.5 Mt with 5.2 g/t Au and about 16 g/t Ag, including a sheeted vein zone with 2.45 Mt with 9.15 g/t Au. Reserves for Cinola are about 31 Mt with 2.19 g/t Au; the deposit has a feeder zone at depth that contains material containing in excess of 100 g/t Au.

ECONOMIC LIMITATIONS: Refractory primary ore in deposits that lack significant oxidation renders many of the lower grade deposits uneconomic.

IMPORTANCE: Individual deposits are attractive economically, for example, the McLaughlin mine in California.

REFERENCES

Berger, B.R. (1985): Geologic-Geochemical Features of Hot-spring Precious Metal Deposits: U.S. Geological Survey, Bulletin 1646, pages 47-53.
Berger, B.R. (1986): Descriptive Model of Hot-spring Au-Ag; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors,U.S. Geological Survey, Bulletin 1693, page 143.
Cunneen, R. and Sillitoe, R.H. (1989): Paleozoic Hot Spring Sinter in the Drummond Basin, Queensland, Australia; Economic Geology, Volume 84, pages 135-142.
Lehrman, N.J. (1986): The McLaughlin Mine, Napa and Yolo Counties, California; Nevada Bureau of Mines and Geology, Report 41, pages 85-89.
Peters, E.K. (1991): Gold-bearing Hot Spring Systems of the Northern Coast Ranges, California; Economic Geology, Volume 86, pages 1519-1528.
Sillitoe, R.H. (1993): Epithermal Models: Genetic Types, Geometric Controls and Shallow Features; in Ore Deposits Modeling, Geological Association of Canada, Special Volume 40, pages 403-417.
Tosdal, R.M., Enderlin, D.A., Nelson, G.C. and Lehrman, N.J. (1993): Overview of the McLaughlin Precious Metal Deposit, Napa and Yolo Counties, Northern California; in Active and Geothermal Systems and Gold/Mercury Deposits in the Sonoma/Clear Lake Volcanic Fields, California, J.J. Rytuba, Editor, Society of Economic Geologists, Guidebook Series, Volume 16, pages 312-329.
White, D. (1981): Active Geothermal Systems and Hydrothermal Ore Deposits; Economic Geology, 75th Anniversary Volume, pages 392-423.

[Back to top]

EPITHERMAL Au-Ag-Cu: HIGH SULPHIDATION

H04

by A. Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1996): Epithermal Au-Ag-Cu: High Sulphidation, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 37-39.

IDENTIFICATION

SYNONYMS: (Epithermal) acid-sulphate, quartz-alunite Au, alunite-kaolinite ± pyrophyllite, advanced argillic, Nansatsu-type, enargite gold. The deposits are commonly referred to as acid-sulphate type after the chemistry of the hydrothermal fluids, quartz-alunite or kaolinite-alunite type after their alteration mineralogy, or high-sulphidation type in reference to the oxidation state of the acid fluids responsible for alteration and mineralization.

COMMODITIES (BYPRODUCTS): Au, Ag, Cu (As, Sb).

EXAMPLES (British Columbia (MINFILE #) - *International*): Mt. McIntosh/Hushamu (EXPO, 092L 240), Taseko River deposits - Westpine (Empress) (092O 033), Taylor-Windfall (092O 028) and Battlement Creek (092O 005); *Goldfield and Paradise Peak (Nevada, USA), Summitville (Colorado, USA); Nansatsu (Japan), El Indio (Chile); Temora (New South Wales, Australia), Pueblo Viejo (Dominica), Chinkuashih (Taiwan), Rodalquilar (Spain), Lepanto and Nalesbitan (Philippines).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Veins, vuggy breccias and sulphide replacements ranging from pods to massive lenses occur in volcanic sequences associated with high level hydrothermal systems marked by acid-leached, advanced argillic, siliceous alteration.

TECTONIC SETTING: Extensional and transtensional settings, commonly in volcano-plutonic continent-margin and oceanic arcs and back-arcs. In zones with high-level magmatic emplacements where stratovolcanoes and other volcanic edifices are constructed above plutons.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Subvolcanic to volcanic in calderas, flow-dome complexes, rarely maars and other volcanic structures; often associated with subvolcanic stocks and dikes, breccias. Postulated to overlie, and be genetically related to, porphyry copper systems in deeper mineralized intrusions that undelie the stratovolcanoes.

AGE OF MINERALIZATION: Tertiary to Quaternary; less commonly Mesozoic and rarely Paleozoic volcanic belts. The rare preservation of older deposits reflects rapid rates of erosion before burial of subaerial volcanoes in tectonically active arcs.

HOST/ASSOCIATED ROCK TYPES: Volcanic pyroclastic and flow rocks, commonly subaerial andesite to dacite and rhyodacite, and their subvolcanic intrusive equivalents. Permeable sedimentary intervolcanic units can be sites of mineralization.

DEPOSIT FORM: Veins and massive sulphide replacement pods and lenses, stockworks and breccias. Commonly irregular deposit shapes are determined by hostrock permeability and the geometry of ore-controlling structures. Multiple, crosscutting composite veins are common.

TEXTURE/STRUCTURE: Vuggy 'slaggy' silica derived as a residual product of acid leaching is characteristic. Drusy cavities, banded veins, hydrothermal breccias, massive wallrock replacements with fine-grained quartz.

ORE MINERALOGY (Principal and *subordinate*): pyrite, enargite/luzonite, chalcocite, covellite, bornite, gold, electrum; chalcopyrite, sphalerite, tetrahedrite/tennantite, galena, marcasite, arsenopyrite, silver sulphosalts, tellurides including goldfieldite. Two types of ore are commonly present: massive enargite-pyrite and/or quartz-alunite-gold.

GANGUE MINERALOGY (Principal and *subordinate*): Pyrite and quartz predominate. Barite may also occur; carbonate minerals are absent.

ALTERATION MINERALOGY (Principal and *subordinate*): Quartz, kaolinite/dickite, alunite, barite, hematite; sericite/illite, amorphous clays and silica, pyrophyllite, andalusite, diaspore, corundum, tourmaline, dumortierite, topaz, zunyite, jarosite, Al-P sulphates (hinsdalite, woodhouseite, crandalite, etc.) and native sulphur. Advanced argillic alteration is characteristic and can be areally extensive and visually prominent. Quartz occurs as fine-grained replacements and, characteristically, as vuggy, residual silica in acid-leached rocks.

WEATHERING: Weathered rocks may contain abundant limonite (jarosite-goethite-hematite), generally in a groundmass of kaolinite and quartz. Fine-grained supergene alunite veins and nodules are common.

ORE CONTROLS: In volcanic edifices - caldera ring and radial fractures; fracture sets in resurgent domes and flow-dome complexes, hydrothermal breccia pipes and diatremes. Faults and breccias in and around intrusive centres. Permeable lithologies, in some cases with less permeable cappings of hydrothermally altered or other cap rocks. The deposits occur over considerable depths, ranging from high-temperature solfataras at paleosurface down into cupolas of intrusive bodies at depth.

GENETIC MODEL: Recent research, mainly in the southwest Pacific and Andes, has shown that these deposits form in subaerial volcanic complexes or composite island arc volcanoes above degassing magma chambers. The deposits can commonly be genetically related to high-level intrusions. Multiple stages of mineralization are common, presumably related to periodic tectonism with associated intrusive activity and magmatic hydrothermal fluid generation.

ASSOCIATED DEPOSIT TYPES: Porphyry Cu±Mo±Au deposits (L04), subvolcanic Cu-Ag-Au (As- Sb) (L01), epithermal Au-Ag deposits: low sulphidation type (H05), silica-clay- pyrophyllite deposits (Roseki deposits) (H09), hotspring Au-Ag (H03), placer Au deposits (C01, C02).

COMMENTS: High-sulphidation epithermal Au-Ag deposits are much less common in the Canadian Cordillera than low-sulphidation epithermal veins. However, they are the dominant type of epithermal deposit in the Andes.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, Cu, As dominate; also Ag, Zn, Pb, Sb, Mo, Bi, Sn, Te, W, B and Hg.

GEOPHYSICAL SIGNATURE: Magnetic lows in hydrothermally altered (acid-leached) rocks; gravity contrasts may mark boundaries of structural blocks.

OTHER EXPLORATION GUIDES: These deposits are found in second order structures adjacent to crustal-scale fault zones, both normal and strike-slip, as well as local structures associated with subvolcanic intrusions. The deposits tend to overlie and flank porphyry copper-gold deposits and underlie acid-leached siliceous, clay and alunite-bearing ‘lithocaps’.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: There is wide variation in deposit types ranging from bulk-mineable, low-grade to selectively mined, high-grade deposits. Underground mines range in size from 2 to 25 Mt with grades from 178 g/t Au, 109 g/t Ag and 3.87% Cu in direct smelting ores (El Indio) to 2.8 g/t Au and 11.3 g/t Ag and 1.8% Cu (Lepanto). Open pit mines with reserves of <100 Mt to >200 Mt range from Au-Ag mines with 3.8 g/t Au and 20 g/t Ag (Pueblo Viejo, Dominica) to orebodies such as the Nansatsu deposits, Japan that contain a few million tonnes ore grading between 3 and 6 g/t Au. Porphyry Au (Cu) deposits can be overprinted with late-stage acid sulphate alteration zones which can contain in the order of ~1.5 g/t Au with 0.05 to 0.1% Cu in stockworks (Marte and Lobo) or high-grade Cu-Ag-Au veins (La Grande veins, Collahausi). More typically these late stage alteration zones carry <0.4 to 0.9 g/t Au and >0.4 to 2% Cu (Butte, Montana; Dizon, Philippines).

ECONOMIC LIMITATIONS: Oxidation of primary ores is commonly neccessary for desireable metallurgy; primary ores may be refractory and can render low-grade mineralization noneconomic.

IMPORTANCE: This class of deposits has recently become a focus for exploration throughout the circum-Pacific region because of the very attractive Au and Cu grades in some deposits. Silica-rich gold ores (3-4 g/t Au) from the Nansatsu deposits in Japan are used as flux in copper smelters.

REFERENCES

Albino, G.V. (1994): Time-pH-fO2 Paths of Hydrothermal Fluids and the Origin of Quartz-Alunite-Gold Deposits; United States Geological Survey, Bulletin 2081, pages 33- 42.
Berger, B.R. (1986): Descriptive Model of Epithermal Quartz-Alunite Au; in Mineral Deposit Models, Cox, D.P. and Singer, D.A, Editors, U.S. Geological Survey, Bulletin 1693, page 158.
Henley, R.W. (1991): Epithermal Gold Deposits in Volcanic Terranes; in Gold Metallogeny and Exporation, R.P. Foster, Editor, Blackie and Sons Ltd, Glasgow, pages 133-164.
Mosier, D.L. and Menzie, W.D. (1986): Grade and Tonnage Model of Epithermal Quartz-Alunite Au, in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 158.
Panteleyev, A. (1991): Gold in the Canadian Cordillera - A Focus on Epithermal and Deeper Environments, in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B. C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 163-212.
Sillitoe, R.H. (1993): Epithermal Models: Genetic Types, Geometric Controls and Shallow Features; Geological Association of Canada, Special Volume 40, pages 403-417.
White, N.C. (1991): High Sulfidation Epithermal Gold Deposits: Characteristics and a Model for their Origin; in High-temperature Acid Fluids and Associated Alteration and Mineralization, Geological Survey of Japan, Report No. 277, pages 9-20.
White, N.C. and Hedenquist, J.W. (1990): Epithermal Environments and Styles of Mineralization: Variations and their Causes, and Guidelines for Exploration; in Epithermal Gold Mineralization of the Circum-Pacific: Geology, Geochemistry, Origin and Exploration, II, Hedenquist, J.W. , White, N.C. and Siddeley, G., Editors, Journal of Exploration Geochemistry, Volume 36, pages 445-474.

[Back to top]

EPITHERMAL Au-Ag: LOW SULPHIDATION

H05
by A. Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1996): Epithermal Au-Ag: Low Sulphidation, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 41-44.

IDENTIFICATION

SYNONYMS: (Epithermal) adularia-sericite; quartz-adularia, Comstock, Sado-type; bonanza Au-Ag; alkali chloride (hydrothermal).

COMMODITIES (*BYPRODUCTS*): Au, Ag (Pb, Zn, Cu).

EXAMPLES (British Columbia (MINFILE #) - *International*): Toodoggone district deposits - Lawyers (094E 066), Baker (094E 026), Shas (094E 050); Blackdome (092O 050, 092O 051, 092O 052, 092O 053); Premier Gold (Silbak Premier), (104B 054); Cinola (103F 034); *Comstock, Aurora (Nevada, USA), Bodie (California, USA), Creede (Colorado, USA), Republic (Washington, USA), El Bronce (Chile), Guanajuato (Mexico), Sado, Hishikari (Japan), Colqui (Peru), Baguio (Philippines) Ladolam (Lihir, Papua- New Guinea).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Quartz veins, stockworks and breccias carrying gold, silver, electrum, argentite and pyrite with lesser and variable amounts of sphalerite, chalcopyrite, galena, rare tetrahedrite and sulphosalt minerals form in high- level (epizonal) to near-surface environments. The ore commonly exhibits open- space filling textures and is associated with volcanic-related hydrothermal to geothermal systems.

TECTONIC SETTING: Volcanic island and continent-margin magmatic arcs and continental volcanic fields with extensional structures.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level hydrothermal systems from depths of ~1 km to surficial hotspring settings. Regional-scale fracture systems related to grabens, (resurgent) calderas, flow-dome complexes and rarely, maar diatremes. Extensional structures in volcanic fields (normal faults, fault splays, ladder veins and cymoid loops, etc.) are common; locally graben or caldera-fill clastic rocks are present. High-level (subvolcanic) stocks and/or dikes and pebble breccia diatremes occur in some areas. Locally resurgent or domal structures are related to underlying intrusive bodies.

AGE OF MINERALIZATION: Any age. Tertiary deposits are most abundant; in B.C. Jurassic deposits are important. Deposits of Paleozoic age are described in Australia. Closely related to the host volcanic rocks but invariably slightly younger in age (0.5 to 1 Ma, more or less).

HOST/ASSOCIATED ROCK TYPES: Most types of volcanic rocks; calcalkaline andesitic compositions predominate. Some deposits occur in areas with bimodal volcanism and extensive subaerial ashflow deposits. A less common association is with alkalic intrusive rocks and shoshonitic volcanics. Clastic and epiclastic sediments in intra-volcanic basins and structural depressions.

DEPOSIT FORM: Ore zones are typically localized in structures, but may occur in permeable lithologies. Upward-flaring ore zones centred on structurally controlled hydrothermal conduits are typical. Large (> 1 m wide and hundreds of metres in strike length) to small veins and stockworks are common with lesser disseminations and replacements. Vein systems can be laterally extensive but ore shoots have relatively restricted vertical extent. High-grade ores are commonly found in dilational zones in faults at flexures, splays and in cymoid loops.

TEXTURE/STRUCTURE: Open-space filling, symmetrical and other layering, crustification, comb structure, colloform banding and multiple brecciation.

ORE MINERALOGY (Principal and *subordinate*): Pyrite, electrum, gold, silver, argentite; chalcopyrite, sphalerite, galena, tetrahedrite, silver sulphosalt and/or selenide minerals. Deposits can be strongly zoned along strike and vertically. Deposits are commonly zoned vertically over 250 to 350 m from a base metal poor, Au-Ag-rich top to a relatively Ag-rich base metal zone and an underlying base metal rich zone grading at depth into a sparse base metal, pyritic zone. From surface to depth, metal zones contain: Au-Ag-As-Sb-Hg, Au-Ag-Pb-Zn-Cu, Ag- Pb-Zn. In alkalic hostrocks tellurides, V mica (roscoelite) and fluorite may be abundant, with lesser molybdenite.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, amethyst, chalcedony, quartz pseudomorphs after calcite, calcite; adularia, sericite, barite, fluorite, Ca- Mg-Mn-Fe carbonate minerals such as rhodochrosite, hematite and chlorite.

ALTERATION MINERALOGY: Silicification is extensive in ores as multiple generations of quartz and chalcedony are commonly accompanied by adularia and calcite. Pervasive silicification in vein envelopes is flanked by sericite-illite- kaolinite assemblages. Intermediate argillic alteration [kaolinite-illite- montmorillonite (smectite)] formed adjacent to some veins; advanced argillic alteration (kaolinite-alunite) may form along the tops of mineralized zones. Propylitic alteration dominates at depth and peripherally.

WEATHERING: Weathered outcrops are often characterized by resistant quartz ± alunite 'ledges' and extensive flanking bleached, clay-altered zones with supergene alunite, jarosite and other limonite minerals.

ORE CONTROLS: In some districts the epithermal mineralization is tied to a specific metallogenetic event, either structural, magmatic, or both. The veins are emplaced within a restricted stratigraphic interval generally within 1 km of the paleosurface. Mineralization near surface takes place in hotspring systems, or the deeper underlying hydrothermal conduits. At greater depth it can be postulated to occur above, or peripheral to, porphyry and possibly skarn mineralization. Normal faults, margins of grabens, coarse clastic caldera moat-fill units, radial and ring dike fracture sets and both hydrothermal and tectonic breccias are all ore fluid channeling structures. Through-going, branching, bifurcating, anastamosing and intersecting fracture systems are commonly mineralized. Ore shoots form where dilational openings and cymoid loops develop, typically where the strike or dip of veins change. Hangingwall fractures in mineralized structures are particularly favourable for high-grade ore.

GENETIC MODEL: These deposits form in both subaerial, predominantly felsic, volcanic fields in extensional and strike-slip structural regimes and island arc or continental andesitic stratovolcanoes above active subduction zones. Near- surface hydrothermal systems, ranging from hotspring at surface to deeper, structurally and permeability focused fluid flow zones are the sites of mineralization. The ore fluids are relatively dilute and cool solutions that are mixtures of magmatic and meteoric fluids. Mineral deposition takes place as the solutions undergo cooling and degassing by fluid mixing, boiling and decompression.

ASSOCIATED DEPOSIT TYPES: Epithermal Au-Ag: high sulphidation (H04); hotspring Au-Ag (H03); porphyry Cu±Mo±Au (L04) and related polymetallic veins (I05); placer gold (C01, C02).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values in rocks of Au, Ag, Zn, Pb, Cu and As, Sb, Ba, F, Mn; locally Te, Se and Hg.

GEOPHYSICAL SIGNATURE: VLF has been used to trace structures; radiometric surveys may outline strong potassic alteration of wallrocks. Detailed gravity surveys may delineate boundaries of structural blocks with large density contrasts.

OTHER EXPLORATION GUIDES: Silver deposits generally have higher base metal contents than Au and Au-Ag deposits. Drilling feeder zones to hotsprings and siliceous sinters may lead to identification of buried deposits. Prospecting for mineralized siliceous and silica-carbonate float or vein material with diagnostic open-space textures is effective.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The following data describe the median deposits based on worldwide mines and U.S.A. models:

- Au-Ag deposits (41 Comstock-type 'bonanza' deposits) - 0.77 Mt with 7.5 g/t Au, 110 g/t Ag and minor Cu, Zn and Pb. The highest base metal contents in the top decile of deposits all contain <0.1% Cu, Zn and 0.1% Pb
- Au-Cu deposits (20 Sado-type deposits) - 0.3 Mt with 1.3% g/t Au, 38 g/t Ag and >0.3% Cu; 10 % of the deposits contain, on average, about 0.75% Cu with one having >3.2% Cu.

REFERENCES

Buchanan, L.J. (1981): Precious Metal Deposits associated with Volcanic Environments in the Southwest; in Relations of Tectonics to Ore Deposits in the Southern Cordillera; Arizona Geological Society Digest, Volume 14, pages 237-262.
Mosier, D.L., Berger, B.R and Singer, D.A. (1986): Descriptive Model of Sado Epithermal Veins; in Mineral Deposits Models, Cox, D.P. and Singer, D.A., Editors, U. S. Geological Survey, Bulletin 1693, page 154.
Mosier, D.L. and Sato, T. (1986): Grade and Tonnage Model of Sado Epithermal Veins; in Mineral Deposits Models, Cox, D.P. and Singer, D.A., Editors, U. S. Geological Survey, Bulletin 1693, pages 155-157.
Mosier, D.L., Singer, D.A. and Berger, B.R (1986): Descriptive Model of Comstock Epithermal Veins; in Mineral Deposits Models, Cox, D.P. and D.A. Singer, D.A., Editors, U. S. Geological Survey, Bulletin 1693, pages 150-153.
Heald, P., Foley, N.K. and Hayba, D.O. (1987): Comparative Anatomy of Volcanic-Hosted Epithermal Deposits: Acid-Sulfate and Adularia Sericite Types; Economic Geology, Volume 82, pages 1-26.
Mosier, D.L., Sato, T., Page, N.J., Singer, D.A. and Berger, B.R. (1986): Descriptive Model of Creede; in Mineral Deposits Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, pages 145-149.
Panteleyev, A. (1991): Gold in the Canadian Cordillera - A Focus on Epithermal and Deeper Deposits; in Ore Deposits, Tectonic and Metallogeny in the Canadian Cordillera, B.C. Ministry of

Energy, Mines and Petroleum Resources, Paper 1991-4, pages 163-212.
Sillitoe, R.H. (1993): Epithermal Models: Genetic Types, Geometrical Controls and Shallow Features; in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, Geological Association of Canada, Special Paper 40, pages 403-417.
White, N.C. and Hedenquist, J.W. (1990): Epithermal Environments and Styles of Mineralization; Variations and their Causes and Guidelines for Exploration; in Epithermal Gold Mineralization of the Circum-Pacific; Geology, Geochemistry, Origin and Exploration, II; Hedenquist, J.W., White, N.C. and Siddeley, G., Editors, Journal of Geochemical Exploration, Volume 36, pages 445-474.

[Back to top]

Sn-Ag VEINS

H07

by A. Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1996): Epithermal Au-Ag: Low Sulphidation, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 45-48.

IDENTIFICATION

SYNONYMS: Polymetallic Sn veins, Bolivian polymetallic veins, polymetallic tin-silver deposits, polymetallic xenothermal.

COMMODITIES (*BYPRODUCTS*): Ag, Sn (Zn, Cu, Au, Pb, Cd, In, Bi, W).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): D zone (104P 044, 080,081) and Lang Creek veins ('Pant', 104P 082), Cassiar district; *Cerro Rico de Potosi, Oruro, Chocaya, (Bolivia), Pirquitas (Argentina), Ashio, Akenobe and Ikuno (Japan).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Sulphide and quartz-sulphide veins carrying cassiterite, a wide variety of other base metals and zones with silver minerals. They are associated with epizonal (subvolcanic) quartz-bearing intrusions, or their immediate hostrocks. In some places the ore is in volcanic rocks within dacitic to quartz latitic flow-dome complexes.

TECTONIC SETTING: Continental margin; synorogenic to late orogenic belts with high-level plutonism in intermediate to felsic volcanoplutonic arcs. In British Columbia the only significant Sn-bearing deposits occur with S or A-type granites in eastern tectonic assemblages underlain by continental rocks of North American origin.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: In faults, shears and fractures that cut or are proximal to high-level felsic intrusions and in flow-dome complexes, namely domes and their surrounding tuff rings and explosive breccias.

AGE OF MINERALIZATION: Tertiary in the type area of Bolivia; Cretaceous and Tertiary in Japan; Tertiary and older in British Columbia.

HOST/ASSOCIATED ROCK TYPES: Hostrocks for veins can be of any type and do not appear to be an important control on the occurrence of the deposits; they include sedimentary, volcanic and intrusive rocks and sometimes, metasedimentary rocks at depth. Intrusive rocks with which the mineralization is associated are quartz bearing and peraluminous, but seem to be restricted to intermediate compositions between 60 and 70% SiO_2 (dacite to rhyodacite); more felsic rocks are present, but are less common.

DEPOSIT FORM: Veins, commonly with swarms of closely spaced, splaying smaller veins in sheeted zones. Veins vary in width from microveinlets to a few metres, and commonly are less than a metre wide. The ore shoots in veins are commonly 200-300 m along strike and dip but the veins may extend to more than 1000 m in depth and strike length. Vein systems and related stockworks cover areas up to a square kilometre along the tops of conical domes or intrusions 1-2 km wide.

TEXTURE/STRUCTURE: Multistage composite banded veins with abundant ore minerals pass at depth into crystalline quartz veins and upwards into vuggy quartz-bearing veins and stockworks.

ORE MINERALOGY (Principal and *subordinate*): Pyrite, cassiterite; pyrrhotite, marcasite; sphalerite, galena, chalcopyrite, stannite, arsenopyrite, tetrahedrite, scheelite, wolframite, andorite, jamesonite, boulangerite, ruby silver (pyrargyrite), stibnite, bismuthinite, native bismuth, molybdenite, argentite, gold and complex sulphosalt minerals. These deposits are characterized by their mineralogical complexity. There is no consistency between deposits in vertical or lateral zoning, but individual deposits are markedly spatially and temporally zoned. In some deposits, notably intrusion or dome-hosted examples, core zones are denoted by the high-temperature minerals cassiterite, wolframite, bismuthinite and arsenopyrite. Surrounding ores have varying amounts of stannite and chalcopyrite with, most significantly, sphalerite, galena and various Pb sulphosalt and Ag minerals. Silver in the upper parts of the vein systems occurs in argentite, ruby silver and native silver and at depth is mainly present in tetrahedrite.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, sericite, pyrite; tourmaline at depth, kaolinite and chalcedony near surface; rare barite, siderite, calcite, Mn carbonate and fluorite.

ALTERATION MINERALOGY: Quartz-sericite-pyrite is characteristic; elsewhere quartz-sericite-chlorite occurs in envelopes on veins. Near-surface argillic and advanced argillic alteration overprinting is present in some deposits.

WEATHERING: Prominent limonite cappings are derived from the oxidation of pyrite.

ORE CONTROLS: Sets of closely spaced veins, commonly in sheeted zones, fractures and joints within and surrounding plutons are related to the emplacement and cooling of the host intrusions. The open space filling and shear-replacement veins are associated with stockworks, breccia veins and breccia pipes. A few deposits occur in faults, shears, fold axes and cleavage or fracture zones related to regional tectonism. Some early wallrock replacement along narrow fissures is generally followed and dominated by open- space filling in many deposits.

GENETIC MODEL: Dacitic magma and the metal-bearing hydrothermal solutions represent the uppermost products of large magmatic/hydrothermal systems. The Sn is probably a remobilized component of sialic rocks derived from recycled continental crust.

ASSOCIATED DEPOSIT TYPES: Polymetallic veins Ag-Pb-Zn (I05); epithermal Au-Ag: low sulphidation (H05), mantos (J01, J02), porphyry Sn (L06), placers (C01, C02). This deposit type grades with depth into Sn veins and greissens (I13) associated with mesozonal granitic intrusions into sediments. Cassiterite in colluvium can be recovered by placer mining. Mexican-type rhyolite Sn or "wood tin" deposits represent a separate class of deposit (Reed et al., 1986).

COMMENTS: Many Sn-bearing base metal vein systems are known to occur in eastern British Columbia, but there is poor documentation of whether the Sn is present as cassiterite or stannite. The former can be efficiently recovered by simple metallurgy, the latter cannot.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Ag, Cu, Zn, Pb, Sn, W, As, Bi.

OTHER EXPLORATION GUIDES: The vein systems may display impressive vertical and horizontal continuity with marked metal zoning. Bolivian polymetallic vein deposits have formed at depths of 0.5 to 2 km below the paleosurface. Deeper veins of mainly massive sulphide minerals contain Sn, W and Bi; the shallower veins with quartz-barite and chalcedony-barite carry Ag and rarely Au. Metal zoning from depth to surface and from centres outward shows: Sn + W, Cu + Zn, Pb + Zn, Pb + Ag and Ag ± Au; commonly there is considerable 'telescoping' of zones. Oxidized zones may have secondary Ag minerals, such as Ag chlorides.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Considerable variation in metal contents of ores is evident between deposits. Potentially bulk-mineable bedrock deposits contain in the order of 0.2% Sn with 70-179 g/t Ag (Cerro Rico, Potosi, Bolivia).

ECONOMIC LIMITATIONS: These veins tend to be narrow.

IMPORTANCE: These veins are an important source of cassiterite for economic placer deposits around the world and the lodes have been mined in South America. They are currently attractive only when they carry appreciable Ag. In some deposits Au content is economically significant and Au-rich zones might have been overlooked during past work. Future Sn production from these veins will probably be as a byproduct commodity, and only if cassiterite is the main Sn mineral.

REFERENCES

Cunningham, C.G., McNee, J., Pinto Vasquez, J. and Ericksen, G.E. (1991): A Model of Volcanic Dome-hosted Precious Metal Deposits in Bolivia; Economic Geology, Volume 86, pages 415-421.
Ericksen, G.E. and Cunningham, C.G. (1993): Epithermal Precious-metal Deposits Hosted by the Neogene and Quaternary Volcanic Complex in the Central Andes; in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, Geological Association of Canada, Special Volume 40, pages 419-431.
Grant, J.N., Halls, C., Avila, W., and Avila, G. (1977): Igneous Systems and the Evolution of Hydrothermal Systems in some Sub-volcanic Tin Deposits of Bolivia; in Volcanic Process in Orogenesis, Geological Society of London, Special Paper Publication 7, Pages 117-126.
Ludington, S.D., Orris, G.J., Cox, D.P., Long, K.R. and Asher-Bolinder, S. (1992): Mineral Deposit Models; in Geology and Mineral Resources of the Altiplano and Cordillera Occidental, Bolivia, U.S. Geological Survey, Bulletin 1975, pages 63-89.
Nakamura, T. and Hunahashi, M. (1970): Ore Veins of Neogene Volcanic Affinity in Japan; in Volcanism and Ore Genesis, Tatsumi, T., Editor, University of Tokyo Press, pages 215-230.
Reed, B.L., Duffield, W., Ludington, S.D., Maxwell, C.H. and Richter, D.H. (1986): Descriptive Model of Rhyolite-hosted Sn; in Mineral Deposit Models, U.S. Geological Survey, Bulletin 1693, pages 168-171.
Togashi, Y. (1986): Descriptive Model of Sn-Polymetallic Veins; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 109.

[Back to top]

ALKALIC INTRUSION-ASSOCIATED Au-Ag

H08

by Tom G. Schroeter and Robert Cameron
British Columbia Geological Survey

Schroeter, T.G. and Cameron, R. (1996): Alkalic Intrusion-associated Au-Ag, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 49-51.

IDENTIFICATION

SYNONYMS: Alkalic epithermal, Au-Ag-Te veins.

COMMODITIES (*BYPRODUCTS*): Au, Ag (Zn, Pb).

EXAMPLES (British Columbia - *Canada/International*): Flathead (082GSE070), Howell (082GSE037), Howe (082GSE048); *Cripple Creek (Colorado, USA), Zartman, Landusky, Golden Sunlight (Montana, USA), Golden Reward (South Dakota, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: These deposits include quartz veins with pyrite, sphalerite and galena in structural zones and stockworks within alkalic intrusions and/or disseminated pyritic zones in alkalic intrusions, diatremes, coeval volcanics (Cripple Creek) and surrounding sediments. Argillic alteration, +/- silicification, carbonatization, and barite and fluorite veins are common.

TECTONIC SETTINGS: Associated with alkalic intrusive rocks in sedimentary cover rocks above continental crust, generally associated with extensional faulting. Tertiary examples in the USA are related to continental rifting; Rio Grande rift for Cripple Creek, Great Falls tectonic zone for the Montana deposits. Flathead area of British Columbia is in a continental setting but the extensional component is not as apparent.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Diatreme-intrusive complexes, high-level alkalic plugs, and dikes that intrude Proterozoic to Mesozoic continental clastic and carbonate rocks. Cripple Creek is within a large maar diatreme complex. Flathead intrusions are coeval with chemically similar volcanic rocks, the Crowsnest volcanics, in southern Alberta.

AGE OF MINERALIZATION: Any age; Flathead intrusions are early Cretaceous (98.5 Ma)

HOST/ASSOCIATED ROCK TYPES: (Flathead area): Intrusions include alkali feldspar syenite, foid-bearing syenite (nepheline, leucite, nosean, analcite), mela- syenite and related diatreme breccias with 10 % to 100 % intrusive component. Textures include coarse porphyritic sanidine, micro-syenite, tinguaite. Host sedimentary rocks include clastic rocks, shales and argillites to sandstones, and impure fine-grained carbonaceoous limestone and massive calcarenitic limestone. Gold may be present in all rock types.

DEPOSIT FORM: Deposits may be in the form of sheeted veins in structural zones within intrusions (e.g, Zortman, Cripple Creek) with dimensions of 50 m to 100 m in width and hundreds of metres in length to, less commonly, large disseminated, diffuse zones within diatremes (e.g., Montana Tunnels, Cripple Creek), volcanic rocks (e.g., Cripple Creek) or stratabound within favourable sedimentary lithologies.

TEXTURE/STRUCTURE: Ore minerals in quartz and quartz-adularia veins, vein stockworks, disseminated zones and minor breccias.

ORE MINERALOGY (Principal and *subordinate*): Fine-grained (auriferous, arsenical?) pyrite, galena, sphalerite, gold tellurides; chalcopyrite, magnetite, gold, bismuth and tellurium minerals are suspected at Flathead from elevated geochemical values in samples (to 31 ppm Te, 356 ppm Bi).

GAUNGE MINERALOGY (Principal and *subordinate*): Quartz, calcite; adularia, barite, fluorite.

ALTERATION MINERALOGY: Widespread pyrite and carbonate (calcite) alteration of intrusive rocks, silicic and argillic (illite, sericite, jarosite, roscoelite) alteration of wallrocks; also albite and adularia.

WEATHERING: Oxidation with limonite, jarosite, hydrozincite.

ORE CONTROLS: Mineralization is controlled by structural zones within or proximal to alkalic intrusions; also in permeable (e.g., sandstone) or chemically favourable units (impure carbonates or bedding contacts) in country rocks. Diatreme breccias are favourable permeable hosts for focused flow of volatiles.

ASSOCIATED DEPOSIT TYPES: Distal base metal mantos are indicated in the Flathead and South Dakota deposit areas. Possible link with porphyry Mo deposits; polymetallic (I05) veins.

COMMENTS: Some authors consider this deposit type to be a subset of the low- sulphidation epithermal suite of precious metal deposits. This deposit model relates to continental rift settings, but related deposit types are present in oceanic arc settings and include Emperor (Fiji), Porgera and Ladolam (Papua New Guinea) deposits. Similar British Columbia settings may include the Quesnel and Stikine Terrane alkalic volcanic belts which host the alkalic porphyry copper-gold deposits (LO3).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, Ag, As, Sb, Pb, Zn, F, Ba, V, Te, Bi

GEOPHYSICAL SIGNATURE: High chargeability (I.P.) will outline pyritic zones; magnetic surveys will outline magnetite-bearing zones.

ECONOMIC FACTORS:

TYPICAL GRADE AND TONNAGE: Highly variable, from very low mineable grades (e.g., 0.53 g/t Au at Zortman) to very high bonanza grades (e.g., 126 g/t Au at the Cresson vug, Cripple Creek). Recovered gold from the Cripple Creek district totals in excess of 600 tonnes. Grades at Howell Creek include 58 m of 1.3 g/t Au in silicified limestone, with grab samples containing up to 184 g/t at Flathead. Tonnages and grades from a number of deposits include: Cresson deposit, Cripple Creek 70 mt 0.99 g/t Au Cripple Creek, historical prod'n (1891-1989) 41 mt 17.14 g/t Au Golden Sunlight (Dec., 1994) 42.8 mt 1.9 g/t Zortman (Dec., 1994) 55.7 mt 0.68 g/t Au Montana Tunnels (Dec., 1994) 26.6 mt 0.61 g/T Au.

IMPORTANCE: Although these deposits have not been mined in British Columbia, they remain a viable exploration target.

REFERENCES

Bonham, H.F. (1988): Models for Volcanic Hosted Epithermal Precious Metal Deposits; in Bulk Mineable Precious Metal Deposits of the Western United States, Schafer, R.W., Cooper, J.J., and Wikre, P.G., Editors, Geological Society of Nevada, Symposium Proceedings, pages 259-271.
Cameron, R.S. (1989): Reverse Circulation Drilling Report for the Howe Claims, Fort Steele Mining Division, British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Assessment Report 18629. Mutschler, G.E. and
Mooney, T.C. (1993): Precious-metal Deposits Related to Alkalic Igneous Rocks: Provisional Classification, Grade-Tonnage Data and Exploration Frontiers; in Mineral Deposit Modelling, R.V. Kirkham, W.D. Sinlcair, R.I. Thorpe and J.M. Duke, Editors, Geological Survey of Canada, Special

Paper 40, pages 479- 520.
Richards, J.P. and Kerrick, R. (1993): The Porgera Gold Mine, Papua New Guinea: Magmatic Hydrothermal to Epithermal Evolution of an Alkalic-type Precious Metal Deposit; Economic Geology, Violume 88, pages 1017-1052.
Sillitoe, R.H. (1983): Epithermal Models: Genetic Types, Geometrical Controls and Shallow Features; in Mineral Deposit Modelling, R.V. Kirkham, W.D. Sinlcair, R.I. Thorpe and J.M. Duke, Editors, Geological Survey of Canada, Special Paper 40, pages 403-417.
Skupinski. A. and Legun, A. (1989): Geology of Alkalic Rocks at Twentynine Mile Creek, Flathead River Area, Southeastern British Columbia; in Exploration in British Columbia 1988, B.C. Ministry of Energy, Mines and Petroleum Resources, pages B29- B34.

[Back to top]

HYDROTHERMAL CLAYS

H09
by Z.D. Hora

IDENTIFICATION

SYNONYMS: Primary kaolin deposits, hypogene kaolin, hydrothermal kaolin, quartz-kaolinite-alunite deposits, Island Arc kaolin model, argillic alteration deposits, epithermal kaolin, hydrothermal alunite.

COMMODITIES (*BYPRODUCTS*): Kaolin, halloysite, pyrophyllite.

EXAMPLES (British Columbia - Canada/International):
Monteith Bay (092L 072, 117, 246, 343), Pemberton Hills (092L 308); Tintic (Utah, USA), Terraced Hills, (Nevada, USA), Matauri Bay, Mahimahi and Maungaparerua (New Zealand),Chugoku, Itaya and Taishu (Japan), Suzhou (China).

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Kaolin and halloysite, with or without alunite and pyrophyllite, occurs as veins and massive alteration masses in volcanic and granitic rocks. They formed in geothermal fields and hot springs areas associated with volcanic activity nearby.

TECTONIC SETTINGS: Active volcanic arcs (oceanic island arcs, continental margin arcs), extensional and transtensional settings, continental margin rifting. Typically the biggest deposits occur in volcanic island arcs, but may develop also in volcanic centres near continental margins.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Near surface hydrothermal alteration zones associated with subaerial volcanic centres and geothermal areas. The volcanic centres can be stratovolcanoes and calderas. Alteration zones typically occur in rocks of higher permeability and to depths of up to 100 metres from the paleosurface.

AGE OF MINERALIZATION: Mostly Tertiary to Quaternary; due to erosion and metamorphism the older deposits generally have not been preserved. The Suzhou deposit is reported to be related to Jurassic volcanic activity.

HOST/ASSOCIATED ROCK TYPES: Rhyolite, trachyte, andesite flows, sometimes glassy, and volcaniclastic rocks and their hypabyssal equivalents. Also, any older basement with feldspathic or sericitic rocks. Associated rocks are hydrothermal breccias and travertine and siliceous sinters.

DEPOSIT FORM: Structurally controlled, cone or wedge-shaped bodies are common; sometimes irregular shapes result from variable host rock permeability controlled by fracture density and porosity. Many alteration zones spread out as they approach the surface or form large near-surface zones on the flanks of volcanoes. Many of described ore bodies are less than 100 by 200 metres in size. The largest known deposit, Maungaparerua, covers 350 acres and has been explored to 50 m depth. The Itaya deposit has three zones; the largest one was 300 by 350 metres in plan and 100 metres deep. The Taishu has many orebodies, the largest one being 100 by 200 metres in size.

TEXTURE/STRUCTURE: Relic textures of the original host rock; sometimes aphanitic mixture of clay component with fine-grained silica; stockwork and breccia.

ORE MINERALOGY (Principal and *subordinate*): Halloysite, kaolin, pyrophyllite; *dickite, nacrite*.

GAUNGE MINERALOGY (Principal and *subordinate*): Quartz, calcite; adularia, barite, fluorite.

ALTERATION MINERALOGY: Clay minerals and pyrophyllite are hydrothermal alteration products of host rocks. This process, which starts with alteration of feldspars and other aluminosilicates, can be pervasive or marginal to fractures. In the latter case, some of the rock will be partially altered with hydrous phyllosilicates surrounding relic feldspar, quartz and mica. The alteration minerals can be zoned outward from core zones of silica through alunite to flanking zones of pyrophyllite-kaolinite-halloysite-smectite-illite Byproduct silica is mobilized and can be precipitated as a silica cap, veins and/or a siliceous matrix to the clay minerals.

WEATHERING: Circulating groundwater may further remove leachable elements (K, Na, Ca, Mg, etc.) and improve the quality of clay for a number of end uses. Residual weathering may overprint primary kaolin deposits resulting in superior quality ceramic clay (Maungaparerua, New Zealand). Silica caps on top of the deposit can form topographic heights.

ORE CONTROLS: Volcanic centres are a key control. Diatreme breccias, normal faults, margins of grabens and collapsed calderas can also be loci for some hypogene clay deposits. Alteration zones are often more extensive near the paleosurface. Hydrothermal clays are often hosted by rocks that are feldspathic, contain felsic glass and/or are permeable.

GENETIC MODELS: Clay deposits develop in feldspathic rocks, with or without volcanic glass, due to the circulation of hydrothermal fluids with low pH values (approximately 3.5 to 5) and temperatures from below 100 to 400°C. Halloysite forms at temperatures under ~100°C, kaolinite and alunite between ~100°C and ~350°C and pyrophyllite between ~300°C and ~400°C. Silica compounds and alunite may precipitate in separate zones, but also as a cementing matrix for kaolinite and pyrophyllite. The deposits occur over a considerable depth, ranging from high temperature geothermal fields at the paleosurface down into cupolas of intrusive bodies at depth.

ASSOCIATED DEPOSIT TYPES: Epithermal Au-Ag - low sulphidation (H05), epithermal Au-Ag-Cu: high sulphidation (H04), hot spring Au-Ag (H03), hot spring Hg (H02), solfatara alteration in vents in modern deposits.

COMMENTS: In some cases, near-surface leaching of these alteration zones can produce altered zones containing more than 95% silica. Alunite deposits can be extensive with potential as an aluminum resource, but they are not presently considered to be economic.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: High aluminum contents and reduced alkali contents, increased silica locally. Presence of aluminum sulphate and/or native sulphur.

GEOPHYSICAL SIGNATURE: Seismic techniques can distinguish dense unaltered rock from less dense clay altered zones. Resistivity methods can identify conductive clay zones from resistive unaltered rocks.

OTHER EXPLORATION GUIDES: Presence of siliceous sinters and association with geothermal fields. Search for alteration zones near volcanic centres and associated fault systems.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Published data on individual deposits are very incomplete. Depending on the original quartz content in the host rock, the clay content may vary from approximately 50 to 80%. Original silica content may be increased by precipitation of mobilized silica released by alteration of feldspars. Only a few hydrothermal deposits are large.

ECONOMIC LIMITATIONS: Production from this deposit type is from open pits. Physical properties and chemical composition of clay affect end use. While some deposits in New Zealand produce high-quality ceramic material, others can be used for white cement only. The high level of processing required to meet industry specifications and transportation cost to the end user are the main limiting factors for kaolin use. While local sources compete for low-value markets, high-quality products may be shipped to users overseas.

END USES: Hydrothermal kaolins are used in ceramics, for a variety of filler applications (paper, rubber, paints), refractory use and white cement manufacturing. A high content of fine silica makes hydrothermal kaolin hard and unusable for some applications; their main use is in ceramic applications. Deposits with a residual weathering overprint may have kaolin suitable for higher end uses, like industrial fillers and paper coating.

IMPORTANCE: Globally the least important of the three kaolin deposit types, but regionally may be very important (Japan, New Zealand).

SELECTED BIBLIOGRAPHY

Bristow, C.M. (1987): World Kaolins - Genesis, Exploitation and Application; *Industrial Minerals*, Number 238, pages 45–59.

Clapp, C.H. (1914): The Geology of the Alunite and Pyrophyllite Rocks of Kyuquot Sound, Vancouver Island; Summary Report of the Geological Survey for the calendar year 1913, Ottawa, pages 109–126.

Dill, H.G., Bosse, H.R., Henning, K.H., Fricke, A. and Ahrend, H. (1997): Mineralogical and Chemical Variations in Hypogene and Supergene Kaolin Deposits in a Mobile Fold Belt the Central Andes of Northwestern Peru; *Mineralium Deposita*, Volume 32, pages 149–163.

Hall, R.B. (1982): Model for Hydrothermal Alunite Deposits; *in* Characteristics of Mineral Deposit Occurrences, Erickson, R.L., Editor, *United States Geological Survey*, Open File Report 82-795, pages 148–154.

Harben, P.W. and Kuzwart, M. (1996): Industrial Minerals - A Global Geology; *Metal Bulletin*, London, 462 pages.
Harvey, C.C. and Murray, H.H. (1997): Industrial Clays in the 21st Century: a Perspective of

Exploration, Technology and Utilization; *Applied Clay Science*, Volume 11, pages 285–310.

Malkovsky, M. and Vachtl, J., Editors (1969): Kaolin Deposits of the World, A-Europe, B-Overseas Countries; Proceedings of the Symposium 1, *23rd International Geological Congress*, Prague, 1968,

460 pages.

Malkovsky, M. and Vachtl, J., Editors (1969): Genesis of the Kaolin Deposits; Proceedings of the Symposium 1, *23rd International Geological Congress*, Prague, 1988, 135 pages.

Murray, H.H. (1989): Kaolin Minerals: Their Genesis and Occurrences, Hydrous Phyllosilicates, *in* Reviews in Mineralogy, Bailey, S.W., Editor, *Mineralogical Society of America*, Volume 19, pages 67–89.

Murray, H.H., Bundy, W.M. and Harvey, C.C., Editors (1993): Kaolin Genesis and Utilization; *The Clay Minerals Society*, Boulder, Colorado, 341 pages.

Panteleyev, A. and Koyanagi, V.M. (1994): Advanced Argillic Alteration in Bonanza Volcanic Rocks, Northern Vancouver Island - Lithologic and Permeability Controls; *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 101-110.

** Note: All BC deposit profile #s with an asterisk have no completed deposit profile. USGS deposit model #s with an asterisk had no published model in the late 1990s.*

Examples of Epithermal Deposits

BC Profile #	Global Examples	B.C. Examples
H01	Gardiner (Montana), Salida (Colorado), Lazio (Italy)	Clinton, Slocan, Deep River
H02	Sulphur Bank (California), Steamboat Springs (Nevada)	Ucluelet
H03	McLaughlin (California), Round Mountain (Nevada)	Cinola, Clisbako, Wolf?, Trout?
H04	El Indio (Chile), Nansatsu (Japan)	Westpine, Taylor-Windfall, Mt. McIntosh
H05	Comstock (Nevada), Sado (Japan)	Lawyers, Blackdome, Silbak Premier
H06*	Talamantes (Mexico), Gloryana (New Mexico)	- -
H07	Black Range (New Mexico), Potosi (Bolivia), Ashio (Japan)	D Zone and Lang Creek (Cassiar)

H08	Emperor (Fiji), Cripple Creek (Colorado), Zortman (Montana)	Flathead, Howell, Howe
H09	Cornwall (England)	Monteith Bay, Pemberton Hills

Top

B.C. Home

Ministry of Energy, Mines and Petroleum Resources

Contact Information
Aggregate
Exploration
Geoscience

What's New in Geoscience
- Aggregates

ARIS Assessment Reports
- Bedrock Mapping
- Coal
- Educational Resources
- Exploration and Mines
- Geochemistry
- Geophysical Data
- Geoscience Agencies
- Geoscience Mailbox
- Hiring
- Industrial Minerals
- MapPlace

MINFILE Mineral Inventory
- Metallic Minerals
- Mineral Deposit Profiles
  - Introduction
  - List by Deposit Group
    - A – Organic
    - B - Residual/Surficial
    - C - Placer
    - D - Continental Sediments and Vocanics
    - E - Sediment-Hosted
    - F - Chemical Sediment
    - G - Marine Volcanic Association
    - H - Epithermal
    - I - Vein, Breccia and Stockwork

Ministry of Energy, Mines and Petroleum Resources

I - Vein, Breccia, and Stockwork

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
I01	Au-quartz veins	Mesothermal, Motherlode, saddle reefs	36a
I02	Intrusion-related Au pyrrhotite veins	Subvolcanic shear-hosted gold	- -
I03	Turbidite-hosted Au veins	Meguma type	36a
I04	Iron formation-hosted Au	Iron formation-hosted gold	36b
I05	Polymetallic veins Ag-Pb-Zn±Au	Felsic intrusionassociated Ag-Pb-Zb veins	22c, 25b
I06	Cu±Ag quartz veins	Churchill-type vein Cu	?
I07*	Silica veins	- -	- -
I08	Silica-Hg carbonate	- -	27c
I09	Stibnite veins and disseminations	Simple and disseminated Sb deposits	27d,27e
I10	Vein barite	- -	IM27e
I11	Barite-fluorite veins	- -	26c*
I12*	W veins	Quartz-wolframite veins	15a
I13*	Sn veins and greisens	- -	15b, 15c
I14	Five-element veins Ni-Co-As-Ag±(Bi, U)	Ni-Co-native Ag veins, cobalt-type veins	- -
I15	Classical U veins	Pitchblende veins, vein uranium	- -
I16	Unconformity-associated U	Unconformity-veins, Unconformity U	37a
I17	Cryptocrystalline magnesite veins	Bone magnesite, Kraubath-type magnesite	- -

Au-QUARTZ VEINS

I01

by Chris Ash and Dani Alldrick
British Columbia Geological Survey

Ash, Chris and Alldrick, Dani (1996): Au-quartz Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 53-56.

IDENTIFICATION

SYNONYMS: Mother Lode veins, greenstone gold, Archean lode gold, mesothermal gold-quartz veins, shear-hosted lode gold, low-sulphide gold-quartz veins, lode gold.

COMMODITIES (*BYPRODUCTS*): Au (Ag, Cu, Sb).

EXAMPLES (British Columbia (MINFILE #) - *Canada/ International*):

- Phanerozoic: Bralorne-Pioneer (092JNE001), Erickson (104P 029), Taurus (104P 012), Polaris-Taku (104K 003), Mosquito Creek (093H 010), Cariboo Gold Quartz (093H 019), Midnight (082FSW119); *Carson Hill, Jackson-Plymouth, Mother Lode district; Empire Star and Idaho-Maryland, Grass Valley district (California, USA); Alaska-Juneau, Jualin, Kensington (Alaska, USA), Ural Mountains (Russia).*
- Archean: *Hollinger, Dome, McIntyre and Pamour, Timmins camp; Lake Shore, Kirkland Lake camp; Campbell, Madsen, Red Lake camp; Kerr-Addison, Larder Lake camp (Ontario, Canada), Lamaque and Sigma, Val d'Or camp (Quebec, Canada); Granny Smith, Kalgoorlie and Golden Mile (Western Australia); Kolar (Karnataka, India), Blanket-Vubachikwe (Zimbabwe, Africa).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold-bearing quartz veins and veinlets with minor sulphides crosscut a wide variety of hostrocks and are localized along major regional faults and related splays. The wallrock is typically altered to silica, pyrite and muscovite within a broader carbonate alteration halo.

TECTONIC SETTINGS:

- Phanerozoic: Contained in moderate to gently dipping fault/suture zones related to continental margin collisional tectonism. Suture zones are major crustal breaks which are characterized by dismembered ophiolitic remnants between diverse assemblages of island arcs, subduction complexes and continental-margin clastic wedges.
- Archean: Major transcrustal structural breaks within stable cratonic terranes. May represent remnant terrane collisional boundaries.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Veins form within fault and joint systems produced by regional compression or transpression (terrane collision), including major listric reverse faults, second and third-order splays. Gold is deposited at crustal levels within and near the brittle-ductile transition zone at depths of 6-12 km, pressures between 1 to 3 kilobars and temperatures from 200o to 400 oC. Deposits may have a vertical extent of up to 2 km, and lack pronounced zoning.

AGE OF MINERALIZATION: Mineralization is post-peak metamorphism (i.e. late syncollisional) with gold-quartz veins particularly abundant in the Late Archean and Mesozoic.

- Phanerozoic: In the North America Cordillera gold veins are post-Middle Jurassic and appear to form immediately after accretion of oceanic terranes to the continental margin. In British Columbia deposits are mainly Middle Jurassic (~ 165-170 Ma) and Late Cretaceous (~ 95 Ma). In the Mother Lode belt they are Middle Jurassic (~ 150 Ma) and those along the Juneau belt in Alaska are of Early Tertiary (~56-55 Ma).
- Archean: Ages of mineralization for Archean deposits are well constrained for both the Superior Province, Canadian Shield (~ 2.68 to 2.67 Ga) and the Yilgarn Province, Western Australia (~ 2.64 to 2.63 Ga).

HOST/ASSOCIATED ROCK TYPES: Lithologically highly varied, usually of greenschist metamorphic grade, ranging from virtually undeformed to totally schistose.

- Phanerozoic: Mafic volcanics, serpentinite, peridotite, dunite, gabbro, diorite, trondhjemite/plagiogranites, graywacke, argillite, chert, shale, limestone and quartzite, felsic and intermediate intrusions.
- Archean: Granite-greenstone belts - mafic, ultramafic (komaitiitic) and felsic volcanics, intermediate and felsic intrusive rocks, graywacke and shale.

DEPOSIT FORM: Tabular fissure veins in more competent host lithologies, veinlets and stringers forming stockworks in less competent lithologies. Typically occur as a system of en echelon veins on all scales. Lower grade bulk-tonnage styles of mineralization may develop in areas marginal to

Community Relations

Mineral Exploration and Mining

Oil & Gas

Titles

Library

Publications

Electricity Policy and Development

Ministry Contacts

Links and Related Organizations

veins with gold associated with disseminated sulphides. May also be related to broad areas of fracturing with gold and sulphides associated with quartz veinlet networks.

TEXTURE/STRUCTURE: Veins usually have sharp contacts with wallrocks and exhibit a variety of textures, including massive, ribboned or banded and stockworks with anastamosing gashes and dilations. Textures may be modified or destroyed by subsequent deformation.

ORE MINERALOGY (Principal and *subordinate*): Native gold, pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, pyrrhotite, tellurides, scheelite, bismuth, cosalite, tetrahedrite, stibnite, molybdenite, gersdorffite (NiAsS), bismuthimite (Bi2S2), tetradymite (Bi2Te2S).

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, carbonates (ferroan-dolomite, ankerite ferroan-magnesite, calcite, siderite), albite, mariposite (fuchsite), sericite, muscovite, chlorite, tourmaline, graphite.

ALTERATION MINERALOGY: Silicification, pyritization and potassium metasomatism generally occur adjacent to veins (usually within a metre) within broader zones of carbonate alteration, with or without ferroan dolomite veinlets, extending up to tens of metres from the veins. Type of carbonate alteration reflects the ferromagnesian content of the primary host lithology; ultramafics rocks - talc, Fe-magnesite; mafic volcanic rocks - ankerite, chlorite; sediments - graphite and pyrite; felsic to intermediate intrusions - sericite, albite, calcite, siderite, pyrite. Quartz-carbonate altered rock (listwanite) and pyrite are often the most prominent alteration minerals in the wallrock. Fuchsite, sericite, tourmaline and scheelite are common where veins are associated with felsic to intermediate intrusions.

WEATHERING: Distinctive orange-brown limonite due to the oxidation of Fe-Mg carbonates cut by white veins and veinlets of quartz and ferroan dolomite. Distinctive green Cr-mica may also be present. Abundant quartz float in overburden.

ORE CONTROLS: Gold-quartz veins are found within zones of intense and pervasive carbonate alteration along second order or later faults marginal to transcrustal breaks. They are commonly closely associated with, late syncollisional, structurally controlled intermediate to felsic magmatism. Gold veins are more commonly economic where hosted by relatively large, competent units, such as intrusions or blocks of obducted oceanic crust. Veins are usually at a high angle to the primary collisional fault zone.

- Phanerozoic: Secondary structures at a high angle to relatively flat-lying to moderately dipping collisional suture zones.
- Archean: Steep, transcrustal breaks; best deposits overall are in areas of greenstone.

ASSOCIATED DEPOSIT TYPES: Gold placers (C01, C02), sulphide manto Au (J04), silica veins (I07); iron formation Au (I04) in the Archean.

GENETIC MODEL: Gold quartz veins form in lithologically heterogeneous, deep transcrustal fault zones that develop in response to terrane collision. These faults act as conduits for CO2-H2O-rich (5-30 mol% CO2), low salinity (<3 wt% NaCl) aqueous fluids, with high Au, Ag, As, (±Sb, Te, W, Mo) and low Cu, Pb, Zn metal contents. These fluids are believed to be tectonically or seismically driven by a cycle of pressure build-up that is released by failure and pressure reduction followed by sealing and repetition of the process (Sibson et al., 1988). Gold is deposited at crustal levels within and near the brittle- ductile transition zone with deposition caused by sulphidation (the loss of H2S due to pyrite deposition) primarily as a result of fluid-wallrock reactions, other significant factors may involve phase separation and fluid pressure reduction. The origin of the mineralizing fluids remains controversial, with metamorphic, magmatic and mantle sources being suggested as possible candidates. Within an environment of tectonic crustal thickening in response to terrane collision, metamorphic devolitization or partial melting (anatexis) of either the lower crust or subducted slab may generate such fluids.

COMMENTS: These deposits may be a difficult deposit to evaluate due to "nugget effect", hence the adage, “Drill for structure, drift for grade”. These veins have also been mined in British Columbia as a source of silica for smelter flux.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Au, Ag, As, Sb, K, Li, Bi, W, Te and B ± (Cd, Cu, Pb, Zn and Hg) in rock and soil, Au in stream sediments.

GEOPHYSICAL SIGNATURE: Faults indicated by linear magnetic anomalies. Areas of alteration indicated by negative magnetic anomalies due to destruction of magnetite as a result of carbonate alteration.

OTHER EXPLORATION GUIDES: Placer gold or elevated gold in stream sediment samples is an excellent regional and property-scale guide to gold-quartz veins. Investigate broad 'deformation envelopes' adjacent to regional listric faults where associated with carbonate alteration. Alteration and structural analysis can be used to delineate prospective ground. Within carbonate alteration zones, gold is typically only in areas containing quartz, with or without sulphides. Serpentinite bodies, if present, can be used to delineate favourable regional structures. Largest concentrations of free gold are commonly at, or near, the intersection of quartz veins with serpentinized and carbonate-altered ultramafic rocks.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Individual deposits average 30 000 t with grades of 16 g/t Au and 2.5 g/t Ag (Berger, 1986) and may be as large as 40 Mt. Many major producers in the Canadian Shield range from 1 to 6 Mt at grades of 7 g/t Au (Thorpe and Franklin, 1984). The largest gold-quartz vein deposit in British Columbia is the Bralorne-Pioneer which produced in excess of 117 800 kilograms of Au from ore with an average grade of 9.3 g/t.

ECONOMIC LIMITATIONS: These veins are usually less than 2m wide and therefore, only amenable to underground mining.

IMPORTANCE: These deposits are a major source of the world's gold production and account for approximately a quarter of Canada's output. They are the most prolific gold source after the ores of the Witwatersrand basin.

REFERENCES

Ash, C.H., Macdonald, R.W.J. and Reynolds, P.H. (in preparation): Ophiolite-related Mesothermal Lode Gold in British Columbia: A Deposit Model; B.C. Ministry Energy, Mines and Petroleum Resources, Bulletin.
Berger, B.R. (1986): Descriptive Model of Low-sulphide Au-Quartz Veins; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, pages 239-243.
Bohlke, J.K. and Kistler, R.W. (1986): Rb-Sr, K-Ar and Stable Isotope Evidence for the Ages and Sources of Fluid Components of Gold-bearing Quartz Veins in the Northern Sierra Nevada Foothills Metamorphic Belt; Economic Geology, Volume 81, pages 296- 422.
Gebre-Mariam, M., Hagemann, S.G. and Groves, D.G. (1995): A Classification Scheme for Epigenetic Archean Lode-gold Deposits; Mineralium Deposita, Volume 30, pages 408- 410.
Groves, D.I. (1993): The Crustal Continuum Model for Late Archean Lode-gold Deposits of the Yilgarn Block, Western Australia; Mineralium Deposita, Volume 28, pages 366- 374.
Hodgson, C.J. (1993): Mesothermal Lode-gold Deposits; in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, Geological Association of Canada, Special Paper 40, pages 635-678.
Hodgson, C.J. and Hamilton, J.V. (1989): Gold Mineralization in the Abitibi Greenstone Belt: End Stage of Archean Collisional Tectonics; in The Geology of Gold Deposits: The Perspective in 1988, Economic Geology, Monograph, pages 86-100.
Kerrich, R.W. (1990): Mesothermal Gold Deposits: A Critique of Genetic Hypotheses; in Greenstone Gold and Crustal Evolution, Rober, F., Sheahan, P.A. and Green, S.B., Editors, Geological Association of Canada, NUNA Conference Volume, pages 13-31.
Kerrich, R. and Wyman, D. (1990): Geodynamic Setting of Mesothermal Gold Deposits: An Association with Accretionary Tectonic Regimes; Geology, Volume 18, pages 882-885.
Landefeld, L.A. (1988): The Geology of the Mother Lode Gold Belt, Sierra Nevada Foothills Metamorphic Belt, California; in Proceedings Volume, North American Conference on Tectonic Control of Ore Deposits and the Vertical and Horizontal Extent of Ore Systems, University of Missouri - Rolla, pages 47-56.
Leitch, C.H.B. (1990): Bralorne; a Mesothermal, Shield-type Vein Gold Deposit of Cretaceous Age in Southwestern British Columbia; Canadian Institute of Mining and Metallurgy, Bulletin, Volume 83, Number 941, pages 53-80.
Panteleyev, A. (1991): Gold in the Canadian Cordillera - a Focus on Epithermal and Deeper Environments, in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B.C. Ministry of Energy, Mines and Petroleum Resources; Paper 1991-4, pages 163-212.
Roberts, R.G. (1987): Ore Deposit Models #11. Archean Lode Gold Deposits; Geoscience Canada, Volume 14, Number 1, pages 37-52.
Schroeter, T.G., Lund, C. and Carter, G. (1989): Gold Production and Reserves in British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1989- 22, 86 pages.
Sibson, R.H., Robert, F. and Poulsen, H. (1988): High Angle Faults, Fluid Pressure Cycling and Mesothermal Gold-Quartz Deposits; Geology, Volume 16, pages 551-555.
Thorpe, R.I. and Franklin, J.M. (1984): Volcanic-associated Vein and Shear Zone Gold; in Canadian Mineral Deposit Types, A Geological Synopsis, Eckstrand, O.R., Editor, Geological Survey of Canada, Economic Geology Report 36, page 38.

[Back to top]

INTRUSION-RELATED Au PYRRHOTITE VEINS

I02

by Dani J. Alldrick
British Columbia Geological Survey

Alldrick, D.J. (1996): Intrusion-related Au Pyrrhotite Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 57-58.

IDENTIFICATION

SYNONYMS: Mesothermal veins, extension veins, transitional veins, contact aureole veins.

COMMODITIES (*BYPRODUCTS*): Au, Ag (Cu).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Scottie Gold (104B 034), Snip (104B 250), Johnny Mountain (104B 107), War Eagle (082FSW097), Le Roi (082FSW093), Centre Star (082FSW094); *no international examples known.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Parallel tabular to cymoid veins of massive sulphide and/or bull-quartz-carbonate with native gold, electrum and chalcopyrite are emplaced in a set of en echelon fractures around the periphery of a subvolcanic pluton. Many previous workers have included these veins as mesothermal veins.

TECTONIC SETTINGS: Volcanic arcs in oceanic and continental margin settings. Older deposits are preserved in accreted arc terranes.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: The subvolcanic setting for these deposits is transitional between the setting for subvolcanic porphyry copper systems and for subvolcanic epithermal systems.

AGE OF MINERALIZATION: Recognized examples of this 'new' deposit type are all Early Jurassic.

HOST/ASSOCIATED ROCK TYPES: Hostrocks are andesitic tuffs, turbidites or early intrusive phases around the periphery of phaneritic, locally porphyritic, granodiorite stocks and batholiths.

DEPOSIT FORM: At various deposits the form has been described as: planar, en echelon vein sets, shear veins, cymoid veins, cymoid loops, sigmoidal veins, extension veins, tension gashes, ladder veins, and synthetic Reidel shear veins. Veins vary in width from centimetres to several metres and can be traced up to hundreds of metres.

TEXTURE/STRUCTURE: Two vein types may occur independently or together. Veins may be composed of (i) massive fine-grained pyrrhotite and/or pyrite, or (ii) massive bull quartz with minor calcite and minor to accessory disseminations, knots and crystal aggregates of sulphides. These two types of mineralization may grade into each other along a single vein or may occur in adjacent, but separate veins. Some veins have undergone post-ore ductile and brittle shearing that complicates textural and structural interpretations.

ORE MINERALOGY (Principal and *subordinate*): Native gold, electrum, pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, bornite, argentite, arsenopyrite, magnetite, ilmenite, tetrahedrite, tennantite, molybdenite, cosalite, chalcocite, tellurobismuthite, hessite, volynskite, altaite, native bismuth.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, calcite, ankerite, chlorite, sericite, rhodochrosite, k-feldspar, biotite.

ALTERATION MINERALOGY: Chlorite, sericite, pyrite, silica, carbonate, rhodochrosite, biotite, epidote, K-feldspar, ankerite. Alteration occurs as narrow (4 cm) vein selvages and as moderate alteration haloes extending up to several metres into the country rock.

ORE CONTROLS: Well defined faults and shears control the mineralization. Veins are peripheral to and spatially associated with porphyritic intrusive rocks which may host porphyry copper mineralization.

GENETIC MODEL: Mineralization is syn-intrusive and synvolcanic and formed along the thermally controlled 'brittle-ductile transition envelope' that surrounds subvolcanic intrusions. Late magma movement caused local shear stress, and resultant en echelon vein sets opened and were filled by sulphides and gangue minerals precipitating from circulating hydrothermal fluids. Subsequent shearing may have superimposed foliation or brecciation onto these early-formed veins.

ASSOCIATED DEPOSIT TYPES: Typical deposits of a volcanic arc, especially those in the subvolcanic setting: porphyry Cu+/-Mo+/-Au (L04), skarns, epithermal veins and breccias (H04, H05), 'transitional' deposits (volcanogenic Cu-As-Sb-Au-Ag, L01) and surficial fumarolic hotspring (H03) and exhalative deposits.

COMMENTS: At least one of these deposits was initially interpreted as a volcanogenic exhalative sulphide lens because a massive sulphide vein was discovered in volcanic rocks with no obvious bedding.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Au, Ag, Cu. (As, Zn).

GEOPHYSICAL SIGNATURE: Electromagnetic (ABEM and VLF-EM) and magnetometer (negative anomalies or 'magnetic troughs').

OTHER EXPLORATION GUIDES: Intense prospecting swath extending from 100 metres inside the intrusive contact to 1000 metres outside the intrusive contact of a prospective (sub-volcanic; Early Jurassic) pluton. Detailed soil geochemistry and detailed ground geophysics could be designed to investigate this same area. Small, 'hairline' mineralized fractures are good proximal indicators of a nearby major vein. Increased alteration intensity could also be a good proximal indicator, but this is a more subtle feature. Once the vein orientation on an initial discovery is determined, additional parallel veins should be anticipated and investigated with fences of drill holes.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Gold/silver ratios are close to 1:1. Copper may be a recoverable byproduct. Typical grades are 10 to 20 g/t Au.

IMPORTANCE: The Snip gold mine is currently British Columbia's largest gold producer and the Rossland veins are the province's second largest gold camp.

REFERENCES

Alldrick, D.J. (1993): Geology and Metallogeny of the Stewart Mining Camp, Northwestern, British Columbia, B. C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 85, 105

pages.
Alldrick, D.J., Drown, T.J., Grove, E.W., Kruchkowski, E.R. and Nichols, R.F. (1989): Iskut-Sulphurets Gold, Northern Miner Magazine, January, 1989, Pages 46-49.
Rhys, D. A. (1993): Geology of the Snip Mine, and its Relationship to the Magmatic and Deformational History of the Johnny Mountain Area, Northwestern British Columbia; unpublished M.Sc. thesis, The University of British Columbia, 278 pages.
Rhys, D. A. (1995): The Red Bluff Gold-copper Porphyry and Associated Precious and Base Metal Veins, Northwestern British Columbia; in Schroeter, T.G., Editor, Porphyry Deposits of the northwestern Cordillera of North America, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, pages 838-850.

[Back to top]

TURBIDITE-HOSTED Au VEINS

I03

by R.H. McMillan
Consulting Geologist, Victoria, British Columbia

McMillan, R.H. (1996): Turbidite-hosted Au Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 59-62.

IDENTIFICATION

SYNONYMS: Saddle reefs, Bendigo-type.

COMMODITIES (*BYPRODUCTS*): Au (Ag, W, Sb).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Frasergold (093A 150), Valentine Mountain (092B 108), Island Mountain (093H 019), Mosquito Creek (093H 025), Sheep Creek Deposits - Reno (082FSW036), Queen (082FSW048), Kootenay Belle (082FSW044) and Gold Belt (082FSW040); *Ptarmigan, Burwash, Thompson-Ludmar and other Yellowknife district deposits (Northwest Territories, Canada), Meguma district (Nova Scotia, Canada), Bendigo and Ballarat (Victoria, Australia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold-quartz veins, segregations, lodes and sheeted zones hosted by fractures, faults, folds and openings in anticlines, synclines and along bedding planes in turbidites and associated poorly sorted clastic sedimentary rocks.

TECTONIC SETTING: Hostrocks were deposited in submarine troughs, periarc basins, foreland basins and remnant ocean basins. The sediments were typically formed on continental margins or back-arc basins. Typically these sequences experienced one or two deformational phases with associated metamorphism.

DEPOSITIONAL ENVIRONMENT/GEOLOGICAL SETTING: Thick sediment sequences that have been deformed and metamorphosed; relatively few igneous rocks.

AGE OF MINERALIZATION: Archean to Tertiary; the Bendigo and Meguma districts are underlain by Early Paleozoic strata. The veins are generally considered to be related to later deformational event.

HOST/ ASSOCIATED ROCK TYPES: The predominant rock types are greywackes, siliceous wackes, shales and carbonaceous shales. Bedded cherts, iron formations, fine- grained impure carbonate rocks; minor polymictic conglomerate, tuffaceous members and minor marine volcanic flows may also be part of the stratigraphic sequence. There are younger granitic intrusions in many belts. Metamorphic grade is generally greenschist, but may reach amphibolite rank.

DEPOSIT FORM: Typically deposits are composed of multiple quartz veins up to a few metres in width that are commonly stratabound (either concordant or discordant), bedding-parallel, or discordant, and parallel to fold axial planes. Veins are variably deformed and occur as single strands, as sheeted arrays or as stockworks. Bedding-parallel veins within anticlines and synclines in the Bendigo-Ballarat and Meguma districts are commonly called saddle reefs or saddle troughs.

TEXTURE/STRUCTURE: Veins are well defined with sharp contacts. Bedding veins can be massive or laminated (ribbon texture) with columnar structures or stylolites, while discordant veins are generally massive. Veins can be associated with a variety of structures. Most common are folded veins and saddle reefs related to anticlinal folds. Sheeted, en echelon sigmoidal veins, ladder veins, tension gashes or stockworks may be related to zones of extension or to Reidel shear structures.

ORE MINERALOGY (Principal and *subordinate*): Native gold, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, molybdenite, bismuth, stibnite, bournonite and other sulphosalt minerals. Low sulphide content (<2.5%).

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, carbonates (calcite, dolomite or ankerite), feldspar (albite) and chlorite.

ALTERATION: Generally not prominent, however, disseminated arsenopyrite, pyrite and tourmaline, and more pervasive silica, sericite and carbonate, may develop in wallrocks adjacent to veins.

WEATHERING: In unglaciated terrains deep weathering and alluvial recycling may produce related rich placer deposits, such as the Bendigo region.

ORE CONTROLS: A strong structural control within dilatent areas in fold crests (saddle and trough reefs), discordant veins and tension gashes. This structural control may extend to district scale alignment of deposits. In some districts the veins appear confined to a specific stratigraphic interval, often near a change in lithologies. In the Meguma district, a more subtle stratigraphic control related to the upper (pelitic) portions of individual bouma cycles as well as regionally to the upper portion of the turbidite section. In the Bendigo district there is a relationship between ore and an abundance of graphite in the adjacent wallrocks.

GENETIC MODEL: Genetic theories range from veins formed by magmatic hydrothermal fluids or metamorphogenic fluids to deformed syngenetic mineralization. Most current workers prefer the metamorphogenic-deformational or lateral secretion theories and interpret the laminations as "crack-seal" phenomena formed during episodic re-opening of the veins during their formation. Workers favoring a syngenetic origin interpret the laminations as primary layering. Structural relationships in the Meguma and Bendigo districts indicate that the veins formed contemporaneously with, or prior to the major deformational event and were metamorphically overprinted during the intrusion of Devonian batholithic granitic rocks. Late post-deformational tension veinlets are generally non- auriferous.

ASSOCIATED DEPOSIT TYPES: Placers (C01), iron formation hosted gold deposits (I04) are also mainly hosted in turbidites - some of the Northwest Territories turbidite- hosted deposits are associated with chemical sediments. In several camps, slate horizons carrying finely disseminated, very low grade gold have been reported.

COMMENTS: Although past classification schemes have not recognized this type of deposit in British Columbia, the Valentine Mountain deposit hosted in Leech River schists and Frasergold hosted in Late Triassic clastic Quesnel River Group can be included. Elsewhere, several important vein gold districts in clastic sedimentary (possibly turbiditic) rocks might also be included. For example, the Sheep Creek camp and some of the Barkerville deposits are hosted in siliceous wackes and phyllites.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Si, Fe, S, As, B, Au and Ag generally show strong enrichment in the deposits, while Cu, Mg, Ca, Zn, Cd, Pb, Sb, W and Mn generally show moderate enrichment, and Hg, In, Li, Bi, Se, Te, Mo, F, Co and Ni may show low levels of enrichment.

GEOPHYSICAL SIGNATURE: The low sulphide content of the majority of quartz veins renders most geophysical techniques ineffective as direct exploration tools. However, airborne and ground electromagnetic and magnetic surveys and induced polarization surveys can be useful where deposits show an association with iron formation, massive sulphides or graphite.

OTHER EXPLORATION GUIDES: Standard prospecting techniques to trace mineralization directly or in float trains in glacial till, talus or other debris derived from the gold mineralization remains the most effective prospecting tool. Areas where there has been past gold production from placers are good candidates for prospecting.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Gold production from the Meguma region has come from 60 deposits at grades ranging from 8 to 50 g/t - a total of 35.13 tonnes has been produced from the district. The Bendigo field is much more significant, having produced a minimum of more than 373.3 t (12 M.oz.) of non-alluvial gold from more than 40 Mt of ore since 1851 - grades ranged from a minimum of approximately 5 g/t to more than 30 g/t. The three Barkerville mines produced an aggregate of 2.75 Mt to yield 38.29 t of gold between 1933 and 1987.

ECONOMIC LIMITATIONS: Deposits such as those in the Bendigo and Barkerville districts constitute attractive exploration targets. Although the hand sorting required to recover gold from the Nova Scotia deposits would probably render them uneconomic today, new techniques such as photometric sorting might improve the economics.

IMPORTANCE: Some districts/deposits, such as Bendigo, rank as world class and remain attractive exploration targets. The limited information available about the immense Muruntau deposit suggest that it may be similar to this type.

REFERENCES

ACKNOWLEDGMENTS: Howard Poulsen, Chris Ash, Dani Alldrick and Andre Panteleyev reviewed the profile and provided constructive comments.

Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits, Geological Survey of Canada, Bulletin 280, 584 pages.
Boyle, R.W. (1986): Gold Deposits in Turbidite Sequences: Their Geology, Geochemistry and History of the Theories of their Origin, in Keppie, J. Duncan, Boyle, R.W. and Haynes, S.J., Editors, Turbidite-hosted Gold Deposits, Geological Association of Canada, Special Paper 32, pages 1-14.
Graves, M.C. and Zentilli, M. (1982): A Review of the Geology of Gold in Nova Scotia; in Geology of Canadian Gold Deposits, Hodder, R.W. and Petruk W., Editors, Canadian Institute of Mining and Metallurgy, Special Volume 24, pages 233-242.
Haynes, S.J. (1986): Geology and Chemistry of Turbidite-hosted Gold Deposits, Greenschist Facies, Eastern Nova Scotia, in Turbidite-hosted Gold Deposits, Keppie, J. D., Boyle, R.W. and Haynes, S.J., Editors, Geological Association of Canada, Special Paper 32, pages 161-178.
Mathews, W.H. (1953): Geology of the Sheep Creek Camp, B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 31, -- pages.
Padgham, W.A. (1986): Turbidite-hosted Gold-quartz Veins in the Slave Structural Province, N.W.T, in Turbidite-hosted Gold Deposits, Keppie, J. D., Boyle, R.W. and Haynes, S.J., Editors, Geological Association of Canada, Special Paper 32, pages 119-134.
Panteleyev, A.P. (1991): Gold in the Canadian Cordillera - a Focus on Epithermal and Deeper

Environments, in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 163-212.
Schroeter, T.G. and Lane, R.A. (1991): A Century of Gold Production and Reserves in British Columbia (1890 to 1990). B.C. Ministry of Energy Mines and Petroleum Resources, Open File 1991-19, 42 pages.
Sharpe, E.N. and MacGeehan, P.J. (1990): Bendigo Goldfield; in Geology of the Mineral Deposits of Australia and Papua New Guinea, Hughes, F.E., Editor, The Australasian Institute of Mining and Metallurgy, Monograph No. 14, Volume 2, pages 1287-1296.

[Back to top]

IRON FORMATION-HOSTED Au

I04

by R.H. McMillan
Consulting Geologist, Victoria, British Columbia

McMillan, R.H. (1996): Iron formation-hosted Au, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 63-66.

IDENTIFICATION

SYNONYM: Mesothermal veins.

COMMODITIES (*BYPRODUCTS*): Au (Ag, Cu).

EXAMPLES (British Columbia - *Canada/International*): No B.C. examples; *Lupin and Cullaton Lake B-Zone (Northwest Territories, Canada), Detour Lake, Madsen Red Lake, Pickle Crow, Musselwhite, Dona Lake, (Ontario, Canada), Homestake (South Dakota, USA), Mt. Morgans (Western Australia); Morro Vehlo and Raposos, Mineas Gerais (Brazil); Vubachikwe and Bar 20 (Zimbabwe); Mallappakoda, Kolar District (India).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold in crosscutting quartz veins and veinlets or as fine disseminations associated with pyrite, pyrrhotite and arsenopyrite hosted in iron-formations and adjacent rocks within volcanic or sedimentary sequences. The iron-formations may vary between carbonate-oxide iron-formation and arsenical sulphide-silicate iron-formation.

TECTONIC SETTING: In “greenstone belts” believed to be ancient volcanic arcs; and in adjacent submarine troughs.

DEPOSITIONAL ENVIRONMENT/GEOLOGICAL SETTING: Sedimentary and submarine volcanic sequences in a range of mutually overlapping settings ranging from turbiditic clastic sedimentary environments to distal mafic (and komatiitic) environments with associated felsic tuffaceous and intrusive porphyries.

AGE OF MINERALIZATION: Archean to Proterozoic.

HOST/ ASSOCIATED ROCK TYPES: Contained mainly within various facies of Algoma-type iron-formation and cherts, although veins may extend into other units. Associated with variolitic, tholeiitic and komatiitic volcanic and clastic (commonly turbiditic) rocks, rarely felsic volcanic and intrusive rocks. Metamorphic rank ranges from lowest greenschist to upper amphibolite facies. Silicate-facies iron-formations are associated in some cases but are generally not gold-bearing.

DEPOSIT FORM: In and near crosscutting structures, such as quartz veins, or stratiform zones within chemical sedimentary rocks. Host strata have generally been folded and deformed to varying degree, consequently the deposits may have developed in axial plane cleavage area or be thickened and remobilized in fold hinges.

TEXTURE/STRUCTURE: Highly variable: gold mineralization may be finely disseminated in sulphide minerals in the stratiform examples or occur as the native mineral or in sulphides in crosscutting quartz veins. Sulphidization features such as pyrite overgrowths on magnetite are present in some deposits.

ORE MINERALOGY (Principal and *subordinate*): Native Au, pyrite, arsenopyrite, magnetite, pyrrhotite, chalcopyrite, sphalerite, galena, stibnite, rarely gold tellurides.

GANGUE MINERALOGY (Principal and *subordinate*): Vein quartz, chert, carbonates (calcite, dolomite or ankerite), graphite, grunerite, stilpnomelane, tourmaline, feldspar (albite).

ALTERATION: In deposits at low metamorphic rank, carbonatization (generally ankeritic or ferroan dolomite) is generally prominent. Sulphidization (pyritization, arsenopyritization and pyrrhotitization) is common in wallrocks adjacent to crosscutting quartz veins.

WEATHERING: Highly variable: sulphide-rich, carbonate-poor deposits will produce significant gossans.

ORE CONTROLS: Mineralization is within, or near, favourable iron-formations. Most deposits occur adjacent to prominent regional structural and stratigraphic “breaks” and mineralization is often related to local structures. Contacts between ultramafic (commonly komatiitic) rocks and tholeiitic basalts or sedimentary rocks are important. All known deposits occur in Precambrian sequences, however, there are some potentially favourable chemical sediment horizons in Paleozoic rocks. Pinch outs and facies changes within geologically favourable units are important loci for ore deposition.

GENETIC MODELS: One model proposed for iron formation-hosted Au is that the mineralization may form due to deformation focusing metamorphogenic or magmatic hydrothermal fluids, from depth, into a chemically and structurally (brittle- ductile transition zone) favourable depositional environment, late in the orogenic cycle. This theory is consistent with both the crosscutting relationships and radiometric dates for the gold mineralization. Another model emphasizes a syngenetic origin for the widespread anomalous gold values, similarity of the geological environments to currently active submarine exhalative systems, and the association with chemical sedimentary strata. Replacement features could be explained as normal diagenetic features and contact areas between sulphide-rich ore and carbonate wallrock as facies boundaries.

ASSOCIATED DEPOSIT TYPES: Au-quartz veins (I01), turbidite-hosted Au-quartz veins (I03), Algoma-type iron-formations (G01).

COMMENTS: This type of deposit has not been documented in British Columbia. The closest analogy is the 900 zone on the Debbie property (092F 331) which contains gold in magnetite-jasper-sulphide-bearing bedded chert, in quartz veins and in stockworks cutting ankeritic aphyric pillow basalt. Some workers consider auriferous stratiform pyrite bodies, such as Bousquet, Doyon, and Agnico Eagle in the Canadian Shield, to be closely related to iron formation-hosted Au.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Si, Fe, S, As, B, Mg, Ca, Au and Ag generally show strong enrichment in the deposits, while Cu, Zn, Cd, Pb and Mn generally show moderate enrichment.

GEOPHYSICAL SIGNATURE: Airborne and ground electromagnetic and magnetic surveys and induced polarization surveys can be very useful to detect and map the high sulphide and magnetite content of many of the deposits.

OTHER EXPLORATION GUIDES: Standard prospecting techniques to trace mineralization directly or in float trains in glacial till, talus or other debris derived from the gold mineralization remains the most effective prospecting tool. Areas with gold placers are potential targets. Exploration programs should focus on the primary depositional environment for stratiform deposits.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The more significant deposits fall in the ranges from 6 to 17 g/t Au and 1 to 5 Mt (Thorpe and Franklin, 1984). At the adjacent properties of Morro Velho and Raposos in Brazil, approximately 10 million ounces of gold have been produced at a grade of between 15 and 16 g/t since 1834. In Ontario, the Detour Lake mine contains a resource of 48 t Au and the Madsen Red Lake deposit produced 75 t, the Pickle Crow Deposits 45 tonnes and the Central Patricia 19 tonnes. At the Lupin mine 6.66 Mt of ore grading 10.63 g/t Au were produced between 1982 and the end of 1993 with remaining reserves of 5.1 Mt averaging 9.11 g/t.

ECONOMIC LIMITATIONS: The narrow veins in some deposits require selective mining techniques which are no longer highly profitable. On the other hand, deposits, such as Lupin, are sufficiently large to be mined very profitably utilizing modern mechanized equipment.

IMPORTANCE: Although attention in recent years has been focused on the large epithermal volcanic-hosted gold deposits of the circum-Pacific Belt and on Carlin-type deposits, iron-formation hosted gold deposits, such as Lupin, rank as world class and remain attractive exploration targets. For example, the Homestake mine has produced approximately 300 t of gold since starting production in 1876.

REFERENCES

ACKNOWLEDGMENTS: Chris Ash, Dani Alldrick, Andre Panteleyev and Howard Poulsen reviewed the profile and provided constructive comments.

Berger, B.R. (1986): Descriptive Model of Homestake Au; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors,U.S. Geological Survey, Bulletin 1693, pages 245- 247.
Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits; Geological Survey of Canada, Bulletin 280, 584 pages.
Fyon, J.A., Breaks, F.W., Heather, K.B., Jackson, S.L., Muir, T.L., Stott, G.M. and Thurston, P.C. (1992): Metallogeny of Metallic Mineral Deposits in the Superior Province of Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, pages 1091-1174.
Fripp, R.E.P. (1976): Stratabound Gold Deposits in Archean Banded Iron-Formation, Rhodesia; Economic Geology, Volume 71, pages 58-75.
Kerswill, J.A. (1993): Models for Iron-formation-hosted Gold Deposits; in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, Geological Association of Canada, Special Paper 40, pages 171-200.
Padgham, W.A. and Brophy, J.A. (1986): Gold Deposits of the Northwest Territories; in Gold in the Western Shield, Canadian Institute of Mining and Metallurgy, Special Volume 38, pages 2-25.
Rye, D.M. and Rye, R.O. (1974): Homestake Gold Mine, South Dakota: I. Stable Isotope Studies; Economic Geology, Volume 69, pages 293-317.
Siddaiah, N.S., Hanson, G.N. and Rajamani, V. (1994): Rare Earth Element Evidence for Syngenetic Origin of an Archean Stratiform Gold Sulfide Deposit, Kolar Schist Belt, South India; Economic Geology, Volume 89, pages 1552-1566.
Thorpe, R.I and Franklin, J.M. (1984): Chemical-sediment-hosted Gold; in Canadian Mineral Deposit Types: A Geological Synopsis, Eckstrand, O.R., Editor, Economic Geology Report 36, Geological Survey of Canada, page 29.
Vielreicher, R.M., Groves, D.I., Ridley, J.R. and McNaughton, N.J. (1994): A Replacement Origin for the BIF-hosted Gold Deposit at Mt. Morgans, Yilgarn Block, W.A; Ore Geology Reviews,

Volume 9, pages 325-347.

[Back to top]

POLYMETALLIC VEINS Ag-Pb-Zn+/-Au

I05
by David V. Lefebure and B. Neil Church
British Columbia Geological Survey

Lefebure, D.V. and Church, B.N. (1996): Polymetallic Veins Ag-Pb-Zn+/-Au, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1996-13, pages 67-70.

IDENTIFICATION

SYNONYMS: Clastic metasediment-hosted silver-lead-zinc veins, silver/base metal epithermal deposits.

COMMODITIES (*BYPRODUCTS*): Ag, Pb, Zn (Cu, Au, Mn).

EXAMPLES (British Columbia (MINFILE # - *Canada/International*):

- Metasediment host: Silvana (082FNW050) and Lucky Jim (082KSW023), Slocan-New Denver-Ainsworth district, St. Eugene (082GSW025), Silver Cup (082KNW027), Trout Lake camp; *Hector-Calumet and Elsa, Mayo district (Yukon, Canada), Coeur d'Alene district (Idaho, USA), Harz Mountains and Freiberg district (Germany), Pr¡bram district (Czechoslavakia).*
- Igneous host: Wellington (082ESE072) and Highland Lass - Bell (082ESW030, 133), Beaverdell camp; Silver Queen (093L 002), Duthie (093L 088), Cronin (093L 127), Porter-Idaho (103P 089), Indian (104B 031); *Sunnyside and Idorado, Silverton district and Creede (Colorado, USA), Pachuca (Mexico).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Sulphide-rich veins containing sphalerite, galena, silver and sulphosalt minerals in a carbonate and quartz gangue. These veins can be subdivided into those hosted by metasediments and another group hosted by volcanic or intrusive rocks. The latter type of mineralization is typically contemporaneous with emplacement of a nearby intrusion.

TECTONIC SETTINGS: These veins occur in virtually all tectonic settings except oceanic, including continental margins, island arcs, continental volcanics and cratonic sequences.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING:

- Metasediment host: Veins are emplaced along faults and fractures in sedimentary basins dominated by clastic rocks that have been deformed, metamorphosed and intruded by igneous rocks. Veins postdate deformation and metamorphism.
- Igneous host: Veins typically occur in country rock marginal to an intrusive stock. Typically veins crosscut volcanic sequences and follow volcano- tectonic structures, such as caldera ring-faults or radial faults. In some cases the veins cut older intrusions.

AGE OF MINERALIZATION: Proterozic or younger; mainly Cretaceous to Tertiary in British Columbia.

HOST/ASSOCIATED ROCK TYPES: These veins can occur in virtually any host. Most commonly the veins are hosted by thick sequences of clastic metasediments or by intermediate to felsic volcanic rocks. In many districts there are felsic to intermediate intrusive bodies and mafic igneous rocks are less common. Many veins are associated with dikes following the same structures.

DEPOSIT FORM: Typically steeply dipping, narrow, tabular or splayed veins. Commonly occur as sets of parallel and offset veins. Individual veins vary from centimetres up to more than 3 m wide and can be followed from a few hundred to more than 1000 m in length and depth. Veins may widen to tens of metres in stockwork zones.

TEXTURE/STRUCTURE: Compound veins with a complex paragenetic sequence are common. A wide variety of textures, including cockade texture, colloform banding and crustifications and locally druzy. Veins may grade into broad zones of stockwork or breccia. Coarse-grained sulphides as patches and pods, and fine- grained disseminations are confined to veins.

ORE MINERALOGY (Principal and *subordinate*): Galena, sphalerite, tetrahedrite- tennantite, other sulphosalts including pyrargyrite, stephanite, bournonite and acanthite, native silver, chalcopyrite, pyrite, arsenopyrite, stibnite. Silver minerals often occur as inclusions in galena. Native gold and electrum in some deposits. Rhythmic compostional banding sometimes present in sphalerite. Some veins contain more chalcopyrite and gold at depth and Au grades are normally low for the amount of sulphides present.

GANGUE MINERALOGY (Principal and *subordinate*):

- Metasediment host: Carbonates (most commonly siderite with minor dolomite, ankerite and calcite), quartz, barite, fluorite, magnetite, bitumen.
- Igneous host: Quartz, carbonate (rhodochrosite, siderite, calcite, dolomite), sometimes specular hematite, hematite, barite, fluorite. Carbonate species may correlate with distance from source of hydrothermal fluids with proximal calcium and magnesium-rich carbonates and distal iron and manganese-rich species.

ALTERATION MINERALOGY: Macroscopic wall rock alteration is typically limited in extent (measured in metres or less). The metasediments typically display sericitization, silicification and pyritization. Thin veining of siderite or ankerite may be locally developed adjacent to veins. In the Coeur d'Alene camp a broader zone of bleached sediments is common. In volcanic and intrusive hostrocks the alteration is argillic, sericitic or chloritic and may be quite extensive.

WEATHERING: Black manganese oxide stains, sometimes with whitish melanterite, are common weathering products of some veins. The supergene weathering zone associated with these veins has produced major quantities of manganese. Galena and sphalerite weather to secondary Pb and Zn carbonates and Pb sulphate. In some deposits supergene enrichment has produced native and horn silver.

ORE CONTROLS: Regional faults, fault sets and fractures are an important ore control; however, veins are typically associated with second order structures. In igneous rocks the faults may relate to volcanic centers. Significant deposits restricted to competent lithologies. Dikes are often emplaced along the same faults and in some camps are believed to be roughly contemporaneous with mineralization. Some polymetallic veins are found surrounding intrusions with porphyry deposits or prospects.

GENETIC MODELS: Historically these veins have been considered to result from differentiation of magma with the development of a volatile fluid phase that escaped along faults to form the veins. More recently researchers have preferred to invoke mixing of cooler, upper crustal hydrothermal or meteoric waters with rising fluids that could be metamorphic, groundwater heated by an intrusion or expelled directly from a differentiating magma. Any development of genetic models is complicated by the presence of other types of veins in many districts. For example, the Freiberg district has veins carrying F-Ba, Ni-As- Co-Bi-Ag and U.

COMMENTS: Ag-tetrahedrite veins, such as the Sunshine and Galena mines in Idaho, contain very little sphalerite or galena. These may belong to this class of deposits or possibly the five-element veins. The styles of alteration, mineralogy, grades and different geometries can usually be used to distinguish the polymetallic veins from stringer zones found below syngenetic massive sulphide deposits.

ASSOCIATED DEPOSIT TYPES:

- Metasediment host: Polymetallic mantos (M01).
- Igneous host: May occur peripheral to virtually all types of porphyry mineralization (L01, L03, L04, L05, L06, L07, L08) and some skarns (K02, K03).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Zn, Pb, Ag, Mn, Cu, Ba and As. Veins may be within arsenic, copper, silver, mercury aureoles caused by the primary dispersion of elements into wallrocks or broader alteration zones associated with porphyry deposit or prospects.

GEOPHYSICAL SIGNATURE: May have elongate zones of low magnetic response and/or electromagnetic, self potential or induced polarization anomalies related to ore zones.

OTHER EXPLORATION GUIDES: Strong structural control on veins and common occurrence of deposits in clusters can be used to locate new veins.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : Individual vein systems range from several hundred to several million tonnes grading from 5 to 1500 g/t Ag, 0.5 to 20% Pb and 0.5 to 8% Zn. Average grades are strongly influenced by the minimum size of deposit included in the population. For B.C. deposits larger than 20 000 t the average size is 161 000 t with grades of 304 g/t Ag, 3.47 % Pb and 2.66 % Zn. Copper and gold are reported in less than half the occurrences, with average grades of 0.09 % Cu and 4 g/t Au.

ECONOMIC LIMITATIONS: These veins usually support small to medium-size underground mines. The mineralization may contain arsenic which typically reduces smelting credits.

IMPORTANCE: The most common deposit type in British Columbia with over 2 000 occurrences; these veins were a significant source of Ag, Pb and Zn until the 1960s. They have declined in importance as industry focused more on syngenetic massive sulphide deposits. Larger polymetallic vein deposits are still attractive because of their high grades and relatively easy benefication. They are potential sources of cadmium and germanium.

REFERENCES

ACKNOWLEDGEMENTS: Georges Beaudoin and Don Sangster are thanked for their suggestions to improve the profile.

Barton, P., Bethke, P., Wetlaufer, P.H., Foley, N., Hayba, D. and Goss, J. (1982): Silver/Base Metal Epithermal Deposits; in Characteristics of Mineral Deposit Occurrences, Erickson, R.L., Compiler, U.S. Geological Survey, pages 127- 130.
Beaudoin, G. and Sangster, D.F. (1992): A Descriptive Model for Silver-Lead-Zinc Veins in Clastic Metasedimentary Terranes; Economic Geology, Volume 87, pages 1005-1021.
Beaudoin, G. and Sangster, D.F. (in press): Clastic Metasediment-hosted Vein Silver- Lead-Zinc; in Geology of Canadian Mineral Deposit Types, Eckstrand, O.R., Sinclair, W.D. and Thorpe, R.I., Editors, Geological Survey of Canada, Geology of Canada, No. 8, pages 393-398.
Boyle, R.W. (1965): Geology, Geochemistry and Origin of the Lead-Zinc-Silver Deposits of the Keno Hill - Galena Hill Area, Yukon Territory; Geological Survey of Canada, Bulletin 111, 302 pages.
Boyle, R.W. (1968): The Geochemistry of Silver and its Deposits; Geological Survey of Canada, Bulletin 160, 264 pages.
Corbett, G.J. and Leach, T.M. (1995): S.W. Pacific Rim Au/Cu Systems: Structure, Alteration and Mineralization; Mineral Deposit Research Unit, The University of British Columbia, Short Course No. 17 notes, 150 pages.
Cox, D.P. (1986): Descriptive Model of Polymetallic Veins; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors,U.S. Geological Survey, Bulletin 1693, pages 125-129.
Godwin, C.I., Watson, P.H. and Shen, K. (1986): Genesis of the Lass Vein System, Beaverdell Silver Camp, South-central British Columbia; Canadian Journal of Earth Sciences, Volume 23, pages 1615-1626.
Fyles, J.T. (1967): Geology of the Ainsworth-Kaslo Area, British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 53, 125 pages.
Little, H.W. (1960): Nelson Map Area, West Half, British Columbia; Geological Survey of Canada, Memoir 308, pages 305.
Steven, T.A. and Eaton, G.P. (1975): Environment of Ore Deposition in the Creede Mining District, San Juan Mountains, Colorado: I. Geologic, Hydrologic, and Geophysical Setting; Economic Geology, Volume 70, pages 1023-1037.

[Back to top]

Cu+/-Ag QUARTZ VEINS

I06

by David V. Lefebure
British Columbia Geological Survey

Lefebure, D.V. (1996): Cu+/- Ag Quartz Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 71-74.

IDENTIFICATION

SYNONYMS: Churchill-type vein copper, vein copper

COMMODITY (*BYPRODUCTS*): Cu (Ag, rarely Au).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Davis-Keays (094K 012, 050), Churchill Copper (Magnum, 094K 003), Bull River (082GNW002), Copper Road (092K 060), Copper Star (092HNE036), Copper Standard (092HNE079), Rainbow (093L 044); *Bruce Mines and Crownbridge (Ontario, Canada), Blue Wing and Seaboard (North Carolina, USA), Matahambre (Cuba), Inyati (Zimbabwe), Copper Hills (Western Australia), Tocopilla area (Chile), Burgas district (Bulgaria), Butte (Montana, USA), Rosario (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Quartz-carbonate veins containing patches and disseminations of chalcopyrite with bornite, tetrahedrite, covellite and pyrite. These veins typically crosscut clastic sedimentary or volcanic sequences, however, there are also Cu quartz veins related to porphyry Cu systems and associated with felsic to intermediate intrusions.

TECTONIC SETTINGS: A diversity of tectonic settings reflecting the wide variety of hostrocks including extensional sedimentary basins (often Proterozoic) and volcanic sequences associated with rifting or subduction-related continental and island arc settings.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Veins emplaced along faults; they commonly postdate major deformation and metamorphism. The veins related to felsic intrusions form adjacent to, and are contemporaneous with, mesozonal stocks.

AGE OF MINERALIZATION: Any age; can be much younger than hostrocks.

HOST/ASSOCIATED ROCK TYPES: CuñAg quartz veins occur in virtually any rocks although the most common hosts are clastic metasediments and mafic volcanic sequences. Mafic dikes and sills are often spatially associated with metasediment-hosted veins. These veins are also found within and adjacent to felsic to intermediate intrusions.

DEPOSIT FORM: The deposits form simple to complicated veins and vein sets which typically follow high-angle faults which may be associated with major fold sets. Single veins vary in thickness from centimetres up to tens of metres. Major vein systems extend hundreds of metres along strike and down dip. In some exceptional cases the veins extend more than a kilometre along the maximum dimension.

TEXTURE/STRUCTURE: Sulphides are irregularly distributed as patches and disseminations. Vein breccias and stockworks are associated with some deposits.

ORE MINERALOGY (Principal and *subordinate*):

- Metasediment and volcanic-hosted: Chalcopyrite, pyrite, chalcocite; bornite, tetrahedrite, argentite, pyrrhotite, covellite, galena.
- Intrusion-related: Chalcopyrite, bornite, chalcocite, pyrite, pyrrhotite; enargite, tetrahedrite-tennantite, bismuthinite, molybdenite, sphalerite, native gold and electrum.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz and carbonate (calcite, dolomite, ankerite or siderite); hematite, specularite, barite.

ALTERATION MINERALOGY: Wallrocks are typically altered for distances of centimetres to tens of metres outwards from the veins.

- Metasediment and volcanic-hosted: The metasediments display carbonatization and silicification. At the Churchill and Davis-Keays deposits, decalcification of limy rocks and zones of disseminated pyrite in roughly stratabound zones are reported. The volcanic hostrocks exhibit abundant epidote with associated calcite and chlorite.
- Intrusion-related: Sericitization, in places with clay alteration and chloritization.

WEATHERING: Malachite or azurite staining; silicified linear “ridges”.

ORE CONTROLS: Veins and associated dikes follow faults. Ore shoots commonly localized along dilational bends within veins. Sulphides may occur preferentially in parts of veins which crosscut carbonate or other favourable lithologies. Intersections of veins are an important locus for ore.

GENETIC MODEL: The metasediment and volcanic-hosted veins are associated with major faults related to crustal extension which control the ascent of hydrothermal fluids to suitable sites for deposition of metals. The fluids are believed to be derived from mafic intrusions which are also the source for compositionally similar dikes and sills associated with the veins. Intrusion-related veins, like Butte in Montana and Rosario in Chile, are clearly associated with high- level felsic to intermediate intrusions hosting porphyry Cu deposits or prospects.

ASSOCIATED DEPOSIT TYPES:

- Metasediment and volcanic-hosted: Possibly related to sediment-hosted Cu (E04) and basaltic Cu (D03).
- Intrusion-related: High sulphidation (H04), copper skarns (K01), porphyries (L01?, L03, L04) and polymetallic veins (I05).

COMMENTS: CuñAg quartz veins are common in copper metallogenetic provinces; they often are more important as indicators of the presence of other types of copper deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: High Cu and Ag in regional silt samples. The Churchill-type deposits appear to have very limited wallrock dispersion of pathfinder elements; however, alteration halos of silica and carbonate addition or depletion might prove useful. Porpyhyry-related veins exhibit many of the geochemical signatures of porphyry copper systems.

GEOPHYSICAL SIGNATURE: Large veins with conductive massive sulphides may show up as electromagnetic conductors, particularly on ground surveys. Associated structures may be defined by ground magnetic, very low frequency or electromagnetic surveys. Airborne surveys may identify prospective major structures.

OTHER EXPLORATION GUIDES: Commonly camp-scale or regional structural controls define a dominant orientation for veins.

ECONOMIC FACTORS

GRADE AND TONNAGE: Typically range from 10 000 to 100 0000 t with grades of 1 to 4% Cu, nil to 300 g/t Ag. The Churchill deposit has reserves of 90 000 t of 3 % Cu and produced 501 019 t grading 3% Cu and the Davis-Keays deposit has reserves of 1 119 089 t grading 3.43 % Cu. The Big Bull deposit has reserves of 732 000 t grading 1.94% Cu. The intrusion-related veins range up to millions of tonnes with grades of up to 6% Cu. The Butte veins in Montana have produced several hundred million tonnes of ore with much of this production from open-pit operations.

ECONOMIC LIMITATIONS: Currently only the large and/or high-grade veins (usually associated with porphyry deposits) are economically attractive.

IMPORTANCE: From pre-historic times until the early 1900s, high-grade copper veins were an important source of this metal. With hand sorting and labour-intensive mining they represented very attractive deposits.

REFERENCES

ACKNOWLEDGEMENTS: This deposit profile represents the results of a literature review. It benefited from comments by David Sinclair and Vic Preto.

Benes, K. and Hanus, V. (1967): Structural Control and History of Origin of Hydrothermal Metallogeny in Western Cuba; Mineralium Deposita, Volume 2, pages 318-333.
Carr, J.M. (1971): Geology of the Churchill Copper Deposit; The Canadian Institute of Mining and Metallurgy, Bulletin, Volume 64, pages 50-54.
Hammer, D.F. and Peterson, D.W. (1968): Geology of the Magma Mine Arizona; in Ore Deposits of the United States 1933-1967, Ridge, J.D., Editor, American Institute of Mining Engineers, New York, pages 1282-1310.
Kirkham, R.D. (1984): Vein Copper; in Canadian Mineral Deposit Types: A Geological Synopsis, Eckstrand, O.R., Editor, Geological Survey of Canada, Economic Geology Report 36, page 65.
Kirkham, R.D. and Sinclair, W.D. (in press): Vein Copper; in Geology of Canadian Mineral Deposit Types, Eckstrand, O.R., Sinclair, W.D. and Thorpe, R.I., (Editors), Geological Survey of Canada, Geology of Canada, No. 8, pages 383-392.
Kish, S.A. (1989): Post-Acadian Metasomatic Origin for Copper-bearing Vein Deposits of the Virgilina District, North Carolina and Virginia; Economic Geology, Volume 84, pages 1903-1920.
Laznicka, P. (1986): Empirical Metallogeny, Depositional Environments, Lithologic Associations and Metallic Ores, Volume 1, Phanerozoic Environments, Associations and Deposits; Elsevier, New York, 1758 pages.
Nockleberg, W.J., Bundtzen, T.K., Berg, H.C., Brew, D.A., Grybeck, D., Robinson, M.S., Smith, T.E. and Yeend, W. (1987): Significant Metalliferous Lode Deposits and Placer Districts of Alaska, U.S. Geological Survey, Bulletin 1786, 104 pages.
Pearson, W.N. (1979): Copper Metallogeny, North Shore of Lake Huron, Ontario; in Current Research, Part A, Geological Survey of Canada, Paper 79-1A, pages 289-304.
Pearson, W.N., Bretzlaff, R.E. and Carriere, J.J. (1985): Copper Deposits and Occurrences in the North Shore Region of Lake Huron, Ontario; Geological Survey of Canada, Paper 83-28, 34 pages.
Preto, V.A. (1972): Lode Copper Deposits of the Racing River - Gataga River Area; in Geology, Exploration and Mining in British Columbia 1971, B. C. Ministry of Energy, Mines and Petroleum Resources, pages 75-107.
Roberts, A.E. (1973): The Geological Setting of Copper Orebodies at Inyati Mine, Headlans District, Rhodesia; Geological Society of South Africa, Special Publication 3, , pages 189-196.

[Back to top]

SILICA-CARBONATE Hg

I08

by Chris Ash
British Columbia Geological Survey

Ash, Chris (1996): Silica-carbonate Hg, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 75-76.

IDENTIFICATION

SYNONYMS: Serpentinite-type, listwanite-type.

COMMODITIES (*BYPRODUCTS*): Hg (Sb, Ag, Au).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Pinchi (093K 049), Bralorne Takla (093N 008), Eagle Mercury (092JNE062), Silverquick (092O 017), Manitou (092O 023); *New Almaden, New Idria (California, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cinnabar occurs associated with quartz and carbonate alteration in zones of intense brittle fracturing at relatively shallow levels along major fault zones. Commonly occur in areas of active geothermal systems.

TECTONIC SETTING: Within orogenic belts.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: At shallow levels within high-angle, regional-scale, deep crustal faults marked by the presence of ophiolitic ultramafic rocks. Typically at brittle faulted contacts between competent lithologies, e.g. carbonate-altered ultramafics, limestone, etc. Locally associated with recent volcanism and hotspring activity. Mercury deposits in B.C. are concentrated along several north to northwest-trending, high-angle transcurrent fault zones which border oceanic terranes. These include the Pinchi, Yalakom and Germansen faults.

AGE OF MINERALIZATION: Eocene to Recent?

HOST/ASSOCIATED ROCK TYPES: Serpentinite, limestone, siltstone, graywacke, conglomerate, mafic volcanic rocks.

DEPOSIT FORM: Deposits are typically highly irregular within major fault zones.

TEXTURE/STRUCTURE: Thin discontinuous stringers or fracture and cavity coatings in areas of shattering and brecciation along major faults.

ORE MINERALOGY (Principal and *subordinate*): Cinnabar, native mercury (quicksilver), metacinnabar, livingstonite (HgSb4S9).

GANGUE MINERALOGY: Pyrite, marcasite, quartz, carbonate, limestone, serpentinite.

ALTERATION MINERALOGY: "Silica-carbonate rock" or "listwanite/listvenite", magnesite, ankerite, dolomite, quartz, chalcedony, kaolinite, sericite (fuchsite/mariposite).

WEATHERING: Mineralized areas display distinctive limonite stain due to the presence of iron carbonates.

ORE CONTROLS: High-angle fault zones marginal to accreted oceanic terranes. In general, grade of ore increases with fracture density in the hostrock.

GENETIC MODELS: Deposits form where relatively low temperature (between 100o and 200oC) CO2-H2O aqueous fluids (< 2 wt. % chlorine), charged with Hg migrate upward along permeable fault zones and precipitate cinnabar in fractured hostrocks at shallow levels due to cooling and mixing with meteoric water. At this stage a vapour phase evolves which emanates from hotsprings at surface.

ASSOCIATED DEPOSIT TYPES: Sb veins.

COMMENTS: Due to the liquid state of this metal, mercury is generally measured in “flasks” and quoted in dollar value per flask. Flasks are standard steel containers that hold 76 lb (about 2.5 L) of the liquid metal.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Hg, Sb (Cu, Zn).

GEOPHYSICAL SIGNATURE: Not generally applicable.

OTHER EXPLORATION GUIDES: Soil, stream sediment and geobotanical sampling for Hg has proven successful. The spatial association of hotsprings with major fault zones associated with ophiolitic ultramafic rocks.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Deposits of this type are typically less than 1 Mt, but may be up to several million tonnes with mercury grades averaging 0.5% and ranging from 0.2 to 0.8%.

ECONOMIC LIMITATIONS: The low grade of these deposits relative to other mercury deposit types, extreme fluctuations in the price of the metal, and inherent pollution problems are all factors in the economics of this deposit type.

IMPORTANCE: Although historically significant as a source of mercury, these deposits are not currently mined due to their low grades and small size relative to the much larger and richer Almaden-type mercury deposits. The only significant past-producing mines in B.C. include the Pinchi and Bralorne Takla. Both deposits are along the Pinchi fault.

REFERENCES

Armstrong, J.E. (1966): Tectonics and Mercury Deposits in British Columbia; in Tectonic History and Mineral Deposits of the Western Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume No. 8, pages 341-348.
Bailey, E.H., Clark, A.L. and Smith, R.M. (1973): Mercury; in United States Mineral Resources, Brobst, D.A. and Pratt, W.P., Editors, U.S. Geological Survey, Professional Paper 820, pages 401-414.
Barnes, I., O’Neill, J.R., Rapp, J.B. and White, D.E. (1973): Silica-Carbonate Alteration of Serpentinite: Wall Rock Alteration in Mercury Deposits of the California Coast Ranges; Economic Geology, Volume 68, pages 388-398.
Henderson, F.B. (1969): Hydrothermal Alteration and Ore Deposition in Serpentinite-type Mercury Deposits; Economic Geology, Volume 64, 489-499.
Rytuba, J.J. (1986): Descriptive Model of Silica-Carbonate Hg; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 181.
Rytuba, J.J. and Cargill, S.M. (1986): Grade and Tonnage Model of Silica-Carbonate Hg; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, pages 181-182.

Stevenson, S.J. (1940): Mercury Deposits of British Columbia; B.C. Department of Mines, Bulletin Number 5, 93 pages.
Studemeister P.A. (1984): Mercury Deposits of Western California: An Overview; Mineralium Deposita, Volume 19, pages 202-207.
Varekamp J.C. and Buseck P.R. (1984): The Speciation of Mercury in Hydrothermal Systems, with Applications to Ore Deposition; Geochimica and Cosmochimica Acta, Volume 48, pages 177-185.

[Back to top]

STIBNITE VEINS and DISSEMINATIONS

I09

by Andre Panteleyev
British Columbia Geological Survey

Panteleyev, Andre (1996): Stibnite Veins and Disseminations, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 77-80.

IDENTIFICATION

SYNONYMS: Quartz-stibnite, simple antimony, syntectonic stibnite, mesothermal Sb-Au.

COMMODITIES (*BYPRODUCTS*): Sb (Au).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): a) Veins - Minto (092JNE075) and Congress (092JNE029), Bridge River area; Snowbird (093K 036); *Becker-Cochran (Yukon, Canada), Lake George (New Brunswick, Canada), Beaver Brook (Newfoundland, Canada), Murchison Range deposits (South Africa), Caracota and numerous other deposits in the Cordillera Occidental (Bolivia). b) Disseminated - Caracota and Espiritu Santo (Bolivia), many deposits (Turkey).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stibnite veins, pods, disseminations and stibnite-bearing quartz and quartz-carbonate veins occur in, or adjacent to, shears, fault zones and brecciated rocks in sedimentary or metasedimentary sequences.

TECTONIC SETTING: Any orogenic area, particularly where large-scale fault structures are present.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Fault and shear zones, notably in fault splays and fault-related breccias in which shallow to intermediate-depth hydrothermal systems have been operative.
AGE OF MINERALIZATION: Deposits range from Paleozoic to Tertiary age.

HOST/ASSOCIATED ROCK TYPES: Any faulted lithologies with a wide variety of rock types; sedimentary and metasedimentary rocks are commonly present. British Columbia deposits tend to be near major fault zones with attendant serpentinized mafic and ultramafic rocks.

DEPOSIT FORM: Stibnite occurs in veins; also as fine to coarse grains in sheared or brecciated rocks. Some stibnite is disseminated in carbonate-altered wallrocks surrounding structures and may form within pressure shadows at crests of folds. Massive stibnite-pyrite replacements which may form pods or lenses up to tens of metres long, are relatively uncommon, but are sources of rich ore.

TEXTURE/STRUCTURE: Veins have fine to coarse-grained, commonly euhedral bladed crystals of stibnite, quartz and carbonate in masses of stibnite. Quartz and quartz-carbonate gangue minerals range from fine to coarse grained, commonly with white 'bull quartz" present.

ORE MINERALOGY (Principal and *subordinate*): Stibnite, pyrite, arsenopyrite; sphalerite, galena, tetrahedrite, marcasite, chalcopyrite, jamesonite, berthierite, gold, cinnabar, scheelite, argentite and sulphosalt minerals. Other than stibnite, the overall sulphide content of the veins is low.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, calcite, dolomite; chalcedony, siderite, rare barite and fluorite.

ALTERATION MINERALOGY: Quartz-carbonate envelopes on veins; some silicification, sericite, and intermediate argillic alteration. Chlorite, serpentinization and 'listwanite' (quartz-carbonate-talc-chromian mica-sulphide minerals) green- coloured alteration may be present when mafic and untramafic rocks are involved.

WEATHERING: Stibnite weathers to various oxides of yellowish (kermsite) or whitish (cerrantite or stibiconite) colour.

ORE CONTROLS: Fissure, shear zones and breccia associated with faults. Some open-space filling in porous rocks and structurally induced openings (joints, saddle reefs, ladder veins). Minor replacement in limestones.

GENETIC MODEL: The origin is not well documented. Deposits are spatially closely associated with, and in many ways resemble, low-sulphide gold-quartz (mesothermal) veins. Their (mutual) origin is thought to be from dilute, CO2 rich fluids generated by metamorphic dehydration. Structural channelways focus the hydrothermal fluids during regional deformation. Some deposits are associated with felsic intrusive bodies, for example a Tertiary rhyolite plug at Becker-Cochran deposit, Yukon, and with porphyry W-Mo mineralization in granitic rocks at the Lake George Sb deposit, New Brunswick.

ASSOCIATED DEPOSIT TYPES: Quartz-carbonate gold (low-sulphide gold-quartz vein or I01), polymetallic vein Ag-Pb-Zn (I05), epithermal Au-Ag: low sulphidation (H05), hotspring Au-Ag (H03), Sn-W vein (??), W-Mo porphyry (L07); silica-carbonate Hg (I08), placer gold (C01, C02); possibly Carlin-type sediment-hosted Ag-Ag (E03).

COMMENTS: Occurrences of typical stibnite veins in the Bridge River gold camp in British Columbia were thought to be part of a regional deposit zoning pattern. The deposits are now known to be younger than the gold deposits by about 15-20 Ma. Farther north, the Snowbird deposit near Stuart Lake, has been shown to be Middle Jurassic in age by radiometric dating and is interpreted to be related to large-scale crustal structures. This deformation possibly involves the Pinchi fault system in which the largest known mercury deposits in the province are found.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sb, As, Au, Ag, Pb, Zn; locally W or Hg.

GEOPHYSICAL SIGNATURE: VLF surveys may detect faults.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Veins typically have high grade but small ore shoots; the disseminated deposits are also relatively small. Grade-tonnage data from 81 “typical” vein deposits (predominately, hand-sorted ore from USA mines) is 180 t with 35 % Sb; 10 % of the deposits contained > 1 g/t Au and > 16 g/t Ag. The disseminated deposits average 88 000 t with an average grade of 3.6 % Sb.

ECONOMIC LIMITATIONS: Antimony is a low-priced metal so only high-grade deposits are mined. Deposits (veins and disseminations) containing gold offer the best potential.

IMPORTANCE: Bolivia, Turkey and China dominate the antimony market; Cordilleran production will likely be only as a byproduct from precious metal bearing deposits.

REFERENCES

Bliss, J.D. and Orris, J. (1986): Descriptive Model of Simple Sb Deposits (and Disseminated Sb Deposits); in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, pages 183-188.
Lehrberger, G. (1988): Gold-Antimonite Deposits in Marine Sediments of the Eastern Cordillera of the Bolivian Andes; in Bicentennial Gold `88, Geological Society of Australia, Extended Abstracts: Poster Session, Volume 23, pages 319-321.
Madu, B.E., Nesbitt, B.E. and Muehlenabachs, K. (1990): A Mesothermal Gold-Stibnite-Quartz Vein Occurrence in the Canadian Cordillera; Economic Geology, Volume 85, pages 1260-1268.
Nesbitt, B.E., Muehlenbachs, K. and Murowchick, J.B. (1989): Genetic Implications of Stable Isotope Characteristics of Mesothermal Au Deposits and Related Sb and Hg Deposits in the Canadian Cordillera; Economic Geology, Volume 84, pages 1489-1506.
Seal, R.R.,II, Clark, A.H., and Morissy, C.J. (1988): Lake George, Southeastern New Brunswick; A Silurian, Multi-stage, Polymetallic (Sb-W-Mo-Au-Base Metal) Hydrothermal Centre; in Recent Advances in the Geology of Granite-Related Mineral Deposits; Taylor, R.P. and Strong, D.F., Editors, Canadian Institute of Mining and Metallurgy, CIM Special Volime 39, pages 252-264.
Wu, J. (1993): Antimony Vein Deposits of China; in Vein-type Ore Deposits, Ore Geology Reviews, Haynes, S.J., Editor, Volume 8, pages 213-232.

[Back to top]

VEIN BARITE

I10

by Z.D. Hora
British Columbia Geological Survey

Hora, Z.D. (1996): Vein Barite, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 81-84.

IDENTIFICATION

SYNONYM: Epigenetic vein barite.

COMMODITIES (*BYPRODUCTS*): Barite (Ag, Pb, Zn, Cu).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Parson (082N 002), Brisco (082KNE013), Fireside (094M 003); *Matchewan (Ontario, Canada), Lake Ainslie (Nova Scotia, Canada), Collier Cove (Newfoundland, Canada), Nevada, Montana, Virginia, Pennsylvania, Georgia in USA; Bonarta, Jbel Ighoud (Morocco); Wolfach, Bad Lauterberg (Germany); Roznava (Slovakia), China.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Barite in fissure-filling voids resulting from mechanical deformation, including dilatant zones along faults and folds, gash fractures, joints and bedding planes; also in shear and breccia zones along faults.

TECTONIC SETTINGS: Highly varied, frequently but not exclusively at or near the margins of basins with sedex or Kuroko type deposits, or abrupt deep basin- platform sedimentation facies change.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Highly varied; almost any type of sedimentary, metamorphic or intrusive rocks. Veins associated with regional faults and lineaments, also the breccia zones along the margins of rift basins. In carbonate rocks, barite may fill karst cavities and collapse structures and forms manto-like replacement orebodies.

AGE OF MINERALIZATION: Precambrian to Tertiary.

HOST/ASSOCIATED ROCK TYPES: Any sedimentary, metamorphic or even igneous rocks.

DEPOSIT FORM: Tabular/lenticular bodies and breccias, collapse breccias and related cavity fills, veins with manto-type orebodies in carbonate hostrocks. The veins are several hundreds up to over 1000 m in length and sometimes up to 20 m thick. Some veins are mined to the depth of 500 m from surface.

TEXTURE/STRUCTURE: Massive, banded, brecciated. Texture typical of high-level veins, occasional druzy textures.

ORE MINERALOGY (Principal and *subordinate*): Barite, fluorspar, siderite, Pb-Zn-Cu sulphides.

GANGUE MINERALOGY: (Principal and *subordinate*): Quartz, calcite, siderite, witherite, barytocalcite, cinnabar, pyrite.

ALTERATION MINERALOGY: Insignificant.

WEATHERING: Barite float and detrital fragments as a result of physical weathering.

ORE CONTROLS: Dominant structural control with veins along faults, fractures, and shear zones, sometimes related to dilatant zones in major fault systems.

GENETIC MODEL: Epithermal barite veins, with or without sulphides, are common at and near the margins of rift basins, both in continental and continental margin settings. The veins and orebodies occur as open-space fillings in high-angle faults or fractures in sedimentary rocks or adjacent crystalline rocks, sills, and irregular and stratabound collapse structures or mantos. The source fluids are inferred to have been brines of moderate salinity (10 to 16 equivalent weight percent NaCl) and temperatures of 100 degrees to 250 degrees C. Pre-existing fractures and faults are apparently important in localizing the veins and orebodies. Multiple mineralizing episodes and several pulses of fluid migration are evident in many of the vein systems.

ASSOCIATED DEPOSIT TYPES: Polymetallic veins (I05) and replacement deposits (J01, E10-E12), sedex (E14) and Kuroko massive sulphide (G06) deposits, carbonatites (N03).

COMMENTS: This type of barite vein is distinct from barite associated with fluorspar veins. These (fluorspar-barite) veins may have, at least in part, a different barium source and are closely associated with Mississippi Valley type deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Ba, Sr, sometimes Hg, Ag, Pb, Zn and Cu anomalies in soils and silts.

GEOPHYSICAL SIGNATURE: Linear gravity highs over large veins.

OTHER EXPLORATION GUIDES: Clastic barite in stream sediments, both in sand and silt fractions.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Most deposits in production are selectively mining high-grade orebodies with over 80% barite. The deposit size varies from a few thousand up to some 3 Mt. Brisco mine produced approximately 250,000 tonnes during its life; Parson is expected to produce close to 1 Mt.

ECONOMIC LIMITATIONS: Dependant on the end use. White, high-purity barite is suitable for filler and chemical applications and can be mined from even very small deposits. Drilling mud is a lower priced grade and, if processing is required to reach the required 4.2 specific gravity, only large deposits can be operated successfully. Even a small amount of contamination by siderite or witherite may make the barite unusable in drilling mud applications. Barite which is contaminated with small quantities (ppm) of heavy metals like Pb, Zn, Cu and Hg may result in environmental problems with disposal of spent drilling mud.

END USES: Drilling muds, fillers, chemicals, radiation shields, speciality glass and ceramics.

IMPORTANCE: Probably the main source of barite worldwide, but in North America very subordinate to bedded barite deposits.

REFERENCES

Brobst, D.A. (1984): The Geological Framework of Barite Resources; The Institution of Mining and Metallurgy, Transactions Volume 93, pages A123-A130.
Dawson, K.R. (1985): Geology of Barium, Strontium, and Fluorine Deposits in Canada; Economic Geology Report 34, Geological Survey of Canada, 135 pages.
Harben, P.W. and Bates, R.L. (1990): Industrial Minerals Geology and World Deposits; Metal Bulletin, London, 312 pages.
Hofmann, R. and Baumann A. (1984): Preliminary Report on the Sr Isotopic Composition of

Hydrothermal Vein Barites in the Federal Republic of Germany; Mineral Deposita, Volume 19, pages 166-169.
Kuzvart, M. (1984): Deposits of Industrial Minerals; Academia, Prague, 440 pages. Leach, D.L. (1980): Nature of Mineralizing Fluids in the Barite Deposits of Central and Southeast Missouri; Economic Geology, Volume 75, pages 1168-1180.
Maynard, J.B. and Okita, P.M. (1991): Bedded Barite Deposits in the United States, Canada, Germany, and China: Two Major Types Based on Tectonic Setting; Economic Geology, Volume 86, pp. 364-376.
Morrow, D.W., Krouse, H.R., Ghent, E.D., Taylor, G.C. and Dawson, K.R. (1978): A Hypothesis Concerning the Origin of Barite in Devonian Carbonate Rocks of North- eastern British Columbia; Canadian Journal of Earth Sciences, Volume 15, pages 1391 - 1406.
Papke, K.G. (1984): Barite in Nevada; Nevada Bureau of Mines and Geology, Bulletin 98, 125 pages.
Robinson, G.R. Jr., and Woodruff, L.G. (1988): Characteristics of Base-metal and Barite Vein Deposits associated with Rift Basins, with Examples from some Early Mesozoic Basins of Eastern North America, in Studies of Early Mesozoic Basins of the Eastern US, Frolich, T.J. and Robinson, G.R. Jr., Editors, US Geological Survey, Bulletin 1776, pages 377-390.

[Back to top]

VEIN FLUORITE-BARITE

I11

by Z.D. Hora
British Columbia Geological Survey

Hora, Z.D. (1996): Vein Fluorite-barite, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 85-88.

IDENTIFICATION

SYNONYM: Epigenetic fluorite/barite vein.

COMMODITIES (BYPRODUCTS): Fluorite, sometimes barite (occasionally Pb, Zn, and Cu. Some fluorites contain the recoverable Be minerals bertrandite and phenacite.

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Rock Candy (082ESE070), Eaglet (093A 046), Rexspar (082M 007); *Madoc (Ontario, Canada); St. Lawrence (Newfoundland, Canada); Nevada, Utah, New Mexico (USA); Nabburg- Woelsendorf, Ilmenau, Schoenbrunn (Germany); Torgola, Prestavel, Gerrai (Italy); Auvergne, Morvan (France); Mongolia, China.*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Fluorite and barite fill dilatant shear and breccia zones along faults and folds, gash fractures, joints and bedding planes as well as stockworks. In carbonate rocks, the fissure veins are frequently associated with replacement bodies and mantos. Fluorite veins commonly show affinities with barite veins and may grade into polymetallic veins with barite gangue.

TECTONIC SETTINGS: Highly varied - but in terrains underlain by sialic crust. In young orogenic belts: postorogenic and lateorogenic granite intrusions or rift-related alkaline rocks (from syenites to nepheline syenites to carbonatites) may be associated with fluorite veins. In old orogenic belts: proximity of major tectonic zones, grabens, tensional rifts and lineaments.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Highly varied, sometimes linked to volatile-rich intrusives of alkaline to granite composition. In the Cordillera, topaz rhyolites, particularly, are associated with many fluorite veins.

AGE OF MINERALIZATION: Precambrian to Tertiary; in B.C. Devono-Mississippian (Rexspar), Cretaceous (Eaglet) and Tertiary (Rock Candy).

HOST/ASSOCIATED ROCK TYPES: Any sedimentary, metamorphic or igneous rock; in volcanic environment usually associated with topaz rhyolite.

DEPOSIT FORM: Tabular or lenticular bodies and breccias or stockworks and breccia pipes. The veins are usually 1-5 m thick and may be over a 1000 m long. Some particularly large veins in Sardinia are 3 km in length; the Torgola vein is reported to be 20 m thick. Some vein deposits were mined up to 500 m below surface, however the usual mining depth is 200 to 300 m down the dip from the outcrop.

TEXTURE/STRUCTURE: Massive, banded, brecciated. Drusy textures are common, fluorspar may be coarse grained or fine grained with radiating texture. Banding of different colour varieties of fluorspar is very common (coontail type). Bands of barite in fluorite, or young silica replacement of fluorspar along the cleavage and crystal borders are common features.

ORE MINERALOGY (Principal and *subordinate*): Fluorite, barite, celestite, barytocalcite, galena, sphalerite, chalcopyrite, pyrite, adularia or K-feldspar, red jasper. Dark purple fluorite may contain uraninite. Bertrandite and other Be minerals are sometimes accessory components. Fluorite is often the main or even only vein mineral.

GANGUE MINERALOGY: (Principal and *subordinate*) Gangue may be a variety of minerals such as quartz, chalcedony, jasper, barite and Ca-Fe-Mg carbonates. Barite commonly varies in colour from yellow to pink or red; jasper may have a red colour due to finely dispersed haematite.

ALTERATION MINERALOGY: Kaolinization and/or silicification of wallrocks, sometimes pervasive potassic alteration (Eaglet, Rexspar); occasionally montmorillonite in wallrocks.

WEATHERING: Physical weathering mostly; in high-sulphide environment fluorspar may be dissolved by sulphuric acid. Floats of vein quartz with voids after weathered out fluorspar crystals are a common feature.

ORE CONTROLS: Faults, fractures, shear zones. Vertical zoning of veins is a common feature, but not very well understood.

GENETIC MODEL: Fluorite veins are generally found in the proximity of continental rifts and lineaments. In young orogenic belts fluorite can be linked to late or postorogenic granitic intrusions, particularly in areas of sialic crust. Rift- related alkaline intrusions are also linked to some fluorite veins. In old orogenic belts, fluorite veins are also in fracture zones within major faults and graben structures which facilitated circulation of mineralized fluids far from original fluorine source. Fluorite is precipitated from fluids by cooling low-pH solutions or by an increase in the pH of acid ore fluids. The fluids usually have a high Na/K ratio.

ASSOCIATED DEPOSIT TYPES: Pb-Zn veins (I05), carbonatite plugs, dikes and sills with Nb-REE (N02); Sn-W greisen (I13), F/Be deposits (Spor Mountain), Pb-Zn mantos (J01) and Mississippi Valley type deposits (E10, E11, E12).

COMMENT: End uses of fluorine chemicals in aluminium and chemical industries are very sensitive to P and As contents of only a few ppm.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: F in stream waters.

GEOPHYSICAL SIGNATURE: Sometimes gamma radiometric anomalies as an expression of potassic alteration or uranium content in certain types of fluorite.

OTHER EXPLORATION GUIDES: Fault control in some districts; regional silicified zones and major quartz veins.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Past producers reported grades in general between 30% and 60% fluorite, with occasional higher grade orebodies. The deposit size varies; up to 6 Mt. In B.C., Eaglet reported 1.8 million tonnes of 15% CaF2, Rexspar 1.4 million tonnes of 23% CaF2.

ECONOMIC LIMITATIONS: In recent years, shipments of high quality fluorspar from China, at very low prices, resulted in the collapse of most fluorspar production centres worldwide.

END USES: Metallurgy of aluminum and uranium, fluorine chemicals, flux in iron and steel metallurgy, glass and ceramics.

IMPORTANCE: Main source of fluorspar worldwide. In B.C., the Rock Candy mine produced 51,495 t of 68% CaF2 between 1918 and 1929.

REFERENCES

Brecke, E.A. (1979): A Hydrothermal System in the Midcontinent Region; Economic Geology, Volume 74, pages 1327-1335
Burt, D.M., Sheridan, M.F., Bikun, J.V. and Christiansen, E.H. (1982): Topaz Rhyolites Distribution, Origin and Significance for Exploration, Economic Geology, Volume 77, pages 1818-1836
Dawson, K.R. (1985): Geology of Barium Strontium and Fluorine Deposits in Canada; Economic Geology Report 34; Geological Survey of Canada, 135 pages.
Deloule, E. (1982): The Genesis of Fluorspar Hydrothermal Deposits at Montroc and Le Burc, the Tarn, as Deduced from Fluid Inclusion Analysis; Economic Geology, Volume 77, pages 1867-1874.
Harben, P.W. and Bates, R.L. (1990): Industrial Minerals Geology and World Deposits; Metal Bulletin, London, 135 pages.
Kesler, S.E., Gesing, J.A., and Haynes, F.M. (1989): Evolution of Minerallizing Brines in the East Tennessee Mississipi Valley - type Ore Field; Geology, Volume 17, pages 466-469.
Kuzvart, M. (1984): Deposits of Industrial Minerals; Academia, Prague, 440 pages.
McAnulty, W.N. (1978): Fluorspar in New Mexico; New Mexico Bureau of Mines and Mineral Resources, Memoir 34, 64 pages.
Orris, G.J. and Bliss, J.D. (1992): Industrial Minerals Deposit Models: Grades and Tonnage Models; U.S. Geological Survey, Open File Report 92- 431, 84 pages.
Papke, K.G. (1979): Fluorspar in Nevada; Nevada Bureau of Mines and Geology, Bulletin 9377 pages. Pell, J. (1992): Fluorspar and Fluorine in British Columbia, B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1992-16, 82 pages.
VanAlstine, R.E. (1976): Continental Rifts and Lineaments Associated with Major Fluorspar Districts; Economic Geology, Volume 71, pages 977-987.

[Back to top]

FIVE-ELEMENT VEINS

Ag-Ni-Co-As+/-(Bi, U)

I14
by David V. Lefebure
British Columbia Geological Survey

Lefebure, D.V. (1996): Five-element Veins Ag-Ni-Co-As+/-(Bi,U), in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 89-92.

IDENTIFICATION

SYNONYMS: Five-element (Ni-Co-As-Ag-Bi) veins, nickel-cobalt-native silver veins, Cobalt-type silver-sulpharsenide veins, Ni-Co-Bi-Ag-U (As) association, Ag- As (Ni,Co,Bi) veins, Schneeberg-Joachimsthal-type.

COMMODITY (*BYPRODUCTS*): Ag, U, Ni, Co, Bi (barite).

EXAMPLES (British Columbia - *Canada/International*): No B.C. examples; *Beaver and Timiskaming, Cobalt camp, Silver Islet, Thunder Bay district (Ontario, Canada), Echo Bay and Eldorado (Port Radium, Northwest Territories, Canada), Black Hawk district (New Mexico, USA), Batopilas district (Mexico), Johanngeogenstadt, Freiberg and Jachymov, Erzgebirge district (Germany), Konsberg-Modum (Norway).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Native silver occurs in carbonate veins associated with a variety of mineral assemblages that are rare in other settings, such as Ni- Co-Fe arsenides, Ni-Co-Fe-Sb sulpharsenides and bismuth minerals. In many cases only some of these minerals are present, although the best examples of this deposit type typically contain significant Ag-Ni-Co. In some deposits uraninite (pitchblende) is an important ore mineral.

TECTONIC SETTINGS: Virtually all occur in areas underlain by continental crust and are generally believed to have formed late or post-tectonically. In some cases the veins appear related to basinal subsidence and continental rifting.

DEPOSTIONAL ENVIRONMENT/GEOLOGICAL SETTING: Veins are believed to be emplaced at shallow depths in a continental setting along high-angle fault systems.

AGE OF MINERALIZATION: Proterozoic or younger, can be much younger than hostrocks.

HOST/ASSOCIATED ROCK TYPES: Found in a wide variety of hostrocks, although metasediments, metamorphosed intrusive rocks and granitic sequences are the most common. Diabase sills are an important host in the Cobalt camp and a number of the deposits in the Thunder Bay region are within a gabbro dike.

DEPOSIT FORM: Simple veins and vein sets. Veins vary from centimetre to metre thicknesses, typically changing over distances of less than tens of metres. Most vein systems appear to have limited depth extent, although some extend more than 500 m.

TEXTURE/STRUCTURE: Commonly open space filling with mineral assemblages and textures commonly due to multiple episodes of deposition. Sulphides are irregularly distributed as massive pods, bands, dendrites, plates and disseminations. The mineralization is more common near the interesections of veins or veins with crosscutting faults. Fragments of wallrock are common in some veins. Faults may be filled with graphite-rich gangue, mylonite or breccia.

ORE MINERALOGY (Principal and *subordinate*): Native silver associated with Ni-Co arsenide minerals (rammelsbergite, safflorite, niccolite, cloanthite, maucherite), sulpharsenides of Co, Ni, Fe and Sb, native bismuth, bismuthinite, argentite, ruby silver, pyrite and uraninite (pitchblende). Chalcopyrite, bornite and chalcocite are common, but minor, constituents of ore. Minor to trace galena, tetrahedrite, jamesonite, cosalite, sphalerite, arsenopyrite and rare pyrrhotite. In many deposits only a partial mineral assemblage occurs containing a subset of the many elements which may occur in these veins. These veins are characterized by the absence of gold.

GANGUE MINERALOGY (Principal and *subordinate*): Calcite and dolomite are usually associated directly with native silver mineralization; quartz, jasper, barite and fluorite are less common. The carbonate minerals are common in the cores of some veins.

ALTERATION MINERALOGY: Not conspicuous or well documented. In the Cobalt camp calcite and chlorite alteration extends 2-5 cm from the vein, approximately equivalent in width to the vein.

WEATHERING: No obvious gossans because of the low sulphide content; locally “cobalt bloom”.

ORE CONTROLS: Veins occupy faults which often trend in only one or two directions in a particular district. Ore shoots may be localized at dilational bends within veins. Intersections of veins are an important locus for ore. Possibly five-element veins are more common in Proterozoic rocks.

GENETIC MODEL: In regions of crustal extension, faults controled the ascent of hydrothermal fluids to suitable sites for deposition of metals at depths of approximately 1 to 4 km below surface. The fluids were strongly saline brines at temperatures of 150ø to 250øC, which may have been derived from late-stage differentiation of magmas, convective circulation of water from the country rocks driven by cooling intrusive phases or formation brines migrating upwards or towards the edge of sedimentary basins. Sulphide-rich strata (including Fahlbands) and carbonaceous shales in the stratigraphy are potential sources of the metals. Deposition occurs where the fluid encounters a reductant or structural trap.

ASSOCIATED DEPOSIT TYPES: ‘Classical’ U veins (I15), polymetallic veins (I05). In the Great Bear Lake area there are associated “giant” quartz veins with virtually no other minerals.

COMMENTS: Several Co-AgñNiñBi veins are found in the Rossland Camp in British Columbia. These may be five-element veins, however, they also contain the atypical elements Au and Mo.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: The rare association of anomalous values of Ag with Ni, Co, Bi, U and As in rock samples is diagnostic.

GEOPHYSICAL SIGNATURE: Associated structures may be defined by ground magnetic or VLF-EM surveys. Airborne surveys may identify prospective major structures. Gamma ray scintillometers and spectrometers can be used to detect the uraninite-bearing veins in outcrop or in float trains in glacial till, frost boils, talus or other debris.

OTHER EXPLORATION GUIDES: Commonly camp or regional structural controls will define a dominant orientation for veins.

ECONOMIC FACTORS

GRADE AND TONNAGE: Typically range from tens of thousands of tonnes to a few hundreds of thousands of tonnes with very high grades of silver (more than 1000 g/t Ag for Canadian mines, with grades up to 30 000 g/t Ag).

IMPORTANCE: There has been no significant production from a native silver vein in British Columbia, however, these veins have historically been an important Canadian and world source of Ag and U with minor production of Co. More recently the narrow widths and discontinuous nature of these veins has led to the closure of virtually all mines of this type.

REFERENCES

Andrews, A.J. (1986): Silver Vein Deposits: Summary of Recent Research; Canadian Journal of Earth Sciences, Volume 23, pages 1459-1462.
Andrews, A.J., Owsiacki, L., Kerrich, R. and Strong, D.F. (1986): The Silver Deposits at Cobalt and Gowganda, Ontario. I: Geology, Petrography, and Whole-rock Geochemistry; Canadian Journal of Earth Sciences, Volume 23, pages 1480-1506.
Bastin, E.S. (1939): The Nickel-Cobalt-Native Silver Ore-type; Economic Geology, Volume 34, pages 1-40.
Boyle, R.W. (1968): The Geochemistry of Silver and its Deposits; Geological Survey of Canada, Bulletin 160, 264 pages.
Franklin, J.M., Kissin, S.A., Smyk, M.C. and Scott, S.D. (1986): Silver Deposits Associated with the Proterozoic Rocks of the Thunder Bay District, Ontario; Canadian Journal of Earth Sciences, Volume 23, pages 1576-1591.
Kissan, S.A. (1993): Five-element (Ni-Co-As-Ag-Bi) Veins, in Ore Deposit Models, Sheahan, P.A. and Cherry, M.E., Editors, Geoscience Canada, Reprint Series 6, pages 87-99.
Laznicka, P. (1986): Empirical Metallogeny, Depositional Environments, Lithologic Associations and Metallic Ores, Volume 1: Phanerozoic Environments, Associations and Deposits; Elsevier, New York, pages 1268- 1272.
Rogers, M.C. (1995): Cobalt-type Silver-supharsenide Vein; in Descriptive Mineral Deposit Models of Metallic and Industrial Deposit Types and Related Mineral Potential Assessment Criteria, Ontario Geological Survey, Open File Report 5916, pages 133-136.
Thorpe, R.I. (1984): Arsenide Vein Silver, Uranium; in Canadian Mineral Deposit Types: A Geological Synopsis, Eckstrand, O.R., Editor, Geological Survey of Canada, Economic Geology Report 36, page 63.
Wilkerson, G., Deng, Q., llavon, R. and Goodell, P. (1988): Batopilas Mining District, Chihuahaua, Mexico; Economic Geology, Volume 83, pages 1721- 1736.

[Back to top]

"CLASSICAL" U VEINS

I15

by R.H. McMillan
Consulting Geologist, Victoria, British Columbia

McMillian, R.H. (1996): "Classical" U Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 93-96.

IDENTIFICATION

SYNONYMS: Pitchblende veins, vein uranium, intragranitic veins, perigranitic veins.

COMMODITIES (*BYPRODUCTS*): U (Bi, Co, Ni, As, Ag, Cu, Mo).

EXAMPLES (British Columbia - *Canada/International*): In the Atlin area structurally controlled scheelite-bearing veins host uranium at the Purple Rose, Fisher, Dixie, Cy 4, Mir 3 and IRA occurrences, Ace Fay-Verna and Gunnar, *Beaverlodge area (Saskatchewan, Canada), Christopher Island-Kazan-Angikuni district, Baker Lake area (Northwest Territories, Canada), Millet Brook (Nova Scotia, Canada), Schwartzwalder (Colorado, USA), Xiazhuang district (China), La Crouzille area, Massif Central and Vendee district, Armorican Massif, (France), Jachymov and Pribram districts (Czech Republic), Shinkolobwe (Shaba province, Zaire).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Pitchblende (Th-poor uraninite), coffinite or brannerite with only minor amounts of associated metallic minerals in a carbonate and quartz gangue in veins. These deposits show affinities with, and can grade into, five- element veins which have significant native silver, Co-Ni arsenides, Bi or other metallic minerals.

TECTONIC SETTING: Postorogenic continental environments, commonly associated with calcalkaline felsic plutonic and volcanic rocks. "Red beds" and sediments of extensional successor basins are common in the host sequence. The economic deposits appear confined to areas underlain by Proterozoic basement rocks.

DEPOSITIONAL ENVIRONMENT: Ore is deposited in open spaces within fracture zones, breccias and stockworks commonly associated with major or subsidiary, steeply dipping fault systems.

AGE OF MINERALIZATION: Proterozoic to Tertiary. None are older than approximately 2.2 Ga, the time when the atmosphere evolved to the current oxygen-rich condition.

HOST/ ASSOCIATED ROCK TYPES: A wide variety of hostrocks, including granitic rocks, commonly peraluminous two-mica granites and syenites, felsic volcanic rocks, and older sedimentary and metamorphic rocks. The uranium-rich veins tend to have an affinity to felsic igneous rocks. Some veins are closely associated with diabase and lamprophyre dikes and sills.

DEPOSIT FORM: Orebodies may be tabular or prismatic in shape generally ranging from centimetres up to a few metres thick and rarely up to about 15 m. Many deposits have a limited depth potential of a few hundred metres, however, some deposits extend from 700 m up to 2 km down dip. Disseminated mineralization is present within the alteration envelopes in some deposits.

TEXTURE/STRUCTURE: Features such as drusy textures, crustification banding, colloform, botryoidal and dendritic textures are common in deposits which have not undergone deformation and shearing. The veins typically fill subsidiary dilatant zones associated with major faults and shear zones. Mylonites are closely associated with the St. Louis fault zone at the Ace-Fay-Verna mines.

ORE MINERALOGY (Principal and *subordinate*): Pitchblende (Th-poor uraninite), coffinite, uranophane, thucolite, brannerite, iron sulphides, native silver, Co-Ni arsenides and sulpharsenides, selenides, tellurides, vanadinites, jordesite, chalcopyrite, galena, sphalerite, native gold and platinum group elements. Some deposits have a "simple" mineralogy of with only pitchblende and coffinite. Those veins with the more complex mineralogy are often interpreted to have had the other minerals formed at an earlier or later stage.

GANGUE MINERALOGY (Principal and *subordinate*): Carbonates (calcite and dolomite), quartz (often chalcedonic), hematite, K-feldspar, albite, muscovite, fluorite, barite.

ALTERATION: Chloritization, hematization, feldspathization. A few of the intrusive-hosted deposits are surrounded by desilicated, porous feldspar-mica rock called "episyenite" in the La Crouzille area of France and "sponge-rock" at the Gunnar mine in Saskatchewan. In most cases the hematization is due to oxidation of ferrous iron bearing minerals in the wallrocks during mineralization. The intense brick-red hematite adjacent to some high-grade uranium ores is probably due to loss of electrons during radioactive disintegration of uranium and its daughter products.

WEATHERING: Uranium is highly soluble in the +6 valence state above the water table. It will re-precipitate as uraninite and coffinite below the water table in the +4 valence state in the presence of reducing agents such as humic material or carbonaceous "trash". Some uranium phosphates, vanadinites, sulphates, silicates and arsenates are semi-stable under oxidizing conditions, consequently autunite, torbernite, carnotite, zippeite, uranophane, uranospinite and numerous other secondary minerals may be found in the zone of oxidation , particularly in arid environments.

ORE CONTROLS: Pronounced structural control related to dilatant zones in major fault systems and shear zones. A redox control related to the loss of electrons associated with hematitic alteration and precipitation of uranium is evident but not completely understood. Many deposits are associated with continental unconformities and have affinities with unconformity-associated U deposits (I16).

GENETIC MODEL: Vein U deposits are generally found in areas of high uranium Clarke, and generally there are other types of uranium deposits in the vicinity. The veins might be best considered polygenetic. The U appears to be derived from late magmatic differentiates of granites and alkaline rocks with high K or Na contents. Uranium is then separated from (or enriched within) the parent rocks by aqueous solutions which may originate either as low-temperature hydrothermal, connate or meteoric fluids. Current opinion is divided on the source of the fluids and some authors prefer models that incorporate mixing fluids. Studies of carbon and oxygen isotopes indicate that the mineralizing solutions in many cases are hydrothermal fluids which have mixed with meteoric water. In some cases temperatures exceeding 400 §C were attained during mineralization. The uranium minerals are precipitated within faults at some distance from the source of the fluids. Wallrocks containing carbonaceous material, sulphide and ferromagnesian minerals are favourable loci for precipitation of ore. Radiometric age dating indicates that mineralization is generally significantly younger than the associated felsic igneous rocks, but commonly close to the age of associated diabase or lamprophyre dikes.

ASSOCIATED DEPOSIT TYPES: Stratabound, disseminated and pegmatitic occurrences of U are commonly found in older metamorphic rocks. Sandstone-hosted U deposits (D05) are commonly found in associated red-bed supracrustal strata, and surficial deposits (B08) in arid or semi-arid environments.

COMMENTS: The Cretaceous to Tertiary Surprise Lake batholith in the Atlin area hosts several fracture-controlled veins with zeunerite, kasolite, autunite and Cu, Ag, W, Pb and Zn minerals. These include the Purple Rose, Fisher, Dixie, Cy 4, Mir 3 and IRA. Southwest of Hazelton, Th-poor uraninite associated with Au, Ag, Co-Ni sulpharsenides, Mo and W is found in high-temperature quartz veins within the Cretaceous Rocher D‚boul‚ granodiorite stock at the Red Rose, Victoria and Rocher Deboule properties. Although the veins are past producers of Au, Ag, Cu and W, no U has been produced.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Uranium and sometimes any, or all, of Ni, Co, Cu, Mo, Bi, As and Ag are good pathfinder elements which can be utilized in standard stream silt, lake bottom sediment and soil surveys. Stream and lake bottom water samples can be analyzed for U and Ra. In addition, the inert gases He and Ra can often be detected above a U-rich source in soil and soil gas surveys, as well as in groundwater and springs.

GEOPHYSICAL SIGNATURE: Standard prospecting techniques using sensitive gamma ray scintillometers and spectrometers to detect U mineralization in place or in float trains in glacial till, frost boils, talus or other debris remains the most effective prospecting methods. Because most deposits do not contain more than a few percent metallic minerals, electromagnetic and induced polarization surveys are not likely to provide direct guides to ore. VLF-EM surveys are useful to map the fault zones which are hosts to the veins. Magnetic surveys may be useful to detect areas of magnetite destruction in hematite-altered wallrocks.

OTHER EXPLORATION GUIDES: Secondary uranium minerals are typically yellow and are useful surface indicators.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Individual deposits are generally small (< 100 000 t) with grades of 0.15% to 0.25% U, however districts containing several deposits can aggregate considerable tonnages. The large Ace-Fay-Verna system produced 9 Mt of ore at an average grade of 0.21% U from numerous orebodies over a length of 4.5 km. and a depth of 1500 m. Gunnar produced 5 Mt of ore grading 0.15% U from a single orebody. The Schwartzwalder mine in Colorado was the largest “hardrock” uranium mine in the United States, producing approximately 4 300 tonnes U, and contains unmined reserves of approximately the same amount.

ECONOMIC LIMITATIONS: The generally narrow mining widths and grades of 0.15% to 0.25% U rendered most vein deposits uneconomic after the late 1960s discovery of the high-grade unconformity-type deposits.

IMPORTANCE: This type of deposit was the source of most of the world’s uranium until the 1950s. By 1988, significant production from veins was restricted to France, with production of 3 372 tonnes U or 9.2% of the world production for that year.

REFERENCES

ACKNOWLEDGMENTS: Sunial Gandhi, Nirankar Prasad, Larry Jones and Neil Church reviewed the profile and provided many constructive comments.

Chen, Z. and Fang, X. (1985): Main Characteristics and Genesis of Phanerozoic Vein-type Uranium Deposits; in Uranium Deposits in Volcanic Rocks, International Atomic Energy Agency, IAEA-TC-490/12, pages 69-82.
Evoy, E.F. (1986): The Gunnar Uranium Deposit; in Uranium Deposits of Canada, Evans, E.L., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 250-260.
Jones, Larry D. (1990): Uranium and Thorium occurrences in British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1990-32, 78 pages.
Lang, A.H., Griffith, J.W. and Steacy, H.R. (1962): Canadian Deposits of Uranium and Thorium; Geological Survey of Canada, Economic Geology Series No. 16, 324 pages.
Leroy, J. (1978): The Magnac and Funay Uranium Deposits of the La Crouzille District (Western Massif Central, France): Geologic and Fluid Inclusion Studies; Economic Geology, volume 73, pages 1611-1634.
Miller, A.R., Stanton, R.A., Cluff, G.R. and Male, M.J. (1986): Uranium Deposits and Prospects of the Baker Lake Basin and Subbasins, Central District of Keewatin, Northwest Territories; in Uranium Deposits of Canada, Evans, E.L., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 263-285.
Nash, J.T., Granger, H.C. and Adams, S.S. (1981): Geology and Concepts of Genesis of Important Types of Uranium Deposits; in Economic Geology, 75th Anniversary Volume, pages 63-116.
Ruzicka, V. (1993): Vein Uranium Deposits; Ore Geology Reviews, Volume 8, pages 247-276.
Smith, E.E.N (1986): Geology of the Beaverlodge Operation, Eldorado Nuclear Limited. in Uranium Deposits of Canada, Evans, E.L., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 95-109.
Stevenson, J.S. (1951): Uranium Mineralization in British Columbia; Economic Geology, Volume 46, pages 353-366.
Tremblay, L.P. (1972): Geology of the Beaverlodge Mining Area, Saskatchewan; Geological Survey of Canada, Memoir 367, 265 pages.
Tremblay, L.P. and Ruzicka, V. (1984): Vein Uranium; in Economic Geology Report 36, Geological Survey of Canada, page 64.
Wallace, A.R. (1986): Geology and Origin of the Schwartzwalder Uranium Deposit, Front Range, Colorado, U.S.A; in Vein Type Uranium Deposits, Fuchs, H., Editor, International Atomic Energy Agency, Vienna, IAEA-TECDOC-361, pages 159 - 168.

[Back to top]

UNCONFORMITY-ASSOCIATED U

I16

by R. H. McMillan
Consulting Geologist

McMillan, R.H. (1998): Unconformity-associated U, in Geological Fieldwork 1997, British Columbia

Ministry of Employment and Investment, Paper 1998-1, pages 24G-1 to 24G-4.

IDENTIFICATION

SYNONYMS: Unconformity-veins, unconformity-type uranium, unconformity U.

COMMODITIES (*BYPRODUCTS*): U (Au, Ni).

EXAMPLES (British Columbia - *Canada/International*): None in British Columbia; *Rabbit Lake, Key Lake, Cluff Lake, Midwest Lake, McClean Lake, McArthur River, Cigar Lake and Maurice Bay in the Athabasca uranium district (Saskatchewan, Canada), Lone Gull (Kiggavik) and Boomerang Lake, Thelon Basin district (Northwest Territories, Canada), Jabiluka, Ranger, Koongarra and Nabarlek, Alligator River district (Northern Territory, Australia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Uranium minerals, generally pitchblende and coffinite, occur as fracture and breccia fillings and disseminations in elongate, prismatic-shaped or tabular zones hosted by sedimentary/metasedimentary rocks located below, above or across a major continental unconformity.

TECTONIC SETTING: Intracratonic sedimentary basins.

GEOLOGICAL SETTING/DEPOSITIONAL ENVIRONMENT: Structurally-prepared and porous zones within chemically favourable reduced or otherwise reactive strata.

AGE OF MINERALIZATION: Mid-Proterozoic, however, there is potential for younger deposits.

HOST/ ASSOCIATED ROCK TYPES: Shelf facies metasedimentary (amphibolite or granulite facies) rocks of Early Proterozoic age (graphitic or sulphide-rich metapelites, calcsilicate rocks and metapsammites), regolith and overlying continental sandstones of Middle Proterozoic age. The Early Proterozoic hostrocks in many cases are retrograded amphibolite-facies metamorphic rocks on the flanks of Archean gneiss domes. The overlying continental sandstones are well sorted fluviatile quartz-rich psammites; generally with a clay or siliceous matrix and red or pale in colour. Dikes and sills, commonly diabases and lamprophyres, occur in some districts.

DEPOSIT FORM: Orebodies may be tabular, pencil shaped or irregular in shape extending up to few kilometres in length. Most deposits have a limited depth potential below the unconformity of less than a 100 m, however, the Jabiluka and Eagle Point deposits are concordant within the Lower Proterozoic host rocks and extend for several hundred metres below the unconformity.

TEXTURE/STRUCTURE: Most deposits fill pore space or voids in breccias and vein stockworks. Some Saskatchewan deposits are exceptionally rich with areas of "massive" pitchblende/coffinite. Features such as drusy textures, crustification banding, colloform, botryoidal and dendritic textures are present in some deposits.

ORE MINERALOGY (Principal and *subordinate*): Pitchblende (Th-poor uraninite), coffinite, uranophane, thucolite, brannerite, iron sulphides, native gold, Co-Ni arsenides and sulpharsenides, selenides, tellurides, vanadinites, jordesite (amorphous molybedenite), vanadates, chalcopyrite, galena, sphalerite, native Ag and PGE. Some deposits are "simple" with only pitchblende and coffinite, while others are "complex" and contain Co-Ni arsenides and other metallic minerals.

GANGUE MINERALOGY: Carbonates (calcite, dolomite, magnesite and siderite), chalcedonic quartz, sericite (illite) chlorite and dravite (tourmaline).

ALTERATION: Chloritization, hematization, kaolinization, illitization and silicification. In most cases hematization is due to oxidation of ferrous iron bearing minerals in the wallrocks caused by oxidizing mineralizing fluids, however, the intense brick-red hematite adjacent to some high grade uranium ores is probably due to loss of electrons during radioactive disintegration of U and its daughter products. An interesting feature of the clay alteration zone is the presence of pseudomorphs of high grade metamorphic minerals, such as cordierite and garnet, in the retrograded basement wallrock.

WEATHERING: Uranium is highly soluble in the +6 valence state above the water table. It will re-precipitate as uraninite and coffinite below the water table in the +4 valence state in the presence of a reducing agents such as humic material or carbonaceous "trash". Some U phosphates, vanadates, sulphates, silicates and arsenates are semi-stable under oxidizing conditions, consequently autunite, torbernite, carnotite, zippeite, uranophane, uranospinite and numerous other secondary minerals may be found in the near-surface zone of oxidation, particularly in arid environments.

ORE CONTROLS: A pronounced control related to a mid-Proterozoic unconformity and to favourable stratigraphic horizons within Lower Proterozoic hostrocks - these strata are commonly graphitic. Local and regional fault zones that intersect the unconformity may be important features. Generally found close to basement granitic rocks with a high U clarke.

GENETIC MODEL: The exceptionally rich ore grades which characterize this type of deposit point to a complex and probably polygenetic origin.

- Some form of very early preconcentration of U in the Archean basement rocks seems to have been important.
- The hostrocks are commonly Lower Proterozoic in age, and are comprised of metamorphosed rocks derived from marginal marine and near-shore facies sedimentary rocks which may have concentrated U by syngenetic and diagenetic processes.
- Although the behaviour of U under metamorphic and ultrametamorphic conditions is poorly known, it is possible that U could have been mobilized in the vicinity of Archean gneiss domes and anatectic granites and precipitated in pegmatites and stratabound deposits as non-refractory, soluable uraninite.

- Supergene enrichment in paleo regoliths, that now underlie the unconformity, may have been an important process in the additional concentration of U.
- Typically the overlying quartz-rich fluviatile sandstones have undergone little deformation, but are affected by normal and reverse faults that are probably re-activated basement faults. In Saskatchewan, these faults carry ore in several deposits and in others appear to have facilitated the transport of U within the cover sandstones.
- Hydrothermal/diagenetic concentration of U through mixing of oxidized basinal and reduced basement fluids appear to have resulted in exceptional concentrations of U and Ni. There is a possibility that radiogenic heat developed in these extremely rich deposits may have been instrumental in heating formational fluids and in remobilizing the metals upwards above the deposit.
- Diabase dikes occur in faults near some deposits and some researchers have suggested that the dikes might have provided the thermal energy that remobilized and further upgraded U concentrations. Recent age dates of the Mackenzie dikes in the Athabaska district do not support this interpretation.

ASSOCIATED DEPOSIT TYPES: Sandstone-hosted U deposits (D05) are found in associated supracrustal quartz-rich arenites. Stratabound disseminated or skarn deposits, such as the Dudderidge Lake and Burbidge Lake deposits (Saskatchewan) and pegmatitic occurrences are commonly present in the metamorphosed basement rocks. In arid or semi-arid environments surficial deposits may be present in the overburden. The deposits have affinities to "Classical" U veins (I15).

COMMENTS: Virtually all the known unconformity-associated uranium deposits are found in the Athabasca Basin, Alligator River district and Thelon Basin. In British Columbia favourable target areas for this style of mineralization might be found within strongly metamorphosed shelf-facies Proterozoic strata near gneiss domes, particularly in plateau areas near the Cretaceous-Tertiary paleosurface. The Midnite mine, located 100 km south of Osoyoos, British Columbia, may be an unconformity-associated U deposit. The ore comprises fracture-controlled and disseminated U and alteration minerals (pitchblende, coffinite as well as autunite and other secondary minerals) within metamorphosed shelf-facies pelitic and calcareous rocks of the Precambrian Togo Formation. Production and reserves prior to closing at the Midnite mine are estimated at approximately 3.9 Mt grading 0.12% U.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: U, Ni, Co, As, Pb and Cu are good pathfinder elements which can be utilized in standard stream silt, lake bottom sediment and soil surveys. Stream and lake bottom water samples can be analyzed for U and Ra. In addition, the inert gases He and Ra can often be detected above a U-rich source in soil and soil gas surveys, as well as in groundwater and springs. In Saskatchewan, lithogeochemical signatures have been documented in Athabasca Group quartz arenites for several hundred metres directly above the deposits and in glacially dispersed boulders located "down ice" - the signature includes boron (dravite) and low, but anomalous U as well as K and/or Mg clay mineral alteration (illite and chlorite).

GEOPHYSICAL SIGNATURE: During early phases of exploration of the Athabasca Basin, airborne and ground radiometric surveys detected near surface uranium deposits and their glacial dispersions. Currently, deeply penetrating ground and airborne elecromagnetic surveys are used to map the graphitic argillites associated with most deposits. The complete spectrum of modern techniques (gravity, magnetic, magneto-telluric, electromagnetic, VLF-EM, induced polarization, resistivity) can be utilized to map various aspects of structure as well as hostrock and alteration mineral assemblages in the search for deep targets.

OTHER EXPLORATION GUIDES: Standard techniques using sensitive gamma ray scintillometers to detect mineralization directly in bedrock or in float trains in glacial till, frost boils, talus or other debris derived from U mineralization remain the most effective prospecting methods.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Individual deposits are generally small, but can be exceedingly high-grade, up to several percent U. The median size for 36 Saskatchewan and Australian deposits is 260 000 t grading 0.42% U (Grauch and Mosier, 1986). Some deposits are exceptionally high grade such as the Key Lake Gaertner-Deilmann deposits (2.5 Mt @ 2.3% U), Cigar Lake deposits (900 000 t @ 12.2% U) and McArthur River (1.4 Mt @12.7% U).

ECONOMIC LIMITATIONS: Since the early 1980s, average ore grades have generally risen to exceed 0.25% U.
Problems related to the pervasively clay-altered wallrocks and presence of radon gas and other potentially dangerous elements associated with some high-grade uranium deposits in Saskatchewan have resulted in exceptionally high mining costs in some cases.

IMPORTANCE: The Rabbit Lake mine, opened in 1975, was the first major producer of unconformity-type ore. Since then the proportion of the world's production to come from unconformity-type deposits has increased to 33% and is expected to rise in the future.

SELECTED BIBLIOGRAPHY

ACKNOWLEDGMENTS: Nirankar Prasad and Sunil Gandhi of the Geological Survey of Canada, Larry Jones of the British Columbia Geological Survey and Jim Murphy of Uranerz Exploration reviewed the profile and provided many constructive comments.

Cady, J.W. and Fox, K.F. Jr. (1984): Geophysical Interpretation of the Gneiss Terrane of Northern Washington and Southern British Columbia, and its Implication for Uranium Exploration; U.S. Geological Survey, Professional Paper 1260, 29 pages.
Farstad, J. and Ayers, D.E. (1986): Midwest Uranium Deposit, Northern Saskatchewan, in Uranium Deposits of Canada, Evans, E.I., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 178-183.
Fogwill, W.D. (1985): Canadian and Saskatchewan Uranium Deposits: Compilation, Metallogeny, Models Exploration; in Geology of Uranium Deposits, Sibbald T.I.I. and Petruk W. Editors, Canadian Institute of Mining and Metallurgy, Special Volume 32, pages 3-19.
Jones, L.D. (1990): Uranium and Thorium Occurrences in British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1990-32, 78 pages.
Grauch, R.I. and Mosier, Dan L. (1986): Descriptive Model of Unconformity U-Au; in Mineral Deposit Models, Cox, D. P. and Singer, D. A., Editors, United States Geological Survey, Bulletin 1693, pages 248-250.
Milne, P.C. (1979): Uranium in Washington State: Proven Deposits and Exploration Targets; The Canadian Institute of Mining and Metallurgy, Bulletin, Volume 72, pages 95-101.
Nash, J.T., Granger, H.C. and Adams, S.S. (1981): Geology and Concepts of Genesis of Important Types of Uranium Deposits; in Economic Geology, 75th Anniversary Volume, pages 63-116.
Ruzicka, Vlad (1986): Uranium deposits of the Rabbit Lake -Collins Bay area, Saskatchewan; in Uranium Deposits of Canada, Evans, E.I., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 144-154.
Tremblay, L.P. and Ruzicka, V. (1984): Unconformity-associated Uranium; in Canadian Mineral Deposit Types: A Geological Synopsis, Eckstrand, O.R., Editor, Geological Survey of Canada,Economic Geology Report 36, page 61.
Wallis, R.H., Saracoglu, N., Brummer, J.J., and Golightly, J.P. (1986): The Geology of the McClean Uranium Deposits, Northern Saskatchewan; in Uranium Deposits of Canada, Evans, E.I., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 33, pages 193-217.

[Back to top]

CRYPTOCRYSTALLINE ULTRAMAFIC-HOSTED MAGNESITE VEINS

I17

by S. Paradis and G.J. Simandl
Geological Survey of Canada and British Columbia Geological Survey

Paradis, S. and Simandl, G.J. (1996): Cryptocrystalline Ultramafic-hosted Magnesite Veins, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T, Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 97-100.

IDENTIFICATION

SYNONYMS: Cryptocrystalline or microcrystalline magnesite, "Kraubath-type" magnesite, "Bone magnesite", "amorphous magnesite".

COMMODITY: Magnesite.

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Sunny (092O 014), Pinchi Lake (093K 065); *Chalkidiky area (Greece); Kraubath (Austria); Eskisehir and Kutaya (Turkey)*.

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cryptocrystalline magnesite deposits are related to faults cutting ultramafic rocks. Individual deposits may consist of two styles of mineralization. Steeply dipping magnesite veins, up to several metres thick, pass gradually upward into magnesite stockworks or breccias cemented by magnesite.

TECTONIC SETTINGS: Typically in allochthonous serpentinized ophiolitic sequences or along structural breaks within ultramafic layered complexes; however, other settings containing ultramafic rocks are also favourable.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: The veins are emplaced along steep faults in near surface environments.

AGE OF MINERALIZATION: Post-date ultramafic hostrock that is Archean to Paleogene in age.

HOST/ASSOCIATED ROCK TYPES: Serpentinite, peridotite; other olivine-rich rocks of the typical ophiolitic sequence and layered ultramafic complexes.

DEPOSIT FORM: Stockworks, branching veins, single veins up to several metres in thickness, and less frequently, irregular masses. The maximum reported vertical extent is 200 m. The footwall of the deposits is commonly sharp and slickensided and coincides with a fault zone. The hangingwall of the fault contains magnesite veins and/or magnesite-cemented breccias.

TEXTURE/STRUCTURE: Magnesite is commonly cryptocrystalline and massive with microscopic "pinolite" texture; rarely granular, fibrous, or "cauliflower-like".

ORE MINERALOGY: Magnesite.

GANGUE MINERALOGY (Principal and *subordinate*): Serpentine, chlorite, talc, iron oxides, dolomite, hydromagnesite, calcite, sepiolite, quartz, opal, chalcedony and quartz in vugs.

ALTERATION MINERALOGY: Ultramafic rocks hosting magnesite are typically, but not always, intensely serpentinised. Alteration minerals are dolomite, quartz, montmorillonite, sepiolite, talc, goethite and deweylite.

WEATHERING: Varies with climatic environment, gangue mineralogy and iron content in the crystal structure of magnesite.

ORE CONTROLS: Tectonic boundaries or major fault breaks, secondary fault zones parallel to major breaks cutting ultramafic rocks. The large magnesite- cemented breccias are commonly located below paleoerosional or erosional surfaces. Most contacts between the magnesite and country rock are sharp and irregular.

GENETIC MODEL: Two hypothesis competing to explain the origin of these deposits are:

1) hypogene low-temperature, CO2-metasomatism of ultramafic rocks (Pohl, 1991):

- 2) low-temperature descending, meteoric waters containing biogenic CO2 and enriched in Mg2+ (Zachmann and Johannes, 1989).

ASSOCIATED DEPOSIT TYPES: Lateritic deposits, chromite deposits and platinum deposits occur in the same geological environment but are not genetically related. The ultramafic-hosted talc deposits (M07) may be genetically related.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: May contain above average Hg.

GEOPHYSICAL SIGNATURE: N/A

OTHER EXPLORATION GUIDES: Favourable lithologic and structural setting. Commonly underlying unconformities. Near-surface (or paleosurface) magnesite deposits may be capped by stratiform magnesite, dolomite-quartz (chalcedony) or chert zones. Some of these deposits are overlain by laterites. Boulder tracing in glaciated areas.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: For stockwork (upper) portions of the deposits the grades vary from 20 to 40% magnesite and reserves ranging from hundreds of thousands to several millions tonnes are typical. The deeper vein portions of these deposits have higher grades and may be almost monomineralic. A representative specimen of Greek cryptocrystalline magnesite is reported to contain 46.6 % MgO, 49.9 % CO2, 0.70 % SiO2, 1.35 % CaO, 0.85% Fe2O3 and Al2O3 combined (Harben and Bates, 1990).

ECONOMIC LIMITATIONS: These deposits compete for markets with sediment-hosted sparry magnesite deposits and seawater or brine-derived magnesia compounds. In the past, European refractory producers preferred cryptocrystalline magnesite over sparry magnesite, because of its higher density and lower iron, manganese and boron content. Recently this advantage was largely lost by availability of excellent quality sparry magnesite exports and by new technical developments in the refractory industry. Natural magnesite-derived compounds in general have to compete with seawater and brine-derived magnesia compounds.

END USES: Source of wide variety of magnesia products used mainly in refractories, cements, insulation, chemicals, fertilizers, fluxes and environmental applications.

IMPORTANCE: These deposits are substantially smaller and, in the case of stockwork-type portions, lower grade than sparry magnesite deposits.

COMMENTS: Stockworks and adjacent ultramafic hostrock are capped in some cases by sediments that may contain nodular magnesite concretions or magnesite/hydromagnesite layers and/or dolomite, quartz or chert. It is not well established if sediments are of sabkha /playa affinity or directly linked to fluids that formed stockworks and veins.

REFERENCES

Grant, B. (1987): Magnesite, Brucite and Hydromagnesite Occurrences in British Columbia; B.C. Ministry of Energy Mines and Petroleum Resources, Open File 1987-13, 80 pages.
Harben, P.W. and Bates, R.L. (1990): Industrial Minerals Geology and World Deposits; Industrial Minerals Division, Metal Bulletin, London, 312 pages.
Pohl, W. (1991): Genesis of Magnesite Deposits - Models and Trends; Geologische Rundschau,

Volume 79, pages 291-299.

[Back to top]

** Note: All BC deposit profile #s with an asterisk have no completed deposit profile. USGS deposit model #s with an asterisk had no published model in the late 1990s.*

Examples of Vein, Breccia, and Stockwork Deposits

BC Profile #	Global Examples	B.C. Examples
I01	Alaska-Juneau (Alaska), Campbell, Dome(Ontario)	Bralorne, Erickson, Polaris-Taku
I02	- -	Scottie, Snip, Johnny Mountain, Iron Colt
I03	Ballarat (Australia), Meguma (Nova Scotia)	Frasergold, Reno, Queen, Island Mountain
I04	Homestake (South Dakota)	- -
I05	Elsa (Yukon), Coeur d'Alene (Idaho), Creede (Colorado)	Silver Queen, Beaverdell, Silvana, Lucky Jim
I06	Nikolai (Alaska), Bruce Mines (Ontario), Butte (Montana)	Davis-Keays, Churchill Copper, Bull River
I07*		Granby Point
I08	Red Devil? (Alaska), New Almaden, New Idria (California)	Pinchi, Bralorne Takla, Silverquick
I09	Becker-Cochran (Yukon), Lake George (New Brunswick), Bolivia	Minto, Congress, Snowbird
I10	Matchewan (Ontario), Jbel Ighoud (Morocco), Wolfach (Germany)	Parson. Brisco, Fireside
I11	St. Lawrence (Newfoundland), Mongolian fluorite belt	Rock Candy, Eaglet
I12*	Pasto Bueno (Peru), Carrock Fell (England)	- -
I13*	Cornwall (England), Lost River (Alaska)	Duncan Lake
I14	Cobalt camp (Ontario), Erzgebirge district (Germany)	- -
I15	Beaverlodge area (Saskatchewan), Schwartzwalder (Colorado)	Purple Rose, Fisher, Dixie
I16	Rabbit lake, Key Lake, Cluff Lake, Midwest Lake, McClean Lake, McArthur River, Cigar Lake and Maurice Bay in the Athabasca uranium district (Saskatchewan, Canada), Lone Gull (Kiggavik) and Boomerang Lake, Thelon Basin district (Northwest Territories, Canada); Jabiluka, Ranger, Koongarra and Nabarlek, Alligator River district (Northern Territory, Australia)	- -
I17	Chalkidiky area (Greece), Kraubath (Austria)	Sunny, Pinchi Lake

Top

Search | All B.C. Government | Ministry of Energy, Mines and Petroleum Resources
Advanced Search | Help | Contact Us | Text Size A A
News | The Premier Online | Ministries & Organizations | Job Opportunities | Main Index
B.C.Home » Ministry Home » Mineral Exploration a ... » Geoscience » Mineral Deposit Profiles » List by Deposit Group » J - Manto | Printer Version

B.C. Home
Ministry of Energy, Mines and Petroleum Resources
Contact Information
Aggregate
Exploration
Geoscience
What's New in Geoscience
- Aggregates
ARIS Assessment Reports
- Bedrock Mapping
- Coal
- Educational Resources
- Exploration and Mines
- Geochemistry
- Geophysical Data
- Geoscience Agencies
- Geoscience Mailbox
- Hiring
- Industrial Minerals
- MapPlace
MINFILE Mineral Inventory
- Metallic Minerals
- Mineral Deposit Profiles
  - Introduction
  - List by Deposit Group
    - A – Organic
    - B - Residual/Surficial
    - C - Placer
    - D - Continental Sediments and Vocanics
    - E - Sediment-Hosted
    - F - Chemical Sediment

J - Manto

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
J01	Polymetallic manto Ag-Pb-Zn	Polymetallic replacement deposits	19a
J02	Manto and stockwork Sn	Replacement Sn, Renison-type	14c
J03*	Mn veins and replacements	covered by I05 and J01	19b
J04	Sulphide manto Au	Au-Ag sulphide mantos	- -

POLYMETALLIC MANTOS Ag-Pb-Zn

J01

by J.L. Nelson
British Columbia Geological Survey

Nelson, J.L. (1996): Polymetallic Mantos Ag-Pb-Zn, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 101-104.

IDENTIFICATION

SYNONYM: Polymetallic replacement deposits.

COMMODITIES (*BYPRODUCTS*): Ag, Pb, Zn (Au, Cu, Sn, Bi).

EXAMPLES (British Columbia (MINFILE #) - *Canada/International*): Midway (104O 038) and Bluebell (082ENW026); *Sa Dena Hes (Yukon, Canada), Prairie Creek (Northwest Territories, Canada), Leadville District (Colorado, USA), East Tintic District (Utah, USA), Eureka District (Nevada, USA), Santa Eulalia, Naica, Fresnillo, Velardena, Providencia (Mexico).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Irregularly shaped, conformable to crosscutting bodies, such as massive lenses, pipes and veins, of sphalerite, galena, pyrite and other sulphides and sulphosalts in carbonate hosts; distal to skarns and to small, high-level felsic intrusions.

TECTONIC SETTING: Intrusions emplaced into miogeoclinal to platformal, continental settings.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: In northern Mexico, most are hosted by Cretaceous limestones. In Colorado, the principal host is the Devonian- Mississippian Leadville limestone; in Utah, the Permian Torweap Formation hosts the Deer Trail deposit. The most favourable hosts in the Canadian Cordillera are massive Lower Cambian and Middle Devonian limestones, rather than impure carbonates and dolostone-quartzite units.

- G - Marine Volcanic Association
- H - Epithermal
- I - Vein, Breccia and Stockwork
- J - Manto
- K - Skarn
- L - Porphyry
- M - Ultramafic / Mafic
- N - Carbonatites
- O - Pegmatite
- P - Metamorphic-hosted
- Q - Gems and Semi-precious Stones
- R - Industrial Rocks
- S - Other
- Lithological Listing
- Listing by Commodity
- Published Index
- Guidelines to Authors
- Selected Profiles
- All Deposit Groups
- Ordering Publications
- Examples of Deposits
- Mineral Potential
- Partnerships
- Property File
- Publications Catalogue

Surficial Geology and Hazards
- Terrain and Soil Maps

Staff: Cordilleran Experts

Health and Safety

History of Mining in B.C.

Legislation

Mineral Statistics

Mineral Titles

AGE OF MINERALIZATION: Canadian Cordilleran examples are Cretaceous to Eocene age; those in the southern Cordillera are typically Tertiary.

HOST/ASSOCIATED ROCK TYPES: Hosted by limestone and dolostone. The carbonates are typically within a thick sediment package with siliciclastic rocks that is cut by granite, quartz monzonite and other intermediate to felsic hypabyssal, porphyritic lithologies. There may be volcanic rocks in the sequence, or more commonly above, which are related to the intrusive rocks.

DEPOSIT FORM: Irregular: mantos (cloak shaped), lenses, pipes, chimneys, veins; in some deposits the chimneys and/or mantos are stacked.

TEXTURE/STRUCTURE: Massive to highly vuggy, porous ore. In some cases fragments of wallrock are incorporated into the ore. Some deposits have breccias: fragments of wallrock and also of sulphide ore within a sulphide matrix.

ORE MINERALOGY (Principal and *subordinate*): Sphalerite, galena, pyrite, chalcopyrite, marcasite; arsenopyrite, pyrargyrite/proustite, enargite, tetrahedrite, geocronite, electrum, digenite, jamesonite, jordanite, bournonite, stephanite, polybasite, rhodochrosite, sylvanite, calaverite. Chimneys may be more Zn-rich, Pb-poor than mantos.

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, barite, gypsum; minor calc-silicate minerals.

ALTERATION MINERALOGY: Limestone wallrocks are commonly dolomitized and/or silicified, whereas shale and igneous rocks are argillized and chloritized. Jasperoid occurs in some U.S. examples.

WEATHERING: In some cases, a deep oxidation zone is developed. Mexican deposits have well developed oxide zones with cassiterite, hematite, Cu and Fe carbonates, cerusite and smithsonite.

ORE CONTROLS: The irregular shapes of these deposits and their occurrence in carbonate hosts emphasize the importance of ground preparation in controlling fluid channels and depositional sites. Controlling factors include faults, fault intersections, fractures, anticlinal culminations, bedding channelways (lithologic contrasts), karst features and pre-existing permeable zones. In several districts karst development associated with unconformities is believed to have led to development of open spaces subsequently filled by ore. Some deposits are spatially associated with dikes.

GENETIC MODEL: Manto deposits are high-temperature replacements as shown by fluid inclusion temperatures in excess of 300 C, high contents of Ag, presence of Sn, W and complex sulphosalts, and association with skarns and small felsic intrusions. They are the product of pluton-driven hydrothermal solutions that followed a variety of permeable pathways, such as bedding, karst features and fracture zones.

ASSOCIATED DEPOSIT TYPES: There is probably an overall outward gradation from granite-hosted Mo-Cu porphyries (L04), endoskarns (K) and possibly W- and Sn mineralization (L06?), through exoskarns (K01, K02) and into Ag-Pb-Zn veins (I05), mantos (J01) and possibly Carlin-type sediment-hosted Au-Ag deposits (E03). Only some, or possibly one, of these types may be manifest in a given district. Ag-Pb-Zn vein, manto and skarn deposits belong to a continuum which includes many individual occurrences with mixed characteristics.

COMMENTS: In the Canadian Cordillera, most mantos are located in the miogeocline (western Ancestral North America, Cassiar and Kootenay terranes) because of the essential coincidence of abundant carbonate and presence of felsic intrusions. There is one known example in Upper Triassic limestone on Vancouver Island, which probably formed distal to skarn mineralization related to a mid- Jurassic intrusion. Most mantos in the Canadian Cordillera are Late Cretaceous to Eocene, coinciding with the age of youngest, F-rich intrusions of the A-type (anorogenic) granite suite. In Mexico, mantos are associated with Early to mid-Tertiary volcanic rocks and cogenetic intrusions. The Colorado deposits may be associated with Tertiary sills, and the Deer Trail deposit in Utah has given a 12 Ma sericite age.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: B.C.: Ag, Pb, Zn, Sn in stream silts, F in waters. U.S.: Districts show outward zoning from Cu-rich core through broad Ag-Pb zone to Zn- Mn fringe. Locally Au, As, Sb, Bi. Jasperoid contains elevated Ba + Ag.

GEOPHYSICAL SIGNATURE: Subsurface granite associated with Midway deposit has negative magnetic signature.

OTHER EXPLORATION GUIDES: Concentration of Ag-Pb-Zn vein deposits in or near carbonates.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Individual deposits average about a million tonnes grading tens to hundreds of grams/tonne Ag and approximately 5 to 20% combined Pb-Zn. Mexico: Santa Eulalia district produced about 24 Mt in this century, grading about 300 g/t Ag, 8% Pb, 9% Zn. U.S.: Leadville deposit mined 30 Mt 70-130 g/t Ag, 12-15% Pb-Zn. B.C.: Midway geological resource is 1 Mt grading 400 g/t Ag 7% Pb, 9.6% Zn. In many mining districts the early

Permitting and Reclamation

- **Regional Offices**
- **Sustainability**

EMPR

[Minister of State for Mining]

[Electricity and Alternative Energy Division]

[Marketing, Aboriginal & Community Relations]

[Mineral Exploration and Mining]

[Oil & Gas]

[Titles]

[Library]

[Publications]

[Electricity Policy and Development]

[Ministry Contacts]

[Links and Related Organizations]

production came from oxidized ore zones that can have higher grades and be easier to mine.

ECONOMIC LIMITATIONS: Generally, although not always, these deposits tend to be small, highly irregular and discontinuous. The Mexican deposits have yielded large quantities of ore because, due to low labour costs, mining provided an effective and low-cost exploration tool.

IMPORTANCE: As sources of base metals, manto deposits are overshadowed on a world scale by the giant syngenetic classes such as sedimentary exhalitive and volcanogenic massive sulphides. However, because of their high precious metal contents, they provide exciting targets for small producers.

REFERENCES

Hewitt, W.P. (1968): Geology and Mineralization of the Main Mineral Zone of the Santa Eulalia district, Chihuahua, Mexico; Society of Mining Engineers, Transactions, Volume 241, pages 228-260.
Jensen, M.L. and Bateman, A.M. (1981), Economic Mineral Deposits, 3rd edition, John Wiley and Sons, New York, 593 pages.
Maldonado, E.D. (1991): Economic Geology of the Santa Eulalia Mining District, Chihuahua; in Economic Geology, Mexico, Salas, G.P., Editor, Geological Society of America, The Geology of North America, Volume P-3, pages 241-257.
Morris, H.T. (1986): Descriptive Model of Polymetallic Replacement Deposits; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, pages 90-91.
Nelson, J.A. (1991): Carbonate-hosted Lead-Zinc (ñ Silver, Gold) Deposits of British Columbia; in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 71-88.
Ohle, E.L. (1991): Lead and Zinc Deposits; in Economic Geology, U.S., Gluskoter, H.J., Rice, D.D. and Taylor, R.B., Editors, Geological Society of America, The Geology of North America, Volume P-2, pages 43-62.
Prescott, B. (1926): The Underlying Principles of the Limestone Replacement Deposits of the Mexican Province - I; Engineering and Mining Journal, Volume 122, pages 246-296.
1. Manto is a Spanish mining term denoting a blanket-shaped orebody which is widely used for replacement deposits of Mexico. It has been used to describe the orientation of individual lenses and also to describe a class of orebodies.

[Back to top]

MANTO AND STOCKWORK Sn

J02
by David Sinclair
Geological Survey of Canda, Ottawa

Sinclair, W.D. (1996): Manto and Stockwork Sn, in Selected British Columbia Mineral Deposit Profiles, Volume 2 - Metallic Deposits, Lefebure, D.V. and Hõy, T., Editors, British Columbia Ministry of Employment and Investment, Open File 1996-13, pages 105-109.

IDENTIFICATION

SYNONYMS: Replacement Sn, distal Sn skarn, Renison-type.

COMMODITIES (*BYPRODUCTS*): Sn (Cu, Zn, Pb, Ag, Sb, Cd, Bi, In).

EXAMPLES (British Columbia - *Canada/International*): *Renison Bell, Cleveland and Mt. Bischoff (Tasmania, Australia), Dachang and Gejiu districts (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Disseminated cassiterite occurs in massive sulphide replacement bodies in carbonate rocks and in associated veins, stockworks and breccias. Felsic intrusions are nearby, or adjacent to the deposits and may also be mineralized.

TECTONIC SETTING: Postorogenic underlain by cratonic crust containing carbonate rocks.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Carbonate rocks intruded by epizonal felsic intrusive rocks.

AGE OF MINERALIZATION: Mainly Paleozoic to Mesozoic, but other ages possible.

HOST/ASSOCIATED ROCK TYPES: Mainly limestone or dolomite; chert, pelitic and Fe-rich sediments, and volcanic rocks may also be present. Genetically-related granitic plutons and associated felsic dikes are typically F and/or B rich. They are commonly porphyritic.

DEPOSIT FORM: Variable: massive, lensoid to tabular, concordant sulphide-rich bodies in carbonate rocks; veins and irregular stockwork zones in associated rocks.

TEXTURE/STRUCTURE: Massive sulphide-rich bodies tend to follow bedding in host carbonate rocks; associated veins and stockworks include mineralized fractures, veinlets, quartz veins and breccias.

ORE MINERALOGY (Principal and *subordinate*): Cassiterite, chalcopyrite, sphalerite and galena; stannite, stibnite, bismuth, bismuthinite and a wide variety of sulphosalt minerals including jamesonite, bournonite, franckeite, boulangerite, geocronite, matildite and galenobismutite may also be present.

GANGUE MINERALOGY (Principal and *subordinate*): Pyrrhotite (often predominant sulphide) and/or pyrite, arsenopyrite, quartz, calcite, siderite, rhodochrosite, flourite and tourmaline.

ALTERATION MINERALOGY: Dolomite near massive sulphide bodies is typically altered to siderite, and, to a lesser extent, talc, phlogopite and quartz. Rocks hosting vein or stockwork zones may be tourmalinized. Greisen-type alteration, characterized by flourite and/or topaz, F-bearing micas and tourmaline, is best developed in and around genetically related felsic intrusive rocks.

WEATHERING: Oxidation of pyrite and pyrrhotite produces limonitic gossans. Deep weathering and erosion may result in residual concentrations of cassiterite in situ or in placer deposits downslope or downstream.

ORE CONTROLS: Carbonate rocks in the vicinity of F and B rich felsic intrusive rocks; faults and fracture zones in the carbonates and associated rocks provide channelways and also alternate sites of deposition for ore-forming fluids.

GENETIC MODEL: Magmatic-hydrothermal. Magmatic, highly saline aqueous fluids strip Sn and other ore metals from temporally- and genetically related magma. Early Sn deposition is dominantly from these magmatic fluids, mainly in response to increase in pH due to carbonate replacement. Mixing of magmatic with meteoric water during waning stages of the magmatic-hydrothermal system may result in deposition of Sn and other metals in late-stage veins and stockworks.

ASSOCIATED DEPOSIT TYPES: Sn-W skarn deposits (K06, K05), Sn-W vein deposits, Sb-Hg veins, placer deposits (C01, C02).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sn, Cu, Pb, Zn, As, Ag, Sb, Hg, F, W, Bi and In may be anomalously high in hostrocks adjacent to and overlying mineralized zones; Sb and Hg anomalies may extend as much as several hundred metres. Sn, W, F, Cu, Pb and Zn may be anomalously high in stream sediments and Sn, W, and B (tourmaline) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Massive pyrrhotite may be detected by magnetic surveys; massive sulphide zones may also be detected by electromagnetic and resistivity surveys.

OTHER EXPLORATION GUIDES: Deposits commonly occur in zoned, polymetallic districts; Sn and base metal bearing skarns and veins occur close to related intrusive rocks, carbonate- hosted Sn mantos and stockworks are at intermediate distances from the intrusive rocks, and Sb and Hg veins are the outermost deposits. Genetically related felsic intrusive rocks typically have high contents of silica (>74% SiO2) and F (>0.1% F); tourmaline may also be present.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Deposits are large and high grade, containing millions to tens of millions of tonnes averaging about 1% Sn. The following figures are for production plus reserves: Renison Bell (Australia): 27 Mt at 1.1% Sn (Newnham, 1988) Cleveland (Australia): 5.3 Mt at 0.5% Sn, 0.2% Cu (Cox and Dronseika, 1988) Mt. Bischoff (Australia): 6.1 Mt at 0.49% Sn (Newnham, 1988) Dachang (China): 100 Mt at 1% Sn, 3-5% combined Cu, Pb, Zn and Sb (Fu et al., 1993) Gejiu (China): 100 Mt at 1% Sn, 2-5% Cu, 0.5% Pb (Sutphin et al., 1990).

IMPORTANCE: The large tonnage and relatively high grade of these deposits makes them attractive for exploration and development.The Renison Bell deposit in Australia and the Dachang and Gejiu deposits in China are currently major producers of tin on a world scale.

REFERENCES

ACKNOWLEGEMENT: Rod Kirkham kindly reviewed this profile.

Cao, X. (1988): Integrated Geophysical and Geochemical Indicators of the Gejiu Tin Mine and its Neighbouring Areas; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 443-455.
Chen, Y., Huang, M., Xu, Y., Ai, Y., Li, X., Tang, S. and Meng, L. (1988): Geological and Metallogenic Features and Model of the Dachang Cassiterite-Sulphide Polymetallic Ore Belt, Guangxi, China; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 358-372.
Cox, R. and Dronseika, E.V. (1988): The Cleveland Stratabound Tin Deposits, Tasmania: A Review of their Economic Geology, Exploration, Evaluation and Production; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 112-123.

Fu, M., Changkakoti, A., Krouse, H.R., Gray, J. and Kwak, T.A.P. (1991): An Oxygen Hydrogen, Sulfur, and Carbon Isotope Study of Carbonate-replacement (Skarn) Tin Deposits of the Dachang Tin Field, China; Economic Geology, Volume 86, pages 1683-1703.
Fu, M., Kwak, T.A.P. and Mernagh, T.P. (1993): Fluid Inclusion Studies of Zoning in the Dachang Tin-Polymetallic Ore Field, People's Republic of China; Economic Geology, Volume 88, pages 283-300.
Newnham, L. (1988): The Western Tasmanian Tin Province with special reference to the Renison Mine; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 101-111.
Patterson, D.J., Ohmoto, H. and Solomon, M. (1981): Geologic Setting and Genesis of Cassiterite-Sulfide Mineralization at Renison Bell, Western Tasmania; Economic Geology, Volume 76, pages 393-438.
Reed, B.L. (1986): Descriptive Model of Replacement Sn; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U. S. Geological Survey, Bulletin 1693, pages 61-63.
Sutphin, D.M., Sabin, A.E. and Reed, B.L. (1990): International Strategic Minerals Inventory - Tin; U. S. Geological Survey, Circular 930-J, page 52.
Yang, J., Li, D., Zhang, D., Li, S., Li, X. and Lu, X. (1988): Geochemical Characteristics of Indicator Elements and Prospecting Criteria for the Danchi Polymetallic Mineralized Belt of the Dachang Tin Field; in Geology of Tin Deposits in Asia and the Pacific, , Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 339-350.

** Note: All BC deposit profile #s with an asterisk have no completed deposit profile. USGS deposit model #s with an asterisk had no published model in the late 1990s.*

Examples of Manto Deposits

BC Profile #	Global Examples	B.C. Examples
J01	East Tintic district (Utah), Naica (Mexico), Sa Dena Hess (Yukon)	Bluebell, Midway
J02	Renison Bell & Cleveland (Australia), Dachang district (China)	- -
J03*	Lake Valley (New Mexico), Phillipsburg (Montana)	- -
J04	Ketza River (Yukon)	Mosquito Creek , Island Mountain

Top

Search
All B.C. Government | Ministry of Energy, Mines and Petroleum Resources
Advanced Search | Help | Contact Us
Text Size A A

News | The Premier Online | Ministries & Organizations | Job Opportunities | Main Index

B.C.Home » Ministry Home » Mineral Exploration a ... » Geoscience » Mineral Deposit Profiles » List by Deposit Group » K - Skarn
Printer Version

B.C. Home

Ministry of Energy, Mines and Petroleum Resources

Contact Information
Aggregate
Exploration
Geoscience

What's New in Geoscience
Aggregates
ARIS Assessment Reports
Bedrock Mapping
Coal
Educational Resources
Exploration and Mines
Geochemistry
Geophysical Data
Geoscience Agencies
Geoscience Mailbox
Hiring
Industrial Minerals
MapPlace
MINFILE Mineral Inventory
Metallic Minerals
Mineral Deposit Profiles
Introduction
List by Deposit Group
A – Organic
B - Residual/Surficial
C - Placer
D - Continental Sediments and Vocanics
E - Sediment-Hosted
F - Chemical Sediment

Ministry of Energy, Mines and Petroleum Resources

K - Skarn

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
K01	Cu skarns	- -	18a,b
K02	Pb-Zn skarns	- -	18c
K03	Fe skarns	- -	18d
K04	Au skarns	- -	18f*
K05	W skarns	- -	14a
K06	Sn skarns	- -	14b
K07	Mo skarns	- -	- -
K08	Garnet skarns	- -	- -
K09	Wollastonite skarns	- -	18g

Cu SKARNS

K01

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): Cu Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 59-60.

IDENTIFICATION

SYNONYMS: Pyrometasomatic and contact metasomatic copper deposits.

COMMODITIES (*BYPRODUCTS*): Cu (Au, Ag, Mo, W, magnetite).

EXAMPLES (British Columbia - *Canada/International*): Craigmont (092ISE035), Phoenix (082ESE020), Old Sport (092L 035), Queen Victoria (082FSW082); *Mines Gaspé deposits (Québec, Canada), Ruth, Mason Valley and Copper Canyon (Nevada, USA), Carr Fork (Utah, USA), Ok Tedi (Papua New Guinea), Rosita (Nicaragua).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cu-dominant mineralization (generally chalcopyrite) genetically associated with a skarn gangue (includes calcic and magnesian Cu skarns).

TECTONIC SETTING: They are most common where Andean-type plutons intrude older continental-margin carbonate sequences. To a lesser extent (but important in British Columbia), they are associated with oceanic island arc plutonism.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. In British Columbia they are mostly Early to mid-Jurassic.

HOST/ASSOCIATED ROCK TYPES: Porphyritic stocks, dikes and breccia pipes of quartz diorite, granodiorite, monzogranite and tonalite composition, intruding carbonate rocks, calcareous volcanics or tuffs. Cu skarns in oceanic island arcs tend to be associated with more mafic intrusions (quartz diorite to granodiorite), while those formed in continental margin environments are associated with more felsic material.

DEPOSIT FORM: Highly varied; includes stratiform and tabular orebodies, vertical pipes, narrow lenses, and irregular ore zones that are controlled by intrusive contacts.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures.

ORE MINERALOGY (Principal and *subordinate*): Moderate to high sulphide content. Chalcopyrite ± pyrite ± magnetite in inner garnet-pyroxene zone. Bornite ± chalcopyrite ± sphalerite ± tennantite in outer wollastonite zone. Either hematite, pyrrhotite or magnetite may predominate (depending on oxidation state). Scheelite and traces of molybdenite, bismuthinite, galena, cosalite, arsenopyrite, enargite, tennantite, loellingite, cobaltite and tetrahedrite may be present.

ALTERATION MINERALOGY: Exoskarn alteration: high garnet:pyroxene ratios. High Fe, low Al, Mn andradite garnet (Ad35-100), and diopsidic clinopyroxene (Hd2-50). The mineral zoning from stock out to marble is commonly: diopside + andradite (proximal); wollastonite ± tremolite ± garnet ± diopside ± vesuvianite (distal). Retrograde alteration to actinolite, chlorite and montmorillonite is common. In British Columbia, skarn alteration associated with some of the alkalic porphyry Cu-Au deposits contains late scapolite veining. Magnesian Cu skarns also contain olivine, serpentine, monticellite and brucite. Endoskarn alteration: Potassic alteration with K-feldspar, epidote, sericite ± pyroxene ± garnet. Retrograde phyllic alteration generates actinolite, chlorite and clay minerals.

ORE CONTROLS: Irregular or tabular orebodies tend to form in carbonate rocks and/or calcareous volcanics or tuffs near igneous contacts. Pendants within igneous stocks can be important. Cu mineralization is present as stockwork veining and disseminations in both endo and exoskarn; it commonly accompanies retrograde alteration.

COMMENTS: Calcic Cu skarns are more economically important than magnesian Cu skarns. Cu skarns are broadly separable into those associated with strongly altered Cu- porphyry systems, and those associated with barren, generally unaltered stocks; a continuum probably exists between these two types (Einaudi et al., 1981). Copper skarn deposits related to mineralized Cu porphyry intrusions tend to be larger, lower grade, and emplaced at higher structural levels than those associated with barren stocks. Most Cu skarns contain oxidized mineral assemblages, and mineral zoning is common in the skarn envelope. Those with reduced assemblages can be enriched in W, Mo, Bi, Zn, As and Au. Over half of the 340 Cu skarn occurrences in British Columbia lie in the Wrangellia Terrane of the Insular Belt, while another third are associated with intraoceanic island arc plutonism in the Quesnellia and Stikinia terranes. Some alkalic and calcalkalic Cu and Cu-Mo porphyry systems in the province (e.g. Copper Mountain, Mount Polley) are associated with variable amounts of Cu-bearing skarn alteration.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Rock analyses may show Cu-Au-Ag-rich inner zones grading outward through Au-Ag zones with high Au:Ag ratios to an outer Pb-Zn-Ag zone. Co-As-Sb-Bi-Mo-W geochemical anomalies are present in the more reduced Cu skarn deposits.

GEOPHYSICAL SIGNATURE: Magnetic, electromagnetic and induced polarization anomalies.

ASSOCIATED DEPOSIT TYPES: Porphyry Cu deposits (L04), Au (K04), Fe (K03) and Pb-Zn (K02) skarns, and replacement Pb-Zn-Ag deposits (M01).

ECONOMIC FACTORS

GRADE AND TONNAGE: Average 1 to 2 % copper. Worldwide, they generally range from 1 to 100 Mt, although some exceptional deposits exceed 300 Mt. Craigmont, British Columbia's largest Cu skarn, contained approximately 34 Mt grading 1.3 % Cu.

IMPORTANCE: Historically, these deposits were a major source of copper, although porphyry deposits have become much more important during the last 30 years . However, major Cu skarns are still worked throughout the world, including in China and the U.S.

REFERENCES

Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; U.S. Geological Survey, Bulletin 1693, 379 pages.
Dawson, K.M., Panteleyev, A. and Sutherland-Brown, A. (1991): Regional Metallogeny, Chapter 19, in Geology of the Cordilleran Orogen in Canada, Editors, Gabrielse, H. and Yorath, C.J., Geological Survey of Canada, Geology of Canada, Number 4, page 707-768 (also, Geological Society of America, The Geology of North America, Volume G-2).
Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, 86 pages.

Einaudi, M.T. (1982): General Features and Origin of Skarns Associated with Porphyry Copper Plutons, Southwestern North America; in Advances in Geology of the Porphyry Copper Deposits, Southwestern U.S., Titley, S.R., Editor, Univ. Arizona Press, pages 185-209.
Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; Economic Geology; Volume 77, pages 745-754.
Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.
Meinert, L.D. (1983): Variability of Skarn-deposits: Guides to Exploration; in Revolution in the Earth Sciences - Advances in the Past Half-century, Boardman, S.J., Editor; Kendall/Hunt Publishing Company, pages 301-316.

[Back to top]

Pb-Zn SKARNS

K02
by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): Pb-Zn Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 61-62.

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic Pb-Zn deposits.

COMMODITIES (*BYPRODUCTS*): Pb, Zn, Ag, (Cu, Cd, W, Au).

EXAMPLES (British Columbia - *Canada/International*): Piedmont (082FNW129), Contact (104P 004); *Quartz Lake (Yukon, Canada), Groundhog (New Mexico, USA), Darwin (California, USA) San Antonio, Santa Eulalia and Naica (Mexico), Yeonhwa-Ulchin deposits (South Korea), Nakatatsu deposits (Japan), Shuikoushan and Tienpaoshan (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Galena and/or sphalerite-dominant mineralization genetically associated with a skarn gangue.

TECTONIC SETTING: Along continental margins where they are associated with late orogenic plutonism. Pb-Zn skarns occur at a wide range of depths, being associated with subvolcanic aphanitic dikes and high-level breccia pipes, as well as deep-level batholiths. In British Columbia, some Pb-Zn skarns are found in oceanic island arcs where they form distally to larger calcic Fe or Cu skarn systems.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. In British Columbia, the 80 Pb-Zn skarn occurrences identified have a wide age range; over 40 % are Early to mid-Jurassic, 22 % are Cretaceous, and a further 17 % are Eocene-Oligocene in age.

HOST/ASSOCIATED ROCK TYPES: Variable; from high-level skarns in thick limestones, calcareous tuffs and sediment to deeper level skarns in marbles and calcsilicate-bearing migmatites. Associated intrusive rocks are granodiorite to leucogranite, diorite to syenite (mostly quartz monzonite). Pb-Zn skarns tend to be associated with small stocks, sills and dikes and less commonly with larger plutons. The composition of the intrusions responsible for many distal Pb-Zn skarns is uncertain.

DEPOSIT FORM: Variable; commonly occurs along igneous or stratigraphic contacts. Can develop as subvertical chimneys or veins along faults and fissures and as subhorizontal blankets. Pb-Zn skarn deposits formed either at higher structural levels or distal to the intrusions tend to be larger and more Mn- rich compared to those formed at greater depths or more proximal.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn.

ORE MINERALOGY (Principal and *subordinate*): Sphalerite ± galena ± pyrrhotite ± pyrite ± magnetite ± arsenopyrite ± chalcopyrite ± bornite. Other trace minerals reported include scheelite, bismuthinite, stannite, cassiterite, tetrahedrite, molybdenite, fluorite, and native gold. Proximal skarns tend to be richer in Cu and W, whereas distal skarns contain higher amounts of Pb, Ag and Mn.

ALTERATION MINERALOGY: Exoskarn alteration: Mn-rich hedenbergite (Hd30-90, Jo10-50), andraditic garnet (Ad20-100, Spess2-10) ± wollastonite ± bustamite ± rhodonite. Late-stage Mn-rich actinolite ± epidote ± ilvaite ± chlorite ± dannemorite ± rhodochrosite ± axinite. Endoskarn alteration: Highly variable in development, and in many of the distal Pb-Zn skarns the nature of the endoskarn is unknown. However, Zn-rich skarns formed near stocks are often associated with abundant endoskarn that may equal or exceed the exoskarn (Einaudi et al., 1981). Endoskarn mineralogy is dominated by epidote ± amphibole ± chlorite ± sericite with lesser rhodonite ± garnet ± vesuvianite ± pyroxene ± K-feldspar ± biotite and rare topaz. Marginal phases may contain greisen and/or tourmaline.

ORE CONTROLS: Carbonate rocks, particularly along structural and/or lithogical contacts (e.g. shale-limestone contacts or pre-ore dikes). Deposits may occur considerable distances (100-1000 m) from the source intrusions.

ASSOCIATED DEPOSIT TYPES: Pb-Zn-Ag veins (I05), Cu skarns (K01) and Cu porphyries (L03, L04). In B.C., small Pb-Zn skarns occur distally to some Fe (K03) and W (K04) skarns.

COMMENTS: Pb-Zn skarn occurrences are preferentially developed in: (1) continental margin sedimentary rocks of the Cassiar and Ancestral North America terranes, (2) oceanic island arc rocks of the Quesnellia and Stikinia terranes, and (3) arc rocks of the Wrangellia Terrane. Their widespread terrane distribution partly reflects their formation as small distal mineralized occurrences related to other skarns (notably Cu, Fe and W skarns), as well as some porphyry systems. British Columbia is endowed with some large and significant Pb-Zn reserves classified as manto deposits (Nelson, 1991; Dawson et al., 1991). These deposits lack skarn gangue, but are sometimes grouped with the Pb-Zn skarns.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Pb, Zn, Ag, Cu, Mn, As, Bi, W, F, Sn, Mo, Co, Sb, Cd and Au geochemical anomalies.

GEOPHYSICAL SIGNATURE: Generally good induced polarization response. Galena-rich orebodies may be marked by gravity anomalies whereas pyrrhotite-rich mineralization may be detected by magnetic surveys. CS-AMT may also be a useful exploration system.

OTHER EXPLORATION GUIDES: Thick limestones distal to small granitoid stocks; structural traps and lithological contacts; exoskarns with low garnet/pyroxene ratios.

ECONOMIC FACTORS

GRADE AND TONNAGE: Pb-Zn skarns tend to be small (<3 Mt) but can reach 45 Mt, grading up to 15 % Zn, 10 % Pb and > 150 g/t Ag with substantial Cd. Cu grades are generally < 0.2 %. Some deposits (e.g. Naica (Mexico) and Falun (Sweden)) contain Au. The 80 British Columbia Pb-Zn skarn occurrences are generally small and have had no major metal production.

IMPORTANCE: Important past and current producers exist in Mexico, China, U.S.A (New Mexico and California), and Argentina. No large productive Pb-Zn skarns have been discovered in B.C.

REFERENCES

Dawson, K.M. and Dick, L.A. (1978): Regional Metallogeny in the Northern Cordillera: Tungsten and Base Metal-bearing Skarns in Southeastern Yukon and Southwestern Mackenzie; in Current Research, Part A, Geological Survey of Canada, Paper 1978- 1A, pages 287-292.
Dawson, K.M., Panteleyev, A. and Sutherland Brown, A. (1991): Regional Metallogeny, Chapter 19, in Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, Geological Survey of Canada, Geology of Canada, Number 4, page 707-768 (also, Geological Society of America, The Geology of North America, Volume G-2).
Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, 86 pages.
Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; Economic Geology; Volume 77, pages 745-754.
Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.

[Back to top]

Fe SKARNS

K03

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): Fe Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 63-65.

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic iron deposits.

COMMODITIES (*BYPRODUCTS*): Magnetite (Cu, Ag, Au, Co, phlogopite, borate minerals).

EXAMPLES (British Columbia - *Canada/International*): Tasu (103C 003), Jessie (103B 026), Merry Widow (092L 044), Iron Crown (092L 034), Iron Hill (092F 075), Yellow Kid (092F 258), Prescott (092F 106), Paxton (092F 107), Lake (092F 259); *Shinyama (Japan), Cornwall Iron Springs (Utah, USA) Eagle Mountain (California, USA), Perschansk, Dashkesan, Sheregesh and Teya (Russia), Daiquiri (Cuba), San Leone (Italy).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Fe skarns).

TECTONIC SETTING: Calcic Fe skarns: Intra and non-intraoceanic island arcs; rifted continental margins. Magnesian Fe skarns: Cordilleran-type, synorogenic continental margins.

AGE OF MINERALIZATION: Can be of any age, mainly Mesozoic to Cenozoic. Typically Early to mid-Jurassic in British Columbia.

HOST/ASSOCIATED ROCK TYPES: Calcic Fe skarns: Fe-rich, Si-poor intrusions derived from primitive oceanic crust. Large to small stocks and dikes of gabbro to syenite (mostly gabbro-diorite) intruding limestone, calcareous clastic sedimentary rocks, tuffs or mafic volcanics at a high to intermediate structural level. Magnesian Fe skarns: Small stocks, dikes and sills of granodiorite to granite intruding dolomite and dolomitic sedimentary rocks.

DEPOSIT FORM: Variable and includes stratiform orebodies, vertical pipes, fault- controlled sheets, massive lenses or veins, and irregular ore zones along intrusive margins.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures. Magnetite varies from massive to disseminated to veins.

ORE MINERALOGY(Principal and *Subordinate*): Calcic Fe skarns: Magnetite ± chalcopyrite ± pyrite ± cobaltite ± pyrrhotite ± arsenopyrite ± sphalerite ± galena ± molybdenite ± bornite ± hematite ± martite ± gold. Rarely, can contain tellurobismuthite ± fluorite ± scheelite. Magnesian Fe skarns: Magnetite ± chalcopyrite ± bornite ± pyrite ± pyrhhotite ± sphalerite ± molybdenite.

EXOSKARN ALTERATION (both calcic and magnesian): High Fe, low Mn, diopside-hedenbergite clinopyroxene (Hd20-80) and grossular-andradite garnet (Ad20-95), ± epidote ± apatite. Late stage amphibole ± chlorite ± ilvaite ± epidote ± scapolite ± albite ± K-feldspar. Magnesian Fe skarns can contain olivine, spinel, phlogopite, xanthophyllite, brucite, serpentine, and rare borate minerals such as ludwigite, szaibelyite, fluorborite and kotoite.

ENDOSKARN ALTERATION: Calcic Fe skarns: Extensive endoskarn with Na-silicates ± garnet ± pyroxene ± epidote ± scapolite. Magnesian skarns: Minor pyroxene ± garnet endoskarn, and propyllitic alteration.

ORE CONTROLS: Stratigraphic and structural controls. Close proximity to contacts between intrusions and carbonate sequences, volcanics or calcareous tuffs and sediments. Fracture zones near igneous contacts can also be important.

ASSOCIATED DEPOSIT TYPES: Cu porphyries (L03, L04); Cu (K01) and Pb-Zn (K02) skarns; small Pb-Zn veins (I05).

COMMENTS: In both calcic and magnesian Fe skarns, early magnetite is locally intergrown with, or cut by, garnet and magnesian silicates (Korzhinski, 1964, 1965;. Sangster, 1969; Burt, 1977). Some calcic Fe skarns contain relatively small pockets of pyrrhotite-pyrite mineralization that postdate the magnetite; this mineralization can be Au-rich. Byproduct magnetite is also derived from some Sn, Cu and calcic Pb-Zn skarns. Over 90% of the 146 Fe skarn occurrences in British Columbia lie within the Wrangellia Terrane of the Insular Belt. The majority of these form where Early to mid-Jurassic dioritic plutons intrude Late Triassic limestones.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Calcic Fe skarn: enriched in Fe, Cu, Co, Au, Ni, As, Cr. Overall Cu and Au grades are low (<0.2% Cu and 0.5 g/t Au). Magnesian Fe skarn: enriched in Fe, Cu, Zn, Bo.

GEOPHYSICAL SIGNATURE: Strong positive magnetic, electromagnetic and induced polarization anomalies. Possible gravity anomalies.

OTHER EXPLORATION GUIDES: Magnetite-rich float. In the Wrangellia Terrane of British Columbia, the upper and lower contacts of the Late Triassic Quatsino limestone (or equivalent units) are favorable horizons for Fe skarn development.

ECONOMIC FACTORS

GRADE AND TONNAGE: Grades are typically 40 to 50 % Fe. Worldwide, calcic Fe skarns range from 3 to 150 Mt whereas magnesian Fe skarns can be larger (exceeding 250 Mt). In British Columbia, they reach 20 Mt and average approximately 4 Mt mined ore.

IMPORTANCE: Worldwide, these deposits were once an important source of iron, but in the last 40 years the market has been increasingly dominated by iron formation deposits. Nearly 90 % of British Columbia's historic iron production was from skarns.

REFERENCES

Burt, D.M. (1977): Mineralogy and Petrology of Skarn Deposits; Rendiconti, Societa Italiana di Mineralogia e Petrologia, Volume 33 (2), pages 859-873.
Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; U.S. Geological Survey, Bulletin 1693, 379 pages.
Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, 86 pages.
Einaudi, M.T. (1982): General Features and Origin of Skarns Associated with Porphyry Copper Plutons, Southwestern North America; in Advances in Geology of the Porphyry Copper Deposits, Southwestern U.S., Titley, S.R., Editor, Univ. Arizona Press, pages 185-209.
Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.
Korzhinski, D.S. (1964): An Outline of Metasomatic Processes (trans. M.E. Bergunker); International Geol. Review, Volume 6, pages 1713-1734.
Korzhinski, D.S. (1965): The Theory of Systems with Perfectly Mobile Components and Processes of Mineral Formation; American Journal of Science, Volume 263, pages 193-205.
Meinert, L.D. (1984): Mineralogy and Petrology of Iron Skarns in Western British Columbia, Canada; Economic Geology, Volume 79, Number 5, pages 869-882.
Meinert, L.D. (1992): Skarns and Skarn Deposits; Geoscience Canada, Volume 19, No. 4, pages 145-162.
Podlessky, K.V., Vlasova, D.K. and Kudrja, P.F. (1991): Magnetite-bearing Skarns of Mongolia; in Skarns - Their Genesis and Metallogeny, Theophrastus Publications, Athens, Greece, pages 265-298.
Ray, G.E. and Webster, I.C.L. (1991a): Geology and Mineral Occurrences of the Merry Widow Skarn Camp, Northern Vancouver Island, 92L/6; B. C. Ministry of Energy, Mines and Petroleum Resources, Open File Map 1991-8.
Ray, G.E., and Webster, I.C.L. (1991b): An Overview of Skarn Deposits; in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera; McMillan, W.J., compiler, B. C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 213-252.
Sangster, D.F. (1969): The Contact Metasomatic Magnetite Deposits of British Columbia; Geological Survey of Canada, Bulletin 172, 85 pages.

[Back to top]

Au SKARNS

K04

by Gerald E. Ray
British Columbia Geological Survey

Revised 1997
Ray, G.E. (1998): Au Skarns, in Geological Fieldwork 1997, British Columbia Ministry of Employment and Investment, Paper 1998-1, pages 24H-1 to 24H-4.

IDENTIFICATION

SYNONYMS: Pyrometasomatic, tactite, or contact metasomatic Au deposits.

COMMODITIES (*BYPRODUCTS*): Au (Cu, Ag).

EXAMPLES (British Columbia - *Canada/International*): Nickel Plate (092HSE038), French (092HSE059), Canty (092HSE064), Good Hope (092HSE060), QR - Quesnel River (093A 121); *Fortitude, McCoy and Tomboy-Minnie (Nevada,USA), Buckhorn Mountain (Washington,USA), Diamond Hill, New World district and Butte Highlands (Montana,USA), Nixon Fork (Alaska, USA), Thanksgiving (Philippines), Browns Creek and Junction Reefs-Sheahan-Grants (New South Wales, Australia), Mount Biggenden (Queensland, Australia), Savage Lode, Coogee (Western Australia, Australia), Nambija (Ecuador), Wabu (Irian Jaya, Indonesia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold-dominant mineralization genetically associated with a skarn gangue consisting of Ca - Fe - Mg silicates, such as clinopyroxene, garnet and epidote. Gold is often intimately associated with Bi or Au-tellurides, and commonly occurs as minute blebs (<40 microns) that lie within or on sulphide grains. The vast majority of Au skarns are hosted by calcareous rocks (calcic subtype). The much rarer magnesian subtype is hosted by dolomites or Mg-rich volcanics. On the basis of gangue mineralogy, the calcic Au skarns can be separated into either pyroxene-rich, garnet-rich or epidote-rich types; these contrasting mineral assemblages reflect differences in the hostrock lithologies as well as the oxidation and sulphidation conditions in which the skarns developed.

TECTONIC SETTINGS: Most Au skarns form in orogenic belts at convergent plate margins. They tend to be associated with syn to late island arc intrusions emplaced into calcareous sequences in arc or back-arc environments.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Most deposits are related to plutonism associated with the development of oceanic island arcs or back arcs, such as the Late Triassic to Early Jurassic Nicola Group in British Columbia.

AGE OF MINERALIZATION: Phanerozoic (mostly Cenozoic and Mesozoic); in British Columbia Au skarns are mainly of Early to Middle-Jurassic age. The unusual magnesian Au skarns of Western Australia are Archean.

HOST/ASSOCIATED ROCK TYPES: Gold skarns are hosted by sedimentary carbonates, calcareous clastics, volcaniclastics or (rarely) volcanic flows. They are commonly related to high to intermediate level stocks, sills and dikes of gabbro, diorite, quartz diorite or granodiorite composition. Economic mineralization is rarely developed in the endoskarn. The I-type intrusions are commonly porphyritic, undifferentiated, Fe-rich and calc-alkaline. However, the Nambija, Wabu and QR Au skarns are associated with alkalic intrusions.

DEPOSIT FORM: Variable from irregular lenses and veins to tabular or stratiform orebodies with lengths ranging up to many hundreds of metres. Rarely, can occur as vertical pipe-like bodies along permeable structures.

TEXTURE/STRUCTURE: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to layered textures in exoskarn. Some hornfelsic textures. Fractures, sill-dike margins and fold hinges can be an important loci for mineralization.

ORE MINERALOGY (Principal and *subordinate*): The gold is commonly present as micron-sized inclusions in sulphides, or at sulphide grain boundaries. To the naked eye, ore is generally indistinguishable from waste rock. Due to the poor correlation between Au and Cu in some Au skarns, the economic potential of a prospect can be overlooked if Cu-sulphide-rich outcrops are preferentially sampled and other sulphide-bearing or sulphide-lean assemblages are ignored. The ore in pyroxene-rich and garnet-rich skarns tends to have low Cu:Au (<2000:1), Zn:Au (<100:1) and Ag/Au (<1:1) ratios, and the gold is commonly associated with Bi minerals (particularly Bi tellurides).

Magnesian subtype: Native gold ± pyrrhotite ± chalcopyrite ± pyrite ± magnetite ± galena ± tetrahedrite.

Calcic subtype:

Pyroxene-rich Au skarns: Native gold ± pyrrhotite ± arsenopyrite ± chalcopyrite ± tellurides (e.g. hedleyite, tetradymite, altaite and hessite) ± bismuthinite ± cobaltite ± native bismuth ± pyrite ± sphalerite ± maldonite. They generally have a high sulphide content and high pyrrhotite:pyrite ratios. Mineral and metal zoning is common in the skarn envelope. At Nickel Plate for example, this comprises a narrow proximal zone of coarse-grained, garnet skarn containing high Cu:Au ratios, and a wider, distal zone of finer grained pyroxene skarn containing low Cu:Au ratios and the Au-sulphide orebodies.

Garnet-rich Au skarns: Native gold ± chalcopyrite ± pyrite ± arsenopyrite ± sphalerite ± magnetite ± hematite ± pyrrhotite ± galena ± tellurides ± bismuthinite. They generally have a low to moderate sulphide content and low pyrrhotite:pyrite ratios.

Epidote-rich Au skarn: Native gold ± chalcopyrite ± pyrite ± arsenopyrite ± hematite ± magnetite ± pyrrhotite ± galena ± sphalerite ± tellurides. They generally have a moderate to high sulphide content with low pyrrhotite:pyrite ratios.

EXOSKARN MINERALOGY (GANGUE):

Magnesian subtype: Olivine, clinopyroxene (Hd2-50), garnet (Ad7-30), chondrodite and monticellite. Retrograde minerals include serpentine, epidote, vesuvianite, tremolite-actinolite, phlogopite, talc, K-feldspar and chlorite.
Calcic subtype:

Pyroxene-rich Au skarns: Extensive exoskarn, generally with high pyroxene:garnet ratios. Prograde minerals include diopsidic to hedenbergitic clinopyroxene (Hd 20-100), K-feldspar, Fe-rich biotite, low Mn grandite garnet (Ad 10-100), wollastonite and vesuvianite. Other less common minerals include rutile, axinite and sphene. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite, scapolite, tremolite-actinolite, sericite and prehnite.

Garnet-rich Au skarns: Extensive exoskarn, generally with low pyroxene:garnet ratios. Prograde minerals include low Mn grandite garnet (Ad 10-100), K-feldspar, wollastonite, diopsidic clinopyroxene (Hd 0-60), epidote, vesuvianite, sphene and apatite. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite, tremolite-actinolite, sericite, dolomite, siderite and prehnite.

Epidote-rich Au skarns: Abundant epidote and lesser chlorite, tremolite-actinolite, quartz, K-feldspar, garnet, vesuvianite, biotite, clinopyroxene and late carbonate. At the QR deposit, epidote-pyrite and carbonate-pyrite veinlets and coarse aggregates are common, and the best ore occurs in the outer part of the alteration envelope, within 50 m of the epidote skarn front.

ENDOSKARN MINERALOGY (GANGUE): Moderate endoskarn development with K-feldspar, biotite, Mg-pyroxene (Hd 5-30) and garnet. Endoskarn at the epidote-rich QR deposit is characterized by calcite, epidote, clinozoisite and tremolite whereas at the Butte Highlands Mg skarn it contains argillic and propyllitic alteration with garnet, clinopyroxene and epidote.

WEATHERING: In temperate and wet tropical climates, skarns often form topographic features with positive relief.

ORE CONTROLS: The ore exhibits strong stratigraphic and structural controls. Orebodies form along sill-dike intersections, sill-fault contacts, bedding-fault intersections, fold axes and permeable faults or tension zones. In the pyroxene-rich and epidote-rich types, ore commonly develops in the more distal portions of the alteration envelopes. In some districts, specific suites of reduced, Fe-rich intrusions are spatially related to Au skarn mineralization. Ore bodies in the garnet-rich Au skarns tend to lie more proximal to the intrusions.

GENETIC MODEL: Many Au skarns are related to plutons formed during oceanic plate subduction. There is a worldwide spatial, temporal and genetic association between porphyry Cu provinces and calcic Au skarns. Pyroxene-rich Au skarns tend to be hosted by siltstone-dominant packages and form in hydrothermal systems that are sulphur-rich and relatively reduced. Garnet-rich Au skarns tend to be hosted by carbonate-dominant packages and develop in more oxidising and/or more sulphur-poor hydrothermal systems.

ASSOCIATED DEPOSIT TYPES: Au placers (C01, C02), calcic Cu skarns (K01), porphyry Cu deposits (L04) and Au-bearing quartz and/or sulphide veins (I01, I02). Magnesian subtype can be associated with porphyry Mo deposits (L05) and possibly W skarns (K05). In British Columbia there is a negative spatial association between Au and Fe skarns at regional scales, even though both classes are related to arc plutonism. Fe skarns are concentrated in the Wrangellia Terrane whereas most Au skarn occurrences and all the economic deposits lie in Quesnellia.

COMMENTS: Most Au skarns throughout the world are calcic and are associated with island arc plutonism. However, the Savage Lode magnesian Au skarn occurs in the Archean greenstones of Western Australia and the Butte Highlands magnesian Au skarn in Montana is hosted by Cambrian platformal dolomites. Note: although the Nickel Plate deposit lies distal to the Toronto stock in the pyroxene-dominant part of the skarn envelope, the higher grade ore zones commonly lie adjacent to sills and dikes where the exoskarn contains appreciable amounts of garnet with the clinopyroxene.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, As, Bi, Te, Co, Cu, Zn or Ni soil, stream sediment and rock anomalies, as well as some geochemical zoning patterns throughout the skarn envelope (notably in Cu/Au, Ag/Au and Zn/Au ratios). Calcic Au skarns (whether garnet-rich or pyroxene-rich) tend to have lower Zn/Au, Cu/Au and Ag/Au ratios than any other skarn class. The intrusions related to Au skarns may be relatively enriched in the compatible elements Cr, Sc and V, and depleted in lithophile incompatible elements (Rb, Zr, Ce, Nb and La), compared to intrusions associated with most other skarn types.

GEOPHYSICAL SIGNATURE: Airborne magnetic or gravity surveys to locate plutons. Induced polarization and ground magnetic follow-up surveys can outline some deposits.

OTHER EXPLORATION GUIDES: Placer Au. Any carbonates, calcareous tuffs or calcareous volcanic flows intruded by arc-related plutons have a potential for hosting Au skarns. Favorable features in a skarn envelope include the presence of: (a) proximal Cu-bearing garnet skarn and extensive zones of distal pyroxene skarn which may carry micron Au, (b) hedenbergitic pyroxene (although diopsidic pyroxene may predominate overall), (c) sporadic As-Bi-Te geochemical anomalies, and, (d) undifferentiated, Fe-rich intrusions with low Fe_2O_3/FeO ratios. Any permeable calcareous volcanics intruded by high-level porphyry systems (particularly alkalic plutons) have a potential for hosting epidote-rich skarns with micron Au. During exploration, skarns of all types should be routinely sampled and assayed for Au, even if they are lean in sulphides.

ECONOMIC IMPORTANCE

TYPICAL GRADE AND TONNAGE: These deposits range from 0.4 to 13 Mt and from 2 to 15 g/t Au. Theodore et al. (1991) report median grades and tonnage of 8.6 g/t Au, 5.0 g/t Ag and 213 000 t. Nickel Plate produced over 71 tonnes of Au from 13.4 Mt of ore (grading 5.3 g/t Au). The 10.3 Mt Fortitude (Nevada) deposit graded 6.9 g/t Au whereas the 13.2 Mt McCoy skarn (Nevada) graded 1.5 g/t Au. The QR epidote-rich Au skarn has reserves exceeding 1.3 Mt grading 4.7 g/t Au.

IMPORTANCE: Recently, there have been some significant Au skarn deposits discovered around the world (e.g. Buckhorn Mountain, Wabu, Fortitude). Nevertheless, total historic production of Au from skarn (more than 1 000 t of metal) is minute compared to production from other deposit types. The Nickel Plate deposit (Hedley, British Columbia) was probably one of the earliest major Au skarns in the world to be mined. Skarns have accounted for about 16 % of British Columbia's Au production, although nearly half of this was derived as a byproduct from Cu and Fe skarns.

REFERENCES

Billingsley, P. and Hume, C.B. (1941): The Ore Deposits of Nickel Plate Mountain, Hedley, British Columbia; Canadian Institute of Mining and Metallurgy, Bulletin, Volume 44, pages 524-

590.
Brookes, J.W., Meinert, L.D., Kuyper, B.A. and Lane, M.L. (1990): Petrology and Geochemistry of the McCoy Gold Skarn, Lander County, Nevada; in Geology and Ore Deposits of the Great Basin, Symposium Proceedings, Geological Society of Nevada, April 1990.
Ettlinger, A.D. and Ray, G.E. (1989a): Precious Metal Enriched Skarns in British Columbia: An Overview and Geological Study; B. C. Ministry of Energy, Mines and Petroleum Resources, Paper 1989-3, 128 pages.
Ettlinger, A.D., Albers, D., Fredericks, R. and Urbisinov, S. (1995): The Butte Highlands Project, Silver Bow County, Montana; An Olivine-rich Magnesian Gold Skarn; in Symposium Proceedings of Geology and Ore Deposits of American Cordilleran, Geological Society of Nevada, U.S. Geological Survey and Geological Society of Chile, April 10-13, 1995, Reno, Nevada.
Fox, P.E., and Cameron, R.S. (1995): Geology of the QR Gold Deposit, Quesnel River Area, British Columbia; in Porphyry Deposits of the Northwest Cordillera of North America, (editor) T.G. Schroeter, Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, Paper 66, pages 829-837.
Hammarstrom, J.M., Orris, G.J., Bliss, J.D., and Theodore, T.G. (1989): A Deposit Model for Gold-Bearing Skarns; Fifth Annual V.E. McKelvey Forum on Mineral and Energy Resources, U.S. Geological Survey , Circular 1035, pages 27-28.
McKelvey, G.E., and Hammarstrom, J.M. (1991): A Reconnaissance Study of Gold Mineralization Associated with Garnet Skarn at Nambija, Zamora Province, Ecuador, in USGS Research on Mineral Resources - 1991, Program and Abstracts. Editors E.J. Good, J.F. Slack and R.K. Kotra, U.S. Geological Survey, Circular 1062, page 55.
Meinert, L.D. (1989): Gold Skarn Deposits - Geology and Exploration Criteria; in The Geology of Gold Deposits; The Perspective in 1988; Economic Geology; Monograph 6, pages 537-552.
Mueller, A.G. (1991): The Savage Lode Magnesian Skarn in the Marvel Loch Gold-Silver Mine, Southern Cross Greenstone Belt, Western Australia; Part I. Structural Setting, Petrography and Geochemistry; Canadian Journal of Earth Sciences, Volume 28, Number 5, pages 659-685.
Orris, G.J., Bliss, J.D., Hammarstrom, J.M. and Theodore, T.G. (1987): Description and Grades and Tonnages of Gold-bearing Skarns; U. S. Geological Survey, Open File Report 87-273, 50 pages.
Ray, G.E. and Dawson, G.L. (1994): The Geology and Mineral Deposits of the Hedley Gold Skarn District, Southern British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 87, 156 pages.
Ray, G.E. and Webster, I.C.L. (1997): Skarns in British Columbia;, B.C. Ministry of Energy, Mines and Petroleum Resources, Bulletin 101, 260 pages.
Ray, G.E., Ettlinger, A.D. and Meinert, L.D. (1990): Gold Skarns: Their Distribution, Characteristics and Problems in Classification; in Geological Fieldwork 1989, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1990-1, pages 237-246.
Theodore, T.G., Orris, G.J., Hammarstrom, J.M. and Bliss, J.D. (1991): Gold Bearing Skarns; U. S. Geological Survey; Bulletin 1930, 61 pages.

[Back to top]

W SKARNS

K05

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): W Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 71-74.

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic tungsten deposits.

COMMODITIES (*BYPRODUCTS*): W (Mo, Cu, Sn, Zn).

EXAMPLES (British Columbia - *Canada/International*): Emerald Tungsten (082FSW010), Dodger (082FSW011), Feeney (082FSW247), Invincible (082FSW218), Dimac (082M 123); *Fostung (Ontario, Canada), MacTung (Yukon, Canada), Cantung (Northwest Territories, Canada), Pine Creek and Strawberry(California, USA), Osgood Range (Nevada, USA), King Island (Tasmania, Australia), Sang Dong (South Korea).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Scheelite-dominant mineralization genetically associated with a skarn gangue.

TECTONIC SETTING: Continental margin, synorogenic plutonism intruding deeply buried sequences of eugeoclinal carbonate-shale sedimentary rocks. Can develop in tectonically thickened packages in back-arc thrust settings.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. Over 70% of the W skarns in British Columbia are related to Cretaceous intrusions.

HOST/ASSOCIATED ROCK TYPES: Pure and impure limestones, calcareous to carbonaceous pelites. Associated with tonalite, granodiorite, quartz monzonite and granite of both I and S-types. W skarn-related granitoids, compared to Cu skarn- related plutonic rocks, tend to be more differentiated, more contaminated with sedimentary material, and have crystallized at a deeper structural level.

DEPOSIT FORM: Stratiform, tabular and lens-like orebodies. Deposits can be continous for hundreds of metres and follow intrusive contacts.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Biotite hornfelsic textures common.

ORE MINERALOGY (Principal and subordinate): Scheelite ± molybdenite ± chalcopyrite ± pyrrhotite ± sphalerite ± arsenopyrite ± pyrite ± powellite. May contain trace wolframite, fluorite, cassiterite, galena, marcasite and bornite. Reduced types are characterized by pyrrhotite, magnetite, bismuthinite, native bismuth and high pyrrhotite:pyrite ratios. Variable amounts of quartz-vein stockwork (with local molybdenite) can cut both the exo and endoskarn. The Emerald Tungsten skarns in British Columbia include pyrrhotite-arsenopyrite veins and pods that carry up to 4 g/t Au.

ALTERATION MINERALOGY: Exoskarn alteration: Inner zone of diopside-hedenbergite (Hd60-90, Jo5-20) ± grossular-andradite (Ad 10-50, Spess5-50) ± biotite ± vesuvianite, with outer barren wollastonite-bearing zone. An innermost zone of massive quartz may be present. Late-stage spessartine ± almandine ± biotite ± amphibole ± plagioclase ± phlogopite ± epidote ± fluorite ± sphene. Reduced types are characterized by hedenbergitic pyroxene, Fe-rich biotite, fluorite, vesuvianite, scapolite and low garnet:pyroxene ratios, whereas oxidized types are characterized by salitic pyroxene, epidote and andraditic garnet and high garnet:pyroxene ratios. Exoskarn envelope can be associated with extensive areas of biotite hornfels. Endoskarn alteration: Pyroxene ± garnet ± biotite ± epidote ± amphibole ± muscovite ± plagioclase ± pyrite ± pyrrhotite ± trace tourmaline and scapolite; local greisen developed.

ORE CONTROLS: Carbonate rocks in extensive thermal aureoles of intrusions; gently inclined bedding and intrusive contacts; structural and/or stratigraphic traps in sedimentary rocks, and irregular parts of the pluton/country rock contacts.

ASSOCIATED DEPOSIT TYPES: Sn (K06), Mo (K07) and Pb-Zn (K02) skarns. Wollastonite-rich industrial mineral skarns (K09).

COMMENTS: W skarns are separable into two types (Newberry, 1982): reduced skarns (e.g. Cantung, Mactung), formed in carbonaceous rocks and/or at greater depths, and oxidized skarns (e.g. King Island), formed in hematitic or non-carbonaceous rocks, and/or at shallower depths. Late retrograde alteration is an important factor in many W skarns because, during retrogression, the early low-grade mineralization is often scavenged and redeposited into economic high-grade ore zones (e.g. Bateman, 1945; Dick, 1976, 1980). Dolomitic rocks tend to inhibit the development of W skarns; consequently magnesian W skarns are uncommon. In British Columbia they are preferentially associated with Cretaceous intrusions and hosted by calcareous, Cambrian age cratonic, pericratonic and displaced continental margin rocks in the Cassiar, Kootenay-Barkerville, Dorsay and Ancestral North American terranes.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: W, Cu, Mo, As, Bi and B. Less commonly Zn, Pb, Sn, Be and F geochemical anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Grades range between 0.4 and 2 % WO3 (typically 0.7 %). Deposits vary from 0.1 to >30 Mt.

IMPORTANCE: Skarn deposits have accounted for nearly 60 % of the western world's production, and over 80 % of British Columbia's production.

REFERENCES

Bateman, P.C. (1945): Pine Creek and Adamson Tungsten Mines, Inyo County, California; California Journal Mines Geology, Volume 41, pages 231-249.

Dawson, K.M., Panteleyev, A. and Sutherland Brown, A. (1991): Regional Metallogeny, Chapter 19, in Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, Geological Survey of Canada, Geology of Canada, Number 4, pages 707-768 (also, Geological Society of America, The Geology of North America, volume G-2).

Dick, L.A. (1976): Metamorphism and Metasomatism at the MacMillan Pass Tungsten Deposit, Yukon and District of MacKenzie, Canada; unpublished M.Sc. thesis, Queens University, 226 pages.

Dick, L.A. (1980): A Comparative Study of the Geology, Mineralogy and Conditions of Formation of Contact Metasomatic Mineral Deposits in the Northeastern Canadian Cordillera; Unpublished Ph.D. Thesis, Queen's University, 471 pages.

Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, 86 pages.

Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; Economic Geology; Volume 77, pages 745-754.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.

Kwak, T.A.P. (1987): W-Sn Skarn Deposits and Related Metamorphic Skarns and Granitoids; in Developments in Economic Geology, Volume 24, Elsevier Publishing Co., 445 pages.
Kwak, T.A.P. and White, A.J.R. (1982): Contrasting W-Mo-Cu and W-Sn-F Skarn Types and Related Granitoids. Mining Geology. Volume 32(4), pages 339-351.
Lowell, G.R. (1991): Tungsten-bearing Scapolite-Vesuvianite Skarns from the Upper Salcha River Area, East-central Alaska; in Skarns - Their Genesis and Metallogeny, Theophrastus Publications, Athens, Greece, pages 385-418.
Newberry, R.J. (1979): Systematics in the W-Mo-Cu Skarn Formation in the Sierra Nevada: An Overview; Geological Society of America, Abstracts with Programs; Volume 11, page 486.
Newberry, R.J. (1982): Tungsten-bearing Skarns of the Sierra Nevada. I. The Pine Creek Mine, California; Economic Geology, Volume 77, pages 823-844.
Newberry, R.J., and Swanson, S.E. (1986): Scheelite Skarn Granitoids: An Evaluation of the Roles of Magmatic Source and Process; Ore Geology Review, Number 1, pages 57- 81.

[Back to top]

Sn SKARNS

K06

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): Sn Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 75-76.

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic tin deposits.

COMMODITIES (*BYPRODUCTS*): Sn (W, Zn, magnetite).

EXAMPLES (British Columbia - *Canada/International*): Only three in British Columbia - Silver Diamond, Atlin Magnetite, and Daybreak (104N069, 126 and 134 respectively); *JC (Yukon, Canada), Moina, Mount Lindsay, Hole 16 and Mt. Garnet (Tasmania, Australia), Lost River (Alaska, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cassiterite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Sn skarns).

TECTONIC SETTINGS: Late to post orogenic granites emplaced into thick and deeply buried continental margin sedimentary sequences, or sequences in rifted or stable cratonic environments.

AGE OF MINERALIZATION: Most economic deposits are Mesozoic or Paleozoic, but occurrences may be any age (the occurrences in British Columbia are Late Cretaceous).

HOST/ASSOCIATED ROCK TYPES: Carbonates and calcareous sedimentary sequences. Associated with differentiated (low Ca, high Si and K) ilmenite-series granite, adamellite and quartz monzonitic stocks and batholiths (of both I and S-type) intruding carbonate and calcareous clastic rocks. Sn skarns tend to develop in reduced and deep-level environments and may be associated with greisen alteration.

DEPOSIT FORM: Variable; can occur as either stratiform, stockwork, pipe-like or irregular vein-like orebodies.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn; wrigglite skarns contain thin rhythmic and alternating layers rich in either magnetite, fluorite, vesuvianite or tourmaline. Some hornfelsic textures.

ORE MINERALOGY: Cassiterite ± scheelite ± arsenopyrite ± pyrrhotite ± chalcopyrite ± stannite ± magnetite ± bismuthinite ± sphalerite ± pyrite ± ilmenite.

ALTERATION MINERALOGY: Exoskarn alteration: Grandite garnet (Ad15-75, Pyralsp 5-30) (sometimes Sn, F, and Be enriched), hedenbergitic pyroxene (Hd40-95) ± vesuvianite (sometimes Sn and F-enriched) ± malayaite ± Fe and/or F-rich biotite ± stanniferous sphene ± gahnite ± rutile ± Sn-rich ilvaite ± wollastonite ± adularia. Late minerals include muscovite, Fe-rich biotite, chlorite, tourmaline, fluorite, sellaite, stilpnomelane, epidote and amphibole (latter two minerals can be Sn rich). Associated greisens include quartz and muscovite ± tourmaline ± topaz ± fluorite ± cassiterite ± sulphides. Magnesian Sn skarns can also contain olivine, serpentine, spinel, ludwigite, talc and brucite.

ORE CONTROLS: Differentiated plutons intruding carbonate rocks; fractures, lithological or structural contacts. Deposits may develop some distance (up to 500 m) from the source intrusions.

ASSOCIATED DEPOSIT TYPES: W skarns (K05), Sn ± Be greisens (I13), Sn-bearing quartz-sulphide veins and mantos (J02). In British Columbia, some of the Sn and W skarn-related intrusions (e.g. Cassiar batholith, Mount Haskin stock) are associated with small Pb-Zn skarn occurrences (K02).

COMMENTS: Sn skarns generally form at deep structural levels and in reduced oxidation states. However, wrigglite Sn skarns tend to develop in relatively near- surface conditions, such as over the cupolas of high-level granites. The three Sn skarn occurrences in British Columbia are all associated with an S-type, fluorine-rich accretionary granite, the Surprise Lake batholith. However, they are unusual in being hosted in allochthonous oceanic rocks of the Cache Creek Terrane.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sn, W, F, Be, Bi, Mo, As, Zn, Cu, Rb, Li, Cs and Re geochemical anomalies. Borate-bearing magnesian Sn skarns may exhibit B enrichment.

GEOPHYSICAL SIGNATURE: Magnetic, induced polarization and possible radiometric anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Deposits can grade up to 1 % Sn, but much of the metal occurring in malayaite, garnet, amphibole and epidote is not economically recoverable. Worldwide, deposits reach 30 Mt, but most range between 0.1 and 3 Mt.

IMPORTANCE: Worldwide, Sn skarns represent a major reserve of tin. However, current production from skarn is relatively minor compared to that from placer Sn deposits and Sn-rich greissens and mantos. British Columbia has had no Sn production from skarns.

REFERENCES

Burt, D.M. (1978): Tin Silicate-Borate-Oxide Equilibria in Skarns and Greisens - The System CaO-SnO2-SiO2-H2O-B2O3-CO2-F2O-1; Economic Geology, Volume 73, pages 269- 282.
Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; U.S. Geological Survey, Bulletin 1693, 379 pages.
Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.
Kwak, T.A.P. (1987): W-Sn Skarn Deposits and Related Metamorphic Skarns and Granitoids; in Developments in Economic Geology, Volume 24, Elsevier Publishing Co. 445 pages.
Kwak, T.A.P. and Askins, P.W. (1981): Geology and Genesis of the F-Sn-W (-Be-Zn) Skarn (Wrigglite) at Moina, Tasmania, Australia; Economic Geology, Volume 76, pages 439-467.
Mitrofanov, N.P. and Stolyarov, I.S. (1982): Comparative Description of Tin-bearing Skarns of the Ladoga Region and Central Asia; International Geology Revue, Volume 24, No. 11, pages 1299-1305.

[Back to top]

Mo SKARNS

K07

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1995): Mo Skarns, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy and Mines, Open File 1995-20, pages 77-78.

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic Mo deposits.

COMMODITIES (*BYPRODUCTS*): Mo (W, Cu, Pb, Zn, Sn, Bi, U, Au).

EXAMPLES (British Columbia - *Canada/International*): Coxey (082FSW110), Novelty (082FSW107); *Mount Tennyson (New South Wales, Australia), Little Boulder Creek (Idaho, USA), Cannivan Gulch (Montana, USA), Azegour (Morocco), Yangchiachangtze (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Molybdenite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Mo skarns). Mo skarns are broadly separable into polymetallic and “molybdenite-only” types (see comments below).

TECTONIC SETTING: Late orogenic plutonism (derived from transitional crust) intruding continental margin carbonate sequences. Also, some are associated with Mo- bearing porphyry systems developed within intra-oceanic island arcs.

AGE OF MINERALIZATION: Mainly Mesozoic and Paleozoic, but may be any age. In British Columbia, they are mainly of Early to mid-Jurassic in age.

HOST/ASSOCIATED ROCK TYPES: Stocks and dikes of evolved, commonly leucocratic quartz monzonite to granite (some containing primary biotite and muscovite) intruding calcareous clastic rocks. Deposits tend to develop close to intrusive contacts. Some of the Mo skarns in British Columbia are associated with high- level intrusions that have explosive breccia textures.

DEPOSIT FORM: Irregular orebodies along, and controlled by, the intrusive contacts.

TEXTURES: Igneous textures in endoskarn; local explosive breccia textures. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures.

ORE MINERALOGY (Principal and *subordinate*): Molybdenite ± scheelite ± pyrrhotite ± powellite ± chalcopyrite ± arsenopyrite ± pyrite ± pyrrhotite ± bismuthinite ± sphalerite ± fluorite. In rare instances also galena ± magnetite ± uraninite ± pitchblende ± cassiterite ± cobalite ± stannite ± gold.

EXOSKARN ALTERATION: Calcic Mo skarns: Hedenbergite pyroxene (Hd50-80, Jo1-3) ± low Mn grossular-andradite garnet (Ad40-95) ± wollastonite ± biotite ± vesuvianite. Magnesian Mo skarns: olivine (Fo96). Retrograde minerals: Calcic skarns: amphibole ± epidote ± chlorite and muscovite. Magnesian skarns: serpentine ± tremolite ± chlorite.

ENDOSKARN ALTERATION: Clinopyroxene, K-feldspar, hornblende, epidote, quartz veining, sericite, molybdenite.
ORE CONTROLS: Carbonate or calcareous rocks in thermal aureoles adjacent to intrusive margins.

ASSOCIATED DEPOSIT TYPES: Mo porphyries of quartz monzonite type (L05), Mo-sulphide veins, and Zn-sulphide veins (I05). Some Mo skarns in China are associated with distal, sphalerite-rich mineralization.

COMMENTS: Mo skarns are broadly separable into two types: polymetallic (containing molybdenite with other W, Zn, Pb, Bi, Sn, Co or U-rich minerals), and "molybedenite-only" (containing mainly molybdenite with no or few other sulphides). Over 85% of the 21 Mo skarns recorded in British Columbia occur in the Omineca Belt. More than 60% are hosted in cratonic, pericratonic and displaced continental margin rocks of the Kootenay, Cassiar and Ancestral North America terranes, and a further 19% are found in the Quesnellia Terrane.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Enriched in Mo, Zn, Cu, Sn, Bi, As, F, Pb, U, Sb, Co (Au).

GEOPHYSICAL SIGNATURE: Positive magnetic and induced polarization anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Worldwide, grades range from 0.1 to 2 % MoS2, and tonnages between 0.1 and 2 Mt. In British Columbia, the Coxey deposit produced 1 Mt of ore grading approximately 0.17 % MoS2. The Novelty and Giant are polymetallic Mo skarns near Rossland, British Columbia with unusually high grades of up to 47 g/t Au, 1.4 % Ni, 30.5 % As and 4.84 % Co.

IMPORTANCE: Mo skarns tend to be smaller tonnage and less economically important than porphyry Mo deposits.

REFERENCES

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, Economic Geology Publishing Co., pages 317-391.
Theodore, T.G. and Menzie, W.D. (1984): Fluorine-deficient Porphyry Molybdenum Deposits in the Western North American Cordillera; Proceedings of the 6th Quadrennial IAGOD Symposium, Stuttgart, Germany, pages 463-470.

[Back to top]

GARNET SKARNS

K08

by Gerald E. Ray
British Columbia Geological Survey

Ray, G.E. (1998): Garnet Skarns, in Geological Fieldwork 1997, British Columbia Ministry of Employment and Investment, Paper 1998-1, pages 24I-1 to 24I-2.

IDENTIFICATION

SYNONYM: Pyrometasomatic or contact metasomatic garnet deposits.

COMMODITIES (*BYPRODUCTS*): Garnet (wollastonite, magnetite).

EXAMPLES (British Columbia - *Canada/International*): Mount Riordan (Crystal Peak, 082ESW102); *San Pedro (New Mexico, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Garnet-dominant skarn hosted by calcareous rocks generally near an intrusive contact.

TECTONIC SETTINGS: Virtually any setting.

AGE OF DEPOSIT: May be any age.

HOST/ASSOCIATED ROCK TYPES: Garnet is hosted by carbonate or altered calcareous mafic volcanic sequences that are intruded by relatively oxidized plutons.

DEPOSIT FORM: Irregular zones of massive garnet developed in exoskarn close to plutonic contacts. The shape of the deposit may be controlled partly by the morphology of the original conformable units.

TEXTURES: Coarse grained, massive granoblastic textures in exoskarn.

ORE MINERALOGY (Principal and *subordinate*): Abundant and massive, coarse grained garnet (grossular-andradite) ± wollastonite ± magnetite.

ALTERATION MINERALOGY (Principal and *subordinate*): Garnet, clinopyroxene, quartz, feldspar, calcite, sphene, apatite, axinite, vesuvianite and sericite.

OPAQUE MINERALOGY: Economically viable garnet deposits typically have very little or no sulphides.

ORE CONTROLS: Plutonic contacts and oxidized carbonate host rocks. The Mount Riordan garnet skarn lies proximal to the intrusion.

ASSOCIATED DEPOSIT TYPES: Cu, Fe, Au and wollastonite skarns (K01, K03, K04 and K09).

COMMENTS: The best industrial garnets (due to higher specific gravity and hardness) are almandine-pyrope composition. These generally occur in high grade metamorphic rocks and require secondary concentration in beach or stream placers to be mined economically. Examples include the Emerald Creek deposit located in Idaho, USA, and a 6 Mt beach-sand deposit situated near Geraldton, Western Australia that grades 35 per cent garnet. The Mount Riordan deposit is one of the largest and highest grade garnet skarns yet identified; its garnet is suitable for the production of sandblasting and other abrasive products that require high angularity and a wide range of grain sizes. In British Columbia, there have been intermittent attempts to process the garnet-rich tailings from the Iron Hill-Argonaut Fe skarn (092F 075).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: May get very weak W, Mo, Zn and Cu geochemical anomalies.

GEOPHYSICAL SIGNATURE: Gravity and possible magnetic anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: To be economic, garnet skarn deposits should be large tonnage (>20 Mt) and high grade (> 70% garnet). The Mount Riordan (Crystal Peak) deposit contains reserves of 40 Mt grading 78% garnet and San Pedro is a 22 to 30 Mt deposit with 85% andraditic garnet.

ECONOMIC LIMITATIONS: The garnet should be free of inclusions, possess a relatively high specific gravity and high angularity, and be present as discrete grains that can be processed easily by conventional benefication techniques. Economic concentrations of clean and industrially suitable grossularite-andradite garnet in skarn are rare. This is because skarn garnets tend to be relative soft and many contain fine-grained carbonate inclusions. Easy access, low cost transportation and a ready and reliable market for the product are essential features controlling the economic viability of a deposit.

END USES: Sandblasting, water-jet equipment and abrasives, such as sandpaper. Grossular-andradite garnets have more restricted uses than almandine.

IMPORTANCE: World production in 1995 of industrial garnet was approximately 110 000 tonnes, of which just under half (valued at $US 11 million) was produced in the U.S. Worldwide, most garnet is obtained from placer deposits or as a byproduct during hard rock mining of other commodities. The demand in North America for industrial garnet is growing; skarns are expected to be an important future source for the mineral.

SELECTED BIBLIOGRAPHY

Austin, G.T. (1991): Garnet (Industrial); in Mineral Commodity Summaries 1991, Department of the Interior, United States Bureau of Mines, pages 58-59.
Grond, H.C., Wolfe, R., Montgomery, J.H. and Giroux, G.H. (1991): A Massive Skarn-hosted Andradite Deposit near Penticton, British Columbia; in Industrial Minerals of Alberta and British Columbia, Canada, B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1991-23, pages 131-133.
Harben, P.W. and Bates, R.L. (1990): Garnet; in Industrial Minerals, Geology and World Deposits, Industrial Minerals Division, Metal Bulletin Plc., London, pages 120-12.
Hight, R.P. (1983): Abrasives; in Industrial Minerals and Rocks, 5th edition, American Institute of Mining, Metallurgy and Petroleum Engineers, Lefond, S.J., Editor, New York, pages 11-32.
Smoak, J.F. (1985): Garnet; Unites States Bureau of Mines, Bulletin 675, pages 297-304.
Ray, G.E., Grond, H.C., Dawson, G.L. and Webster, I.C.L. (1992): The Mount Riordan (Crystal Peak) Garnet Skarn, Hedley District, Southern British Columbia; Economic Geology, Volume 87, pages 1862-1876.

[Back to top]

WOLLASTONITE SKARNS

K09

by G.J. Simandl[1], S. Paradis[2], G.J Orris[3] and G.E. Ray[1]

[1]British Columbia Geological Survey, Victoria, B.C., Canada

[2]Geological Survey of Canada, Sidney, B.C., Canada

[3]United States Geological Survey, Tucson, Arizona, USA

Simandl, G.J., Paradis, S., Orris, G.J. and Ray, G.E. (1999): Wollastonite Skarns; in Selected British Columbia Mineral Deposit Profiles, Volume 3, Industrial Minerals, G.J. Simandl, Z.D. Hora and D.V. Lefebure, Editors, British Columbia Ministry of Energy and Mines.

IDENTIFICATION

COMMODITIES (*BYPRODUCTS*): Wollastonite (in some cases garnet, clinopyroxene, high calcium carbonate, limestone, marble, Cu and possibly other metals).

EXAMPLES (British Columbia (MINFILE#): *Canada/International*): Mineral Hill (092GNW052), Zippa Mountain (104B 384), Rossland wollastonite (082FSW341); *Fox Knoll and Lewis (New York, USA), Lappeenranta (Finland), Khila (Belkapahar, India), Koytash (Uzbekistan, Commonwealth of Independent States).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Wollastonite deposits form irregular masses or lenses in metamorphosed calcareous rocks. Most form adjacent to or some distance from known igneous intrusions. Some deposits are located in medium to high grade metamorphic terrains and appear unrelated to intrusions.

TECTONIC SETTINGS: Magmatism associated with continental margin orogenesis and rifting; or intracratonic catazonal and/or magmatic settings.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Exoskarns around granitic, syenitic, anorthositic or other intrusions in carbonate rocks. Epizonal to catazonal metamorphic environments. Some deposits are located in catazonal metasedimentary sequences lacking known intrusive bodies and are associated with mylonite zones that acted as channels for fluids. In these cases, it is difficult to determine if they are distal to the intrusions or related to the regional metamorphism.

AGE OF MINERALIZATION: Typically Precambrian to Tertiary.

HOST/ASSOCIATED ROCK TYPES: Hosts are typically calcitic marble, limestone or calcite-rich siliceous metasedimentary rocks. The most common associated igneous rocks are felsic intrusives, charnockites, pegmatites and lithologies of the anorthositic suite including gabbros.

DEPOSIT FORM: Irregular, lens-shaped or planar. Some deposits are several metres to tens of metres thick and can be traced for hundreds of metres.

TEXTURE/STRUCTURE: Wollastonite crystals are accicular and may be porphyroblastic. They can form rosettes, fan-like textures, and millimeter to decimeter scale layering. Sometimes the wollastonite is massive. The wollasonite-rich rocks may contain remnants of the carbonate protolith.

ORE MINERALOGY (Principal and *subordinate*): Wollastonite, sometimes garnet and clinopyroxene or calcite, rarely Cu and other sulphides.

GANGUE MINERALOGY (Principal and *subordinate*): Garnet, clinopyroxene, calcite and quartz may be major constituents. *Tremolite-actinolite, zoisite, clinozoisite, anorthite, prehnite, sulphides, oxides, graphite, vesuvianite and titanite may be minor constituents.*

ALTERATION MINERALOGY: Calc-silicate minerals in high grade metamorphic terrains are commonly affected by retrograde metamorphism. In some of these cases, retrograde clinozoisite, zoisite, prehnite and/or chlorite are present. Wollastonite crystal may be partially corroded and retrograded to quartz and/or calcite.

WEATHERING: Wollastonite commonly weathers with a positive relief in temperate regions.

ORE CONTROLS: Wollastonite often occurs at contacts of carbonate or siliceous calcareous rocks with igneous intrusions or within horses and roof pendants of carbonate rocks in intrusive bodies. Fracture and mylonite zones and hinges of folds and other zones of high paleo-permeability are extremely important, since an open system is the main pre-requisite for formation of high grade wollastonite deposits (Simandl, 1992; pages 265-277).

GENETIC MODEL: Most wollastonite deposits are formed through contact metamorphism or metasomatism of siliceous limestone or other calcareous rocks. Typically fluids emanating from the intrusive rocks provide silica, alumina, iron and manganese which react with calcareous rocks to form skarn minerals. Introduction of silica under favorable physical and chemical conditions results in the formation of wollastonite according to the following reaction:
1 calcite + 1 SiO_2 = 1 wollastonite + 1 CO_2

Stability of the wollastonite is dependent on pressure, temperature and $X(CO_2)$ and $X(H_2O)$ of the ambient fluid.

The temperature required for wollastonite formation increases with increase in $X(CO_2)$ of the fluid and lithostatic

pressure. In some cases, the silica required for wollastonite formation may have been present as impurities within the limy sedimentary protolith. Some deposits in medium to high grade regional metamorphic settings are interpreted to form by interaction of metamorphic or metasomatic fluids with calcareous rocks along permeable zones such as saddle reefs, fracture or fault zones.

ASSOCIATED DEPOSIT TYPES: Cu-, Zn-Pb-, W-, Mo- and Au-bearing skarns (K01, K02, K05, K07, K04) and porphyry Cu (L04). Wollastonite rocks in catazonal environments may be in some cases be cut by crystalline graphite veins.

COMMENTS: Some W, Pb-Zn, or Cu skarn prospects are currently considered as potential sources of wollastonite.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: No direct chemical indicators are known for wollastonite, however associated metallic occurrences can be detected by geochemical methods.

GEOPHYSICAL SIGNATURE: Electromagnetic and magnetic methods may be used to delineate intrusive contacts with calcareous rocks.

OTHER EXPLORATION GUIDES: Commonly found in calcareous sediments cut by igneous rocks. Boulder tracing is a successfully used exploration method; boulders have a rotten wood-like appearance. Wollastonite usually has a positive relief relative to carbonate host rock. In some areas, greenish calcite porphyroblasts within calcitic marbles are common in proximity of wollastonite deposits located in catazonal metamorphic environments.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Highly variable. Wollastonite skarns vary from 0.1 million to 50 million tonnes. Grades vary between 20 and 80% wollastonite. Clinopyroxene and garnet are recovered from some deposits and calcite (limestone or marble) is recovered from others. In rare deposits Cu and wollastonite are recovered as co-products. Median tonnage is 1.3 million tonnes and median grade is 49% wollastonite (Orris, 1992).

ECONOMIC LIMITATIONS: Deposits that can supply high aspect ratio wollastonite products are highly sought after. The relative whiteness, brightness, color, aspect ratio of the particles, oil absorption, particle size, refractive index, pH of 10% slurry, specific gravity and type of impurities do determine possible applications. Specialized milling techniques and surface modification significantly increases the price of the wollastonite concentrate. Diopside and garnet may be separated by electromagnetic methods. If calcite is present and a high quality wollastonite concentrate is sought, then flotation is required. Flotation increases substantially the initial capital costs of the project. In glass and ceramic uses, a high iron content due to impurities, such as garnet, diopside, oxides and sulphides, can be a problem.

END USES: The major end uses of wollastonite are in ceramics, such as semi-vitreous bodies, heat insulators, acoustic tiles, electrical insulators, and fire-resistant products, such as interior or exterior construction boards, roofing materials, specialty refractors and glazes. It is also used as a functional filler in paint, coatings and plastics and metallurgical applications. Use of wollastonite as reinforcing agent in plastics and as asbestos substitute is increasing. High aspect ratio wollastonite (>15:1) with favorable physical properties is used mainly in plastic and paint as functional filler. Markets for low aspect ratio wollastonite are dependent mainly on the chemical composition and impurities and its end uses are in ceramics, fluxes, glass and limited filler applications.

IMPORTANCE: These deposits are the only commercial sources of natural wollastonite. Competition from synthetic wollastonite is limited to specialty products in the low aspect ratio segment of the market.

REFERENCES

Anonymous (1994): The Economics of Wollastonite; Fifth Edition, Roskill Information Services Ltd, London, 138 pages.
Andrews, R.W. (1970): Wollastonite; Monograph, Institute of Geological Sciences, Her Majesty's Stationary Office, London, 114 pages.
Bauer, R.R., Copeland, J.R. and Santini, K. (1994): Wollastonite; in Industrial Minerals and Rocks, 6th edition; Carr, D.D. Senior Editor; Society for Mining, Metallurgy, and Exploration, Inc., Littleton Colorado, pages 1119-1128.
Fischl, P. (1991): Wollastonite and Tremolite Occurrences in British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Open File 1991-17, 52 pages.
Harben, P.W. and Bates, R.L. (1990): Industrial Minerals and World Deposits; Metal Bulletin, London, 312 pages.
Jain, P.M. (1993): Indian Wollastonite - A Success Story; Industrial Minerals, No. 315, pages 39-41.
Jaworski, B.J. and Dipple, G.M. (1996): Zippa Mountain Wollastonite Skarns, Iskut River Map Area; in Geological Fieldwork 1995, Grant, B. and Newell, J.M., Editors, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1996-1, pages 243-249.
Orris, G.J. (1991): Descriptive Model of Wollastonite Skarn; in Some Industrial Mineral Deposit Models: Descriptive Deposit Models; U.S. Geological Survey, Open-File Report 91-11A, pages 5-6
Orris, G.J. (1992): Grade and Tonnage Model of Wollastonite Skarns; in Industrial Mineral Deposit Models: Grade and Tonnage Models; U.S. Department of Interior, U.S. Geological Survey, Open File Report 92-437, pages 20-22**.**
Simandl, G.J. (1992): Graphite deposits in the Gatineau Area, Quebec; Unpublished Ph.D. Thesis, Ecole Polytechnique de Montreal, Montreal (in French), 383 pages.
Simandl, G.J., Valiquette, G., Jacob, H.-L., Paradis, S. (1990): Gîtes de Wollastonite, Province Tectonique de Grenville, Québec; Canadian institute of Mining and Metallurgy, Bulletin, Volume 83, Number 934, pages 101-107.
Simandl, G.J., Valiquette, G. and Martignole, J. (1989): Genesis of Graphite-wollastonite Deposits, Grenville Geological Province, Québec; Geological Association of Canada and Mineralogical Association of Canada, General Program for Annual Meeting, Abstract, page A69.
Xian, Z.-M. (1996): Chinese Wollastonite; Industrial Minerals, Number 345, pages 59-63.

[Back to top]

Examples of Skarn Deposits

BC Profile #	Global Examples	B.C. Examples
K01	Mines Gaspé (Québec), Carr Fork (Yukon)	Craigmont, Phoenix
K02	San Antonio (Mexico), Ban Ban (Australia)	Piedmont, Contact
K03	Shinyama (Japan), Cornwall (Pennsylvannia)	Tasu, Jessie, Merry Widow, HPH
K04	Fortitude, McCoy, and Tomboy-Minnie (Nevada, USA), Buckhorn Mountain (Washington, USA), Diamond Hill, New World district and Butte Highlands (Montana, USA), Nixon Forks (Alaska, USA); Thanksgiving (Phillippines); Browns Creek and Junction Reefs-Sheanan-Grants (New South Wales, Australia), Mount Biggenden (Queensland, Australia), Savage Lode, Coogee (Western Australia, Australia); Nambija (Ecuador); Wabu (Irian Jaya, Indonesia)	Nickel Plate, French, Cante, Good Hope, QR-Quesnel River
K05	Cantung & Mactung (Yukon), Pine Creek (California)	Emerald Tungsten, Dimac
K06	Lost River (Alaska), JC (Yukon)	Daybreak
K07	Little Boulder Creek (Idaho), Mt. Tennyson (Australia)	Coxey, Novelty
K08	San Pedro (New Mexico, USA)	Mount Riordan (Crystal Peak)
K09	Fox Knoll & Lewis (New York)	Mineral Hill, Rossland

L - Porphyry

(Example Deposits)

BC Profile #	Deposit Type	Approximate Synonyms	USGS Model #
L01	Subvolcanic Cu-Ag-Au (As-Sb)	Enargite Au, Transitional Au-Ag	22a/25e
L02	Plutonic-Related Au Quartz Veins	Intrusion-related gold systems	- -
L03	Alkalic porphyry Cu-Au	Diorite porphyry copper	- -
L04	Porphyry Cu ± Mo ± Au	Calcalkaline porphyry	17,20,21a1
L05	Porphyry Mo (Low F- type)	Calcalkaline Mo stockwork	21b
L06	Porphyry Sn	Subvolcanic tin	20a
L07	Porphyry W	Stockwork W-Mo	21c*
L08	Porphyry Mo (Climax-type)	Granite molybdenite	16
L09*	Porphyry-related Au	Granitoid Au, Porphyry Au	20d

SUBVOLCANIC Cu-Au-Ag (As-Sb)

L01
by Andre Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1995): Subvolcanic Cu-Au-Ag (As-Sb), in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 79-82.

IDENTIFICATION

SYNONYMS: Transitional, intrusion-related (polymetallic) stockwork and vein.

COMMODITIES (*BYPRODUCTS*): Cu, Au, Ag (As, Sb).

EXAMPLES (British Columbia - *Canada/International*): Equity Silver (093L 001); Thorn prospect (104K031, 116); *Rochester District (Nevada, USA), Kori Kollo (Bolivia), the 'epithermal gold' zones at Lepanto (Philippines), parts of Recsk (Hungary) and Bor (Serbia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Pyritic veins, stockworks and breccias in subvolcanic intrusive bodies with stratabound to discordant massive pyritic replacements, veins, stockworks, disseminations and related hydrothermal breccias in country rocks. These deposits are located near or above porphyry Cu hydrothermal systems and commonly contain pyritic auriferous polymetallic mineralization with Ag sulphosalt and other As and Sb-bearing minerals.

TECTONIC SETTINGS: Volcano-plutonic belts in island arcs and continental margins; continental volcanic arcs. Subvolcanic intrusions are abundant. Extensional tectonic regimes allow high-level emplacement of the intrusions, but compressive regimes are also permissive.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Uppermost levels of intrusive systems and their adjoining fractured and permeable country rocks, commonly in volcanic terrains with eroded stratovolcanoes. Subvolcanic domes and flow-dome complexes can also be mineralized; their uppermost parts are exposed without much erosion.

AGE OF MINERALIZATION: Mainly Tertiary, a number of older deposits have been identified.

HOST/ASSOCIATED ROCK TYPES: Subvolcanic (hypabyssal) stocks, rhyodacite and dacite flow-dome complexes with fine to coarse-grained quartz-phyric intrusions are common. Dike swarms and other small subvolcanic intrusions are likely to be present. Country rocks range widely in character and age. Where coeval volcanic rocks are present, they range from andesite to rhyolite in composition and occur as flows, breccias and pyroclastic rocks with related erosion products (epiclastic rocks).

DEPOSIT FORM: Stockworks and closely-spaced to sheeted sets of sulphide-bearing veins in zones within intrusions and as structurally controlled and stratabound or bedding plane replacements along permeable units and horizons in hostrocks. Veins and stockworks form in transgressive hydrothermal fluid conduits that can pass into pipe-like and planar breccias. Breccia bodies are commonly tens of metres and, rarely, a few hundred metres in size. Massive sulphide zones can pass outward into auriferous pyrite-quartz-sericite veins and replacements.

TEXTURE/STRUCTURE: Sulphide and sulphide-quartz veins and stockworks. Open space filling and replacement of matrix in breccia units. Bedding and lithic clast replacements by massive sulphide, disseminations and veins. Multiple generations of veins and hydrothermal breccias are common. Pyrite is dominant and quartz is minor to absent in veins.

ORE MINERALOGY (Principal and *subordinate*): Pyrite, commonly as auriferous pyrite, chalcopyrite, terahedrite/tennantite; enargite/luzonite, covellite, chalcocite, bornite, sphalerite, galena, arsenopyrite, argentite, sulphosalts, gold, stibnite, molybdenite, wolframite or scheelite, pyrrhotite, marcasite, realgar,hematite, tin and bismuth minerals. Depth zoning is commonly evident with pyrite-rich deposits containing enargite near surface, passing downwards into tetrahedrite/tennantite + chalcopyrite and then chalcopyrite in porphyry intrusions at depth.

GANGUE MINERALOGY (Principal and *subordinate*): Pyrite, sericite, quartz; kaolinite, alunite, jarosite (mainly in supergene zone).

ALTERATION MINERALOGY (Principal and *subordinate*): Pyrite, sericite, quartz; kaolinite, dickite, pyrophyllite, andalusite, diaspore, corundum, tourmaline, alunite, anhydrite, barite, chalcedony, dumortierite, lazulite (variety scorzalite), rutile and chlorite. Tourmaline as schorlite (a black Fe-rich variety) can be present locally; it is commonly present in breccias with quartz and variable amounts of clay minerals. Late quartz-alunite veins may occur.

WEATHERING: Weathering of pyritic zones can produce limonitic blankets containing abundant jarosite, goethite and, locally, alunite.

GENETIC MODEL: These deposits represent a transition from porphyry copper to epithermal conditions with a blending and blurring of porphyry and epithermal characteristics. Mineralization is related to robust, evolving hydrothermal systems derived from porphyritic, subvolcanic intrusions. Vertical zoning and superimposition of different types of ores is typical due, in large part, to overlapping stages of mineralizations. Ore fluids with varying amounts of magmatic-source fluids have temperatures generally greater than those of epithermal systems, commonly in the order of 300* C and higher. Fluid salinities are also relatively high, commonly more than 10 weight per cent NaCl-equivalent and rarely in the order of 50 %, and greater.

ORE CONTROLS: Strongly fractured to crackled zones in cupolas and internal parts of intrusions and flow-dome complexes; along faulted margins of high-level intrusive bodies. Permeable lithologies, both primary and secondary in origin, in the country rocks. Primary controls are structural features such as faults, shearz, fractured and crackled zones and breccias. Secondary controls are porous volcanic units, bedding plane contacts and unconformities. Breccia pipes provide channelways for hydrothermal fluids originating from porphyry Cu systems and commonly carry elevated values of Au and Ag. The vein and replacement style deposits can be separated from the deeper porphyry Cu mineralization by 200 to 700 m.

ASSOCIATED DEPOSIT TYPES: Porphyry Cu-Au±Mo (L04); epithermal Au-Ag commonly both high-sulphidation (H04) and low-sulphidation (H05) pyrite-sericite-bearing types; auriferous quartz-pyrite veins, enargite massive sulphide also known as enargite gold.

COMMENTS: This deposit type is poorly defined and overall, uncommon. It is in large part stockworks and a closely spaced to sheeted sulphide vein system with local massive to disseminated replacement sulphide zones. It forms as a high- temperature, pyrite-rich, commonly tetrahderite, and rarely enargite-bearing, polymetallic affiliate of epithermal Au-Ag mineralization. Both low and high- sulphidation epithermal styles of mineralization can be present. As and Sb enrichments in ores are characteristic. If abundant gas and gas condensates evolve from the hydrothermal fluids there can be extensive acid leaching and widespread, high-level advanced argillic alteration. This type of alteration is rarely mineralized.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Au, Cu, Ag, As, Sb, Zn, Cd, Pb, Fe and F; at deeper levels Mo, Bi, W and locally Sn. In some deposits there is local strong enrichment in B, Co, Ba, K and depletion of Na. Both depth zoning and lateral zoning are evident.

GEOPHYSICAL SIGNATURE: Induced polarization to delineate pyrite zones. Magnetic surveys are useful in some cases to outline lithologic units and delineate contacts. Electromagnetic surveys can be used effectively where massive sulphide bodies are present.

OTHER EXPLORATION GUIDES: Association with widespread sericite-pyrite and quartz-sericite-pyrite that might be high-level leakage from buried porphyry Cu ± Au ± Mo deposits. Extensive overprinting of sericite/illite by kaolinite; rare alunite. In some deposits, high-temperature aluminous alteration minerals pyrophyllite and andalusite are present but are generally overprinted by abundant sericite and lesser kaolinite. Tourmaline and phosphate minerals can occur. There is commonly marked vertical mineralogical and geochemical depth-zoning.

ECONOMIC FACTORS

GRADE AND TONNAGE: The deposits have pyritic orebodies of various types; vertical stacking and pronounced metal zoning are prevalent. Small, high-grade replacement orebodies containing tetrahedrite/tennantite, and rarely enargite, can form within larger zones of pyritization. The massive sulphide replacement ores have associated smaller peripheral, structurally controlled zones of sericitic alteration that constitute pyritic orebodies grading ~ 4 g/t gold. Similar tetrahedrite-bearing ores with bulk mineable reserves at Equity Silver were in the order of 30 Mt with 0.25% Cu and ~86 g/t Ag and 1 g/t Au. At the Recsk deposit, Hungary, shallow breccia-hosted Cu-Au ores overlie a porphyry deposit containing ~1000 Mt with 0.8 % Cu. The closely spaced pyritic fracture and vein systems at Kollo, La Joya district, Bolivia contained 10 Mt oxide ore with 1.62 g/t Au and 23.6 g/t Ag and had sulphide ore reserves of 64 Mt at 2.26 g/t Au and 13.8 g/t Ag.

REFERENCES

Baksa, C., Cseh-Nemeth, J., Csillag, J., Foldessy, J. and Zelenka, T. (1980): The Recsk Porphyry and Skarn Deposit, Hungary; in European Copper Deposits, Jankovic, S. and Sillitoe, R.H., Editors, Society for Geology Applied to Mineral Deposits (SGA), Special Publication No. 1, pages 73-76.
Columba, M. and Cunningham, C.G. (1993): Geologic Model for the Mineral Deposits of the La Joya District, Oruro, Bolivia; Economic Geology, Volume 88, pages 701-708.
Cyr, J.B., Pease, R.B. and Schroeter, T.G. (1984): Geology and Mineralization at Equity Silver Mine; Economic Geology, Volume 79, pages 947-968.
Jankovic, S., Terzic. M., Aleksic, D., Karamata, S., Spasov, T., Jovanovic, M., Milicic, M., Grubiv, A. and Antonijevic, I. (1980): Metallogenic Features of Copper Deposits in the Volcano-Intrusive Complexes of the Bor District, Yugoslavia; in European Copper Deposits, Jankovic, S. and Sillitoe, R.H., Editors, Society for Geology Applied to Mineral Deposits (SGA), Special Publication No. 1, pages 42-49.
Learned, R., Allen, M.S., Andre*-Ramos, O. and Enriquez, R. (1992): A Geochemical Study of the La Joya District; U. S. Geological Survey, Bulletin 1975, pages 25-46.
Long, K., Ludington, S., du Bray, E., Andre*-Ramos, O. and McKee, E.H. (1992): Geology and Mineral Deposits of the La Joya District, Bolivia, SEG Newsletter, Society of Economic Geologists, Volume 10, Number 1, pages 13-16.
Sillitoe, R.H. (1983): Enargite-bearing Massive Sulfide Deposits High in Porphyry Copper Systems; Economic Geology, Volume 78, pages 348-352.
Sillitoe, R.H. (1992): The Porphyry-epithermal Transition; in Magmatic Contributions To Hydrothermal Systems, Geological Survey of Japan, Report No. 279, pages 156-160.
Sillitoe, R.H. (1994): Erosion and Collapse of Volcanoes; Cuases of Telescoping in Intrusion-centered Ore Deposits, Geology, Volume 22, pages 945-948.
Vikre, P.G. (1981): Silver Mineralization in the Rochester District, Pershing County, Nevada; Economic Geology, Volume 76, pages 580-609.

[Back to top]

PORPHYRY Cu-Au: ALKALIC

L03

by Andre Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1995): Porphyry Cu-Au: Alkalic, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 83-86.

IDENTIFICATION

SYNONYMS: Porphyry copper, porphyry Cu-Au, diorite porphyry copper.

COMMODITIES (*BYPRODUCTS*): Cu, Au (Ag).

EXAMPLES (British Columbian - *Canada/International*): Iron Mask batholith deposits - Afton (092INE023), Ajax (092INE012, 013), Mt. Polley (Cariboo Bell, 093A008), Mt. Milligan (093N196, 194), Copper Mt./Ingerbelle (092HSE001, 004), Galore Creek (104G 090), Lorraine (093N 002); *Ok Tedi (Papua New Guinea); Tai Parit and Marian? (Philippines).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks, veinlets and disseminations of pyrite, chalcopyrite, bornite and magnetite occur in large zones of economically bulk-mineable mineralization in or adjoining porphyritic intrusions of diorite to syenite composition. The mineralization is spatially, temporally and genetically associated with hydrothermal alteration of the intrusive bodies and hostrocks.

TECTONIC SETTING(S): In orogenic belts at convergent plate boundaries, commonly oceanic volcanic island arcs overlying oceanic crust. Chemically distinct magmatism with alkalic intrusions varying in composition from gabbro, diorite and monzonite to nepheline syenite intrusions and coeval shoshonitic volcanic rocks, takes place at certain times in segments of some island arcs. The magmas are introduced along the axis of the arc or in cross-arc structures that coincide with deep-seated faults. The alkalic magmas appear to form where there is slow subduction in steeply dipping, tectonically thickened lithospheric slabs, possibly when polarity reversals (or `flips') take place in the subduction zones. In British Columbia all known deposits are found in Quesnellia and Stikinia terranes.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High level (epizonal) stock emplacement levels in magmatic arcs, commonly oceanic volcanic island arcs with alkalic (shoshonitic) basic flows to intermediate and felsic pyroclastic rocks. Commonly the high-level stocks and related dikes intrude their coeval and cogenetic volcanic piles.

AGE OF MINERALIZATION: Deposits in the Canadian Cordillera are restricted to the Late

Triassic/Early Jurassic (215-180 Ma) with seemingly two clusters around 205-200 and ~ 185 Ma. In southwest Pacific island arcs, deposits are Tertiary to Quaternary in age.

HOST/ASSOCIATED ROCK TYPES: Intrusions range from fine through coarse-grained, equigranular to coarsely porphyritic and, locally, pegmatitic high-level stocks and dike complexes. Commonly there is multiple emplacement of successive intrusive phases and a wide variety of breccias. Compositions range from (alkalic) gabbro to syenite. The syenitic rocks vary from silica-undersaturated to saturated compositions. The most undersaturated nepheline normative rocks contain modal nepheline and, more commonly, pseudoleucite. The silica-undersaturated suites are referred to as nepheline alkalic whereas rocks with silica near-saturation, or slight silica over saturation, are termed quartz alkalic (Lang et al., 1993). Coeval volcanic rocks are basic to intermediate alkalic varieties of the high-K basalt and shoshonite series and rarely phonolites.

DEPOSIT FORM: Stockworks and veinlets, minor disseminations and replacements throughout large areas of hydrothermally altered rock, commonly coincident wholly or in part with hydrothermal or intrusion breccias. Deposit boundaries are determined by economic factors that outline ore zones within larger areas of low-grade, laterally zoned mineralization.

TEXTURE/STRUCTURE: Veinlets and stockworks; breccia, sulphide and magnetite grains in fractures and along fracture selvages; disseminated sulphides as interstitial or grain and lithic clast replacements. Hydrothermally altered rocks can contain coarse-grained assemblages including feldspathic and calcsilicate replacements ('porphyroid' textures) and open space filling with fine to coarse, granular and rarely pegmatitic textures.

ORE MINERALOGY [Principal and *subordinate*]: Chalcopyrite, pyrite and magnetite; bornite, chalcocite and rare galena, sphalerite, tellurides, tetrahderite, gold and silver. Pyrite is less abundant than chalcopyrite in ore zones.

GANGUE MINERALOGY: Biotite, K-feldspar and sericite; garnet, clinopyroxene (diopsidic) and anhydrite. Quartz veins are absent but hydrothermal magnetite veinlets are abundant.

ALTERATION MINERALOGY: Biotite, K-feldspar, sericite, anhydrite/gypsum, magnetite, hematite, actinolite, chlorite, epidote and carbonate. Some alkalic systems contain abundant garnet including the Ti-rich andradite variety - melanite, diopside, plagioclase, scapolite, prehnite, pseudoleucite and apatite; rare barite, fluorite, sodalite, rutile and late-stage quartz. Central and early formed potassic zones, with K-feldspar and generally abundant secondary biotite and anhydrite, commonly coincide with ore. These rocks can contain zones with relatively high-temperature calcsilicate minerals diopside and garnet. Outward there can be flanking zones in basic volcanic rocks with abundant biotite that grades into extensive, marginal propylitic zones. The older alteration assemblages can be overprinted by phyllic sericite-pyrite and, less commonly, sericite-clay-carbonate-pyrite alteration. In some deposits, generally at depth in silica-saturated types, there can be either extensive or local central zones of sodic alteration containing characteristic albite with epidote, pyrite, diopside, actinolite and rarer scapolite and prehnite.

ORE CONTROLS: Igneous contacts, both internal between intrusive phases and external with wallrocks; cupolas and the uppermost, bifurcating parts of stocks, dike swarms and volcanic vents. Breccias, mainly early formed intrusive and hydrothermal types. Zones of most intensely developed fracturing give rise to ore-grade vein stockworks.

ASSOCIATED DEPOSIT TYPES: Skarn copper (K01); Au-Ag and base metal bearing mantos (M01, M04), replacements and breccias in carbonate and non-carbonate rocks; magnetite-apatite breccias (D07); epithermal Au-Ag : both high and low sulphidation types (H04, H05) and alkalic, Te and F-rich epithermal deposits (H08); auriferous and polymetallic base metal quartz and quartz-carbonate veins (I01, I05); placer Au (C01, C02).

COMMENTS: Subdivision of porphyry deposits is made on the basis of metal content, mainly ratios between Cu, Au and Mo. This is a purely arbitrary, economically based criterion; there are few differences in the style of mineralization between the deposits. Differences in composition between the hostrock alkalic and calcalkalic intrusions and subtle, but significant, differences in alteration mineralogy and zoning patterns provide fundamental geologically based contrasts between deposit model types. Porphyry copper deposits associated with calcalkaline hostrocks are described in mineral deposit profile L04.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Alkalic cupriferous systems do not contain economically recoverable Mo (< 100 ppm) but do contain elevated Au (> 0.3 g/t) and Ag (>2 g/t). Cu grades vary widely but commonly exceed 0.5 % and rarely 1 %. Many contain elevated Ti, V, P, F, Ba, Sr, Rb, Nb, Te, Pb, Zn, PGE and have high CO2 content. Leaching and supergene enrichment effects are generally slight and surface outcroppings normally have little of the copper remobilized. Where present, secondary minerals are malachite, azurite, lesser copper oxide and rare sulphate minerals; in some deposits native copper is economically significant (e.g. Afton, Kemess).

GEOPHYSICAL SIGNATURE: Ore zones, particularly those with high Au content, are frequently found in association with magnetite-rich rocks and can be located by magnetic surveys. Pyritic haloes surrounding cupriferous rocks respond well to induced polarization surveys. The more intensely hydrothermally altered rocks produce resistivity lows.

OTHER EXPLORATION GUIDES: Porphyry deposits are marked by large-scale, markedly zoned metal and alteration assemblages. Central parts of mineralized zones appear to haver higher Au/Cu ratios than the margins. The alkalic porphyry Cu deposits are found exclusively in Later Triassic and Early Jurassic volcanic arc terranes in which emergent subaerial rocks are present. The presence of hydrothermally altered clasts in coarse pyroclastic deposits can be used to locate mineralized intrusive centres.

ECONOMIC FACTORS

GRADE AND TONNAGE:

- * Worldwide according to Cox and Singer (U.S. Geological Survey Open File Report 88-46, 1988) 20 typical porphyry Cu-Au deposits, including both calcalkaline and some alkalic

types, contain on average:
160 Mt with 0.55 % Cu, 0.003 % Mo, 0.38 g/t Au and 1.7 g/t Ag.

* British Columbia alkalic porphyry deposits range from <10 to >300 Mt and contain from 0.2 to 1.5 % Cu, 0.2 to 0.6 g/t Au and >2 g/t Ag; Mo contents are negligible. Median values for 22 British Columbia deposits with reported reserves (with a heavy weighting from a number of small deposits in the Iron Mask batholith) are: 15.5 Mt with 0.58 % Cu, 0.3 g/t Au and >2 g/t Ag.

END USES: Production of chalcopyrite or chalcopyrite-bornite concentrates with significant Au credits.

IMPORTANCE: Porphyry deposits contain the largest reserves of Cu and close to 50 % of Au reserves in British Columbia; alkalic porphyry systems contain elevated Au values.

REFERENCES

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A. (1976): The Alkaline Suite Porphyry Deposits - A Summary; in Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A. Editor, Canadian Institute of Mining and Metallurgy, Special Volume 15, pages 359-367.
Lang, J.R., Stanley, C.R. and Thompson, H.F.H. (1993): A Subdivision of Alkalic Porphyry Cu-Au Deposits into Silica-saturated and Silica-undersaturated Subtypes; in Porphyry Copper-Gold Systems of British Columbia, Mineral Deposit Research Unit, University of British Columbia, Annual Technical Report - Year 2, pages 3.2-3.14.
McMillan, W.J. (1991): Porphyry Deposits in the Canadian Cordillera; in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B. C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 253-276.
McMillan, W.J. and Panteleyev, A. (1988): Porphyry Copper Deposits; in Ore Deposit Models, Roberts, R.G. and Sheahan, P.A, Editors, Geoscience Canada, Reprint Series 3, pages 45-58.
Mutschler, F.E. and Mooney, T.C. (1993): Precious Metal Deposits Related to Alkaline Igneous Rocks - Provisional Classification, Grade-Tonnage Data, and Exploration Frontiers; IUGS/UNESCO Conference on Deposit Modeling, Ottawa, 1990, Proceedings Volume, Geological Association of Canada, Special Paper 40, pages 479-520.
Sutherland Brown, A., Editor, (1976): Porphyry Deposits of the Canadian Cordillera; Canadian Institute of Mining and Metallurgy, Special Volume 15, 510 pages.

[Back to top]

PORPHYRY Cu+/-Mo+/-Au

L04
by Andre Panteleyev
British Columbia Geological Survey

Panteleyev, A. (1995): Porphyry Cu+/-Mo+/-Au, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 87-92.

IDENTIFICATION

SYNONYM: Calcalkaline porphyry Cu, Cu-Mo, Cu-Au.

COMMODITIES (*BYPRODUCTS*): Cu, Mo and Au are generally present but quantities range from insufficient for economic recovery to major ore constituents. Minor Ag in most deposits; rare recovery of Re from Island Copper mine.

EXAMPLES (British Columbia - *Canada/International*):

- Volcanic type deposits (Cu + Au * Mo) - Fish Lake (092O 041), Kemess (094E 021,094), Hushamu (EXPO, 092L 240), Red Dog (092L 200), Poison Mountain (092O 046), Bell (093M 001), Morrison (093M 007), Island Copper (092L 158); *Dos Pobres (USA); Far Southeast (Lepanto/Mankayan), Dizon, Guianaong, Taysan and Santo Thomas II (Philippines), Frieda River and Panguna (Papua New Guinea).*
- Classic deposits (Cu + Mo * Au) - Brenda (092HNE047), Berg (093E 046), Huckleberrry (093E 037), Schaft Creek (104G 015); *Casino (Yukon, Canada), Inspiration, Morenci, Ray, Sierrita-Experanza, Twin Buttes, Kalamazoo and Santa Rita (Arizona, USA), Bingham (Utah, USA),El Salvador, (Chile), Bajo de la Alumbrera (Argentina).*
- Plutonic deposits (Cu * Mo) - Highland Valley Copper (092ISE001,011,012,045), Gibraltar (093B 012,007), Catface (092F 120); *Chuquicamata, La Escondida and Quebrada Blanca (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks of quartz veinlets, quartz veins, closely spaced fractures and breccias containing pyrite and chalcopyrite with lesser molybdenite, bornite and magnetite occur in large zones of economically bulk-mineable mineralization in or adjoining porphyritic intrusions and related breccia bodies. Disseminated sulphide minerals are present, generally in subordinate amounts. The mineralization is spatially, temporally and genetically associated with hydrothermal alteration of the hostrock intrusions and wallrocks.

TECTONIC SETTINGS: In orogenic belts at convergent plate boundaries, commonly linked to subduction-related magmatism. Also in association with emplacement of high-level stocks during extensional tectonism related to strike-slip faulting and back-arc spreading following continent margin accretion.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level (epizonal) stock emplacement levels in volcano-plutonic arcs, commonly oceanic volcanic island and continent-margin arcs. Virtually any type of country rock can be mineralized, but commonly the high-level stocks and related dikes intrude their coeval and cogenetic volcanic piles.

AGE OF MINERALIZATION: Two main periods in the Canadian Cordillera: the Triassic/Jurassic (210-180 Ma) and Cretaceous/Tertiary (85-45 Ma). Elsewhere deposits are mainly Tertiary, but range from Archean to Quaternary.

HOST/ASSOCIATED ROCK TYPES: Intrusions range from coarse-grained phaneritic to porphyritic stocks, batholiths and dike swarms; rarely pegmatitic. Compositions range from calcalkaline quartz diorite to granodiorite and quartz monzonite. Commonly there is multiple emplacement of successive intrusive phases and a wide variety of breccias. Alkalic porphyry Cu-Au deposits are associated with syenitic and other alkalic rocks and are considered to be a a distinct deposit type (see model L03).

DEPOSIT FORM: Large zones of hydrothermally altered rock contain quartz veins and stockworks, sulphide-bearing veinlets; fractures and lesser disseminations in areas up to 10 km2 in size, commonly coincident wholly or in part with hydrothermal or intrusion breccias and dike swarms. Deposit boundaries are determined by economic factors that outline ore zones within larger areas of low-grade, concentrically zoned mineralization. Cordilleran deposits are commonly subdivided according to their morphology into three classes - classic, volcanic and plutonic (see Sutherland Brown, 1976; McMillan and Panteleyev, 1988):

* Volcanic type deposits (e.g. Island Copper) are associated with multiple intrusions in subvolcanic settings of small stocks, sills, dikes and diverse types of intrusive breccias. Reconstruction of volcanic landforms, structures, vent-proximal extrusive deposits and subvolcanic intrusive centres is possible in many cases, or can be inferred. Mineralization at depths of 1 km, or less, is mainly associated with breccia development or as lithologically controlled preferential replacement in hostrocks with high primary permeability. Propylitic alteration is widespread and generally flanks early, centrally located potassic alteration; the latter is commonly well mineralized. Younger mineralized phyllic alteration commonly overprints the early mineralization. Barren advanced argillic alteration is rarely present as a late, high-level hydrothermal carapace.
* Classic deposits (e.g., Berg) are stock related with multiple emplacements at shallow depth (1 to 2 km) of generally equant, cylindrical porphyritic intrusions. Numerous dikes and breccias of pre, intra, and post-mineralization age modify the stock geometry. Orebodies occur along margins and adjacent to intrusions as annular ore shells. Lateral outward zoning of alteration and sulphide minerals from a weakly mineralized potassic/propylitic core is usual. Surrounding ore zones with potassic (commonly biotite-rich) or phyllic alteration contain molybdenite * chalcopyrite, then chalcopyrite and a generally widespread propylitic, barren pyritic aureole or 'halo'.
* Plutonic deposits (e.g., the Highland Valley deposits) are found in large plutonic to batholithic intrusions immobilized at relatively deep levels, say 2 to 4 km. Related dikes and intrusive breccia bodies can be emplaced at shallower levels. Hostrocks are phaneritic coarse grained to porphyritic. The intrusions can display internal compositional differences as a result of differentiation with gradational to sharp boundaries between the different phases of magma emplacement. Local swarms of dikes, many with associated breccias, and fault zones are sites of mineralization. Orebodies around silicified alteration zones tend to occur as diffuse vein stockworks carrying chalcopyrite, bornite and minor pyrite in intensely fractured rocks but, overall, sulphide minerals are sparse. Much of the early potassic and phyllic alteration in central parts of orebodies is restricted to the margins of mineralized fractures as selvages. Later phyllic-argillic alteration forms envelopes on the veins and fractures and is more pervasive and widespread. Propylitic alteration is widespread but unobtrusive and is indicated by the presence of rare pyrite with chloritized mafic minerals, saussuritized plagioclase and small amounts of epidote.

TEXTURE/STRUCTURE: Quartz, quartz-sulphide and sulphide veinlets and stockworks; sulphide grains in fractures and fracture selvages. Minor disseminated sulphides commonly replacing primary mafic minerals. Quartz phenocrysts can be partially resorbed and overgrown by silica.

ORE MINERALOGY (Principal and *subordinate*): Pyrite is the predominant sulphide mineral; in some deposits the Fe oxide minerals magnetite, and rarely hematite, are abundant. Ore minerals are chalcopyrite; molybdenite, lesser bornite and rare (primary) chalcocite. Subordinate minerals are tetrahedrite/tennantite, enargite and minor gold , electrum and arsenopyrite. In many deposits late veins commonly contain galena and sphalerite in a gangue of quartz, calcite and barite.

GANGUE MINERALOGY (Principal and *subordinate*): Gangue minerals in mineralized veins are mainly quartz with lesser biotite, sericite, K-feldspar, magnetite, chlorite, calcite, epidote, anhydrite and tourmaline. Many of these minerals are also pervasive alteration products of primary igneous mineral grains.

ALTERATION MINERALOGY: Quartz, sericite, biotite, K-feldspar, albite, anhydrite/gypsum, magnetite, actinolite, chlorite, epidote, calcite, clay minerals, tourmaline. Early formed alteration can be overprinted by younger assemblages. Central and early formed potassic zones (K-feldspar and biotite) commonly coincide with ore. This alteration can be flanked in volcanic hostrocks by biotite-rich rocks that grade outward into propylitic rocks. The biotite is a fine-grained, 'shreddy' looking secondary mineral that is commonly referred to as an early developed biotite (EDB) or a 'biotite hornfels'. These older alteration assemblages in cupriferous zones can be partially to completely overprinted by later biotite and K-feldspar and then phyllic (quartz-sericite-pyrite) alteration, less commonly argillic, and rarely, in the uppermost parts of some ore deposits, advanced argillic alteration (kaolinite-pyrophyllite).

WEATHERING: Secondary (supergene) zones carry chalcocite, covellite and other Cu*2S minerals (digenite, djurleite, etc.), chrysocolla, native copper and copper oxide, carbonate and sulphate minerals. Oxidized and leached zones at surface are marked by ferruginous 'cappings' with supergene clay minerals, limonite (goethite, hematite and jarosite) and residual quartz.

ORE CONTROLS: Igneous contacts, both internal between intrusive phases and external with wallrocks; cupolas and the uppermost, bifurcating parts of stocks, dike swarms. Breccias, mainly early formed intrusive and hydrothermal types. Zones of most intensely developed fracturing give rise to ore-grade vein stockworks, notably where there are coincident or intersecting multiple mineralized fracture sets.

ASSOCIATED DEPOSIT TYPES: Skarn Cu (K01), porphyry Au (K02), epithermal Au-Ag in low sulphidation type (H05) or epithermal Cu-Au-Ag as high-sulphidation type enargite-bearing veins (L01), replacements and stockworks; auriferous and polymetallic base metal quartz and quartz-carbonate veins (I01, I05), Au-Ag and base metal sulphide mantos and replacements in carbonate and non- carbonate rocks (M01, M04), placer Au (C01, C02).

COMMENTS: Subdivision of porphyry copper deposits can be made on the basis of metal content, mainly ratios between Cu, Mo and Au. This is a purely arbitrary, economically based criterion, an artifact of mainly metal prices and metallurgy. There are few differences in the style of mineralization between deposits although the morphology of calcalkaline deposits does provide a basis for subdivision into three distinct subtypes - the 'volcanic, classic, and plutonic' types. A fundamental contrast can be made on the compositional differences between calcalkaline quartz-bearing porphyry copper deposits and the alkalic (silica undersaturated) class. The alkalic porphyry copper deposits are described in a separate model - L03.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Calcalkalic systems can be zoned with a cupriferous (* Mo) ore zone having a 'barren', low-grade pyritic core and surrounded by a pyritic halo with peripheral base and precious metal-bearing veins. Central zones with Cu commonly have coincident Mo, Au and Ag with possibly Bi, W, B and Sr. Peripheral enrichment in Pb, Zn, Mn, V, Sb, As, Se, Te, Co, Ba, Rb and possibly Hg is documented. Overall the deposits are large-scale repositories of sulphur, mainly in the form of metal sulphides, chiefly pyrite.

GEOPHYSICAL SIGNATURE: Ore zones, particularly those with higher Au content, can be associated with magnetite-rich rocks and are indicated by magnetic surveys. Alternatively the more intensely hydrothermally altered rocks, particularly those with quartz-pyrite-sericite (phyllic) alteration produce magnetic and resistivity lows. Pyritic haloes surrounding cupriferous rocks respond well to induced polarization (I.P.) surveys but in sulphide-poor systems the ore itself provides the only significant IP response.

OTHER EXPLORATION GUIDES: Porphyry deposits are marked by large-scale, zoned metal and alteration assemblages. Ore zones can form within certain intrusive phases and breccias or are present as vertical 'shells' or mineralized cupolas around particular intrusive bodies. Weathering can produce a pronounced vertical zonation with an oxidized, limonitic leached zone at surface (leached capping), an underlying zone with copper enrichment (supergene zone with secondary copper minerals) and at depth a zone of primary mineralization (the hypogene zone).

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE:

- Worldwide according Cox and Singer (1988) based on their subdivision of 55 deposits into subtypes according to metal ratios, typical porphyry Cu deposits contain (median values): Porphyry Cu-Au: 160 Mt with 0.55 % Cu, 0.003 % Mo, 0.38 g/t Au and 1.7 g/t Ag. Porphyry Cu-Au-Mo: 390 Mt with 0.48 % Cu, 0.015 % Mo, 0.15 g/t Au and 1.6 g/t Ag. Porphyry Cu-Mo: 500 Mt with 0.41 % Cu, 0.016 % Mo, 0.012 g/t Au and 1.22 g/t Ag.
- A similar subdivision by Cox (1986) using a larger data base results in: Porphyry Cu: 140 Mt with 0.54 %Cu, <0.002 % Mo, <0.02g/t Au and <1 g/t Ag. Porphyry Cu-Au: 100 Mt with 0.5 %Cu, <0.002 % Mo, 0.38g/t Au and 1g/t Ag. (This includes deposits from the British Columbia alkalic porphyry class, B.C. model L03.) Porphyry Cu-Mo: 500 Mt with 0.42 % Cu, 0.016 % Mo, 0.012 g/t Au and 1.2 g/t Ag.
- British Columbia porphyry Cu * Mo ± Au deposits range from <50 to >900 Mt with commonly 0.2 to 0.5 % Cu, <0.1 to 0.6 g/t Au, and 1 to 3 g/t Ag. Mo contents are variable from negligible to 0.04 % Mo. Median values for 40 B.C. deposits with reported reserves are: 115 Mt with 0.37 % Cu, *0.01 % Mo, 0.3g /t Au and 1.3 g/t Ag.

ECONOMIC LIMITATIONS: Mine production in British Columbia is from primary (hypogene) ores. Rare exceptions are Afton mine where native copper was recovered from an oxide zone, and Gibraltar and Bell mines where incipient supergene enrichment has provided some economic benefits.

END USES: Porphyry copper deposits produce Cu and Mo concentrates, mainly for international export.

IMPORTANCE: Porphyry deposits contain the largest reserves of Cu, significant Mo resources and close to 50 % of Au reserves in British Columbia.

REFERENCES

Beane, R.E. and Titley, S.R. (1981): Porphyry Copper Deposits Part II. Hydrothermal Alteration and Mineralization; in 75th Anniversary Volume, Economic Geology, pages 235-269.
Cox, D.P. (1986): Descriptive Model of Porphyry Cu, also Porphyry Cu-Au and Porphyry Cu-Mo; in Mineral Deposit Models; United States Geological Survey, Bulletin 1693, pages 76-81, also pages 110-114 and 115-119.
Cox, D.P. and Singer, D.A. (1988): Distribution of Gold in Porphyry Copper Deposits; U.S. Geological Survey, Open File Report 88-46, 23 pages.
Gustafson, L.B. and Hunt, J.P. (1975): The Porphyry Copper Deposit at El Salvador, Chile; Economic Geology, Volume 70, pages 857-912.
Lowell, J.D. and Guilbert, J.M. (1970): Lateral and Vertical Alteration- Mineralization Zoning in Porphyry Ore Deposits; Economic Geology, Volume 65, pages 373-408.
McMillan, W.J. (1991): Porphyry Deposits in the Canadian Cordillera; in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, B. C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4, pages 253-276.
McMillan, W.J. and Panteleyev, A. (1988): Porphyry Copper Deposits; in Ore Deposit Models, Roberts, R.G. and Sheahan, P.A., Editors, Geoscience Canada Reprint Series 3, Geological Association of Canada, pages 45-58; also in Geoscience Canada, Volume 7, Number 2, pages 52-63.
Schroeter, T.G., Editor (1995): Porphyry Copper Deposits of the Northwestern Cordillera of North America; Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, in preparation.
Sutherland Brown, A., Editor, (1976): Porphyry Deposits of the Canadian Cordillera; Canadian Institute of Mining and Metallurgy, Special Volume 15, 510 pages.
Titley, S.R. (1982): Advances in Geology of the Porphyry Copper Deposits, Southwestern North America; The University of Arizona Press, Tucson, 560 pages.
Titley, S.R. and Beane, R.E. (1981): Porphyry Copper Deposits Part I. Geologic Settings, Petrology, and Tectogenesis, in 75th Anniversary Volume, Economic Geology, pages 214-234.

[Back to top]

PORPHYRY Mo (LOW-F-TYPE)

L05
by W. David Sinclair
Geological Survey of Canada, Ottawa

Sinclair, W.D. (1995): Porphyry Mo (Low-F-type), in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 93-96.

IDENTIFICATION

SYNONYMS: Calcalkaline Mo stockwork; Granite-related Mo; Quartz-monzonite Mo.

COMMODITIES (*BYPRODUCTS*): Mo (Cu, W)

EXAMPLES (British Columbia - *Canada/International*): Endako (093K 006), Boss Mountain (093A 001), Kitsault (103P 120), Adanac (104N 052), Carmi (082ESW029), Bell Moly (103P 234), Red Bird (093E 026), Storie Moly (104P 069), Trout Lake (082KNW087); *Red Mountain (Yukon, Canada)*, *Quartz Hill (Alaska, USA)*, *Cannivan (Montana, USA)*, *Thompson Creek (Idaho, USA)*, *Compaccha (Peru)*, *East Kounrad (Russia)*, *Jinduicheng (China)*.

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockwork of molybdenite-bearing quartz veinlets and fractures in intermediate to felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING(S): Subduction zones related to arc-continent or continent-continent collision.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Archean (e.g. Setting Net Lake, Ontario) to Tertiary; Mesozoic and Tertiary examples are more common.

HOST/ASSOCIATED ROCK TYPES: All kinds of rocks may be hostrocks. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusive rocks. Genetically related intrusive rocks range from granodiorite to granite and their fine-grained equivalents, with quartz monzonite most common: they are commonly porphyritic. The intrusive rocks are characterized by low F contents (generally <0.1 % F) compared to intrusive rocks associated with Climax-type porphyry Mo deposits.

DEPOSIT FORM: Deposits vary in shape from an inverted cup, to roughly cylindrical, to highly irregular. They are typically hundreds of metres across and range from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is predominantly structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets and breccias.

ORE MINERALOGY (Principal and *subordinate*): Molybdenite is the principal ore mineral; chalcopyrite, scheelite, and galena are generally subordinate.

GANGUE MINERALOGY: Quartz, pyrite, K-feldspar, biotite, sericite, clays, calcite and anhydrite.

ALTERATION MINERALOGY: Alteration mineralogy is similar to that of porphyry Cu deposits. A core zone of potassic and silicic alteration is characterized by hydrothermal K-feldspar, biotite, quartz and, in some cases, anhydrite. K-feldspar and biotite commonly occur as alteration selvages on mineralized quartz veinlets and fractures but may be pervasive in areas of intense fracturing and mineralization. Phyllic alteration typically surrounds and may be superimposed to various degrees on the potassic-silicic core; it consists mainly of quartz, sericite and carbonate. Phyllic alteration is commonly pervasive and may be extensive. Propylitic alteration consisting mainly of chlorite and epidote may extend for hundreds of metres beyond the zones of potassic-silicic and phyllic alteration. Zones of argillic alteration, where present, are characterized by clay minerals such as kaolinite and are typically overprinted on the other types of alteration; distribution of argillic alteration is typically irregular.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite produces yellow ferrimolybdite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones superimposed on intermediate to felsic intrusive rocks and surrounding country rocks; multiple stages of mineralization commonly present.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and in associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore-forming process.

ASSOCIATED DEPOSIT TYPES: Ag-Pb-Zn veins (I05), Mo-bearing skarns (K07) may be present.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Mo, Cu, W and F may be anomalously high in hostrocks close to and overlying mineralized zones; anomalously high levels of Pb, Zn and Ag occur in peripheral zones as much as several kilometres distant. Mo, W, F, Cu, Pb, Zn and Ag may be anomalously high in stream sediments. Mo, W and Pb may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Magnetic anomalies may reflect presence of pyrrhotite or magnetite in hornfels zones. Radiometric surveys may be used to outline anomalous K in altered and mineralized zones. Induced polarization and resistivity surveys may be used to outline high-pyrite alteration zones.

OTHER EXPLORATION GUIDES: Limonitic alteration of pyrite can result in widespread gossan zones. Yellow ferrimolybdite may be present in oxidized zones. Ag-Pb-Zn veins may be present in peripheral zones.

ECONOMIC FACTORS

GRADE AND TONNAGE: Typical size is 100 Mt at 0.1 to 0.2 % Mo. The following figures are for production plus reserves.

- Endako (B.C.): 336 Mt at 0.087 % Mo;
- Boss Mountain (B.C.): 63 Mt. at 0.074 % Mo;
- Kitsault (B.C.): 108 Mt at 0.115 % Mo;
- Lucky Ship (B.C.): 14 Mt at 0.090 % Mo;
- Adanac (B.C.): 94 Mt at 0.094 % Mo;
- Carmi (B.C.): 34 Mt at 0.091 % Mo;
- Mount Haskin (B.C.): 12 Mt at 0.090 % Mo;
- Bell Moly (B.C.): 32 Mt at 0.066 % Mo;
- Red Bird (B.C.): 34 Mt at 0.108 % Mo;
- Storie Moly (B.C.): 101 Mt at 0.078 % Mo;
- Trout Lake (B.C.): 50 Mt at 0.138 % Mo;
- Glacier Gulch (B.C.): 125 Mt at 0.151 % Mo;
- Red Mountain (Yukon): 187 Mt at 0.100 % Mo;
- Quartz Hill (Alaska): 793 Mt at 0.091 % Mo;
- Thompson Creek (Idaho): 181 Mt at 0.110 % Mo;
- Compaccha (Peru): 100 Mt at 0.072 % Mo;
- East Kounrad (Russia): 30 Mt at 0.150 % Mo.

IMPORTANCE: Porphyry Mo deposits associated with low-F felsic intrusive rocks have been an important source of world molybdenum production. Virtually all of Canada's Mo production comes from these deposits and from porphyry Cu-Mo deposits.

REFERENCES

Boyle, H.C. and Leitch, C.H.B., (1983): Geology of the Trout Lake Molybdenum Deposit, B.C.; Canadian Institute of Mining and Metallurgy, Bulletin, Volume 76, No. 849, pages 115-124.
Brown, P. and Kahlert, B. (1986): Geology and Mineralization of the Red Mountain Porphyry Molybdenum Deposit, South-central Yukon; in Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 37, pages 288-297.
Carten, R.B., White, W.H. and Stein, H.J. (in press): High-grade Granite-related Mo Systems; Classification and Origin; in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, Geological Association of Canada, Special Paper 40, pages 521-554.
Kirkham, R.V. and Sinclair, W.D. (1984): Porphyry Copper, Molybdenum, Tungsten; in Canadian Mineral Deposit Types; A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, pages 51-52.
Kirkham, R.V., McCann, C., Prasad, N., Soregaroli, A.E., Vokes, F.M. and Wine, G. (1982): Molybdenum in Canada, Part 2: MOLYFILE -- An index-level computer file of molybdenum deposits and occurrences in Canada; Geological Survey of Canada, Economic Geology Report 33, pages 208.
Mutschler, F.E., Wright, E.G., Ludington, S. and Abbott, J. (1981): Granite Molybdenite Systems; Economic Geology, v. 76, pages 874-897.
Pilcher, S.H. and McDougall, J.J. (1976): Characteristics of some Canadian Cordilleran Porphyry Prospects, in Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A. , Editor, Canadian Institute of Mining and Metallurgy, Special Volume 15, pages 79-82.
Sutulov, A. (1978): International Molybdenum Encyclopaedia 1778-1978, Volume 1, Intermet Publications, Santiago, Chile, page 402.
Theodore, T.G. (1986): Descriptive Model of Porphyry Mo, Low-F; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 120.
Theodore, T.G. and Menzie, W.D. (1984): Fluorine-deficient Porphyry Molybdenum Deposits in the Western North American Cordillera; Proceedings of the Six Quadrennial IAGOD Symposium, E. Schweitzerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart, Germany, pages 463-470.
Westra, G. and Keith S.B. (1981): Classification and Genesis of Stockwork Molybdenum Deposits; Economic Geology, Volume 76, pages 844-873.
Woodcock, J.R. and Carter, N.C. (1976): Geology and Geochemistry of the Alice Arm Molybdenum Deposits; in Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 15, pages 462-475.

[Back to top]

PORPHYRY Sn

L06

by W. David Sinclair
Geological Survey of Canada, Ottawa

Sinclair, W.D. (1995): Porphyry Sn, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 97-100.

IDENTIFICATION

SYNONYM: Subvolcanic Sn

COMMODITIES (*BYPRODUCTS*): Sn (Ag, W)

EXAMPLES (British Columbia - *Canada/International*): *Mount Pleasant (New Brunswick, Canada), East Kemptville (Nova Scotia, Canada), Catavi, Chorolque and Cerro Rico stock (Bolivia), Ardlethan and Taronga (Australia), Kingan (Russia), Yinyan (China), Altenberg (Germany).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Fine-grained cassiterite in veinlet and fracture stockwork zones, breccia zones, and disseminated in porphyritic felsic intrusive rocks and associated country rocks.

TECTONIC SETTING: Zones of weak to moderate extension in cratons, particularly post orogenic zones underlain by thick crust, possibly cut by shallow-dipping subduction zones.

GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres in cratons; multiple stages of intrusion may be present.

AGE OF MINERALIZATION: Paleozoic to Tertiary.

HOST/ASSOCIATED ROCK TYPES: Predominantly genetically related intrusive rocks and associated breccias, but may also include related or unrelated sedimentary, volcanic, igneous and metamorphic rocks. Genetically related felsic intrusive rocks are F and/or B enriched and are commonly porphyritic. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits vary in shape from inverted cone, to roughly cylindrical, to highly irregular. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is predominantly structurally controlled in stockworks of crosscutting fractures and quartz veinlets, or disseminated in hydrothermal breccia zones. Veins, vein sets, replacement zones may also be present.

ORE MINERALOGY (Principal and *subordinate*): Cassiterite; stannite, chalcopyrite, sphalerite and galena. Complex tin- and silver-bearing sulphosalts occur in late veins and replacement zones.

GANGUE MINERALOGY: Pyrite, arsenopyrite, löllingite, topaz, fluorite, tourmaline, muscovite, zinnwaldite and lepidolite.

ALTERATION MINERALOGY: In the Bolivian porphyry Sn deposits, sericite + pyrite ± tourmaline alteration is pervasive; in some deposits it surrounds a central zone of quartz + tourmaline. Sericitic alteration is typically bordered by weak propylitic alteration. In other deposits (e.g. , Ardlethan, Yinyan), central zones are characterized by greisen alteration consisting of quartz + topaz + sericite; these zones grade outward to quartz + sericite + chlorite alteration.

WEATHERING: Oxidation of pyrite produces limonitic gossans. Deep weathering and erosion can result in residual concentrations of cassiterite in situ or in placer deposits downslope or downstream.

ORE CONTROLS: Ore minerals occur in fracture stockworks, hydrothermal breccias and replacement zones centred on 1-2 km2, genetically related felsic intrusions.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Sn and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Mixing of magmatic with meteoric water during waning stages of the magmatic- hydrothermal system may result in deposition of some Sn and other metals, particularly in late-stage veins.

ASSOCIATED DEPOSIT TYPES: Sn veins (I13), Sn-polymetallic veins (H07).

COMMENTS: Some of the deposits listed (e.g. Taronga, East Kemptville) are not "subvolcanic" but they are similar to some porphyry Cu deposits with regard to their large size, low grade, relationship to felsic intrusive rocks and dominant structural control (ie., mineralized veins, fractures and breccias).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sn, Ag, W, Cu, Zn, As, Pb, Rb, Li, F, B may be anomalously high in hostrocks close to mineralized zones and in secondary dispersion halos in overburden. Anomalously high contents of Sn, W, F, Cu, Pb and Zn may occur in stream sediments and Sn, W, F (topaz) and B (tourmaline) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite-rather than magnetite-dominant); contact aureole may be magnetic high if pyrrhotite or magnetite are present in associated skarn or hornfels zones. Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

OTHER EXPLORATION GUIDES: Sn (-Ag) deposits may be zoned relative to base metals at both regional (district) and local (deposit) scales.

ECONOMIC FACTORS

GRADE AND TONNAGE: Tens of millions of tonnes at grades of 0.2 to 0.5% Sn. Mount Pleasant (New Brunswick): 5.1 Mt @ 0.79% Sn; East Kemptville (Nova Scotia): 56 Mt @ 0.165% Sn; Catavi (Bolivia): 80 Mt @ 0.3% Sn; Cerro Rico stock, Bolivia: averages 0.3% Sn; Ardlethan (Australia): 9 Mt @ 0.5% Sn; Taronga (Australia): 46.8 Mt @ 0.145% Sn; Altenberg, (Germany): 60 Mt @ 0.3% Sn; Yinyan (China): "large" (50 - 100 Mt?) @ 0.46% Sn

ECONOMIC LIMITATIONS: Low grades require high volumes of production which may not be justified by demand.

IMPORTANCE: A minor source of tin on a world scale; when it was in production, East Kemptville was the major producer of tin in North America.

REFERENCES

Grant, J.N., Halls, C., Avila, W. and Avila, G. (1977): Igneous Systems and Evolution of Hydrothermal Systems in some Sub-volcanic Tin Deposits of Bolivia; in Volcanic Process in Orogenesis; Geological Society of London, Special Paper Publication 7, pages 117-126.
Grant, J.N., Halls, C., Sheppard, S.M.F. and Avila, W. (1980): Evolution of the Porphyry Tin Deposits of Bolivia; in Granitic Magmatism and Related Mineralization, Ishihara, S. and Takenouchi, S., Editors; The Society of Mining Geologists of Japan, Mining Geology Special Issue, No. 8, pages 151-173.

Guan, X., Shou, Y., Xiao, J., Liang, S. and Li, J. (1988): A New Type of Tin Deposit - Yinyan Porphyry Tin Deposit; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 487-494.
Lin, G. (1988): Geological Characteristics of the Ignimbrite-related Xiling Tin Deposit in Guangdong Province; in Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, Springer-Verlag, Berlin, pages 494-506.
Reed, B.L. (1986): Descriptive Model of Porphyry Sn; in Mineral Deposit Models, Cox, D.P. and Singer, D.A. Editors; U.S. Geological Survey, Bulletin 1693, pages 108.
Sillitoe, R.H., Halls, C. and Grant, J.N. (1975): Porphyry Tin Deposits in Bolivia; Economic Geology, Volume 70, pages 913-927.
Taylor, R.G. and Pollard, P.J. (1986): Recent Advances in Exploration Modelling for Tin Deposits and their application to the Southeastern Asian Environment; GEOSEA V Proceedings, Volume 1, Geological Society of Malaysia, Bulletin 19, pages 327-347.

[Back to top]

PORPHYRY W

L07

by W. David Sinclair
Geological Survey of Canada, Ottawa

Sinclair, W.D. (1995): Porphyry W, in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 101-104.

IDENTIFICATION

SYNONYM: Stockwork W-Mo

COMMODITIES (*BYPRODUCTS*): W (Mo, Sn, Ag).

EXAMPLES (British Columbia - *Canada/International*): *Boya; Mount Pleasant (New Brunswick, Canada), Logtung (Yukon, Canada), Xingluokeng, Lianhuashan and Yanchuling (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockwork of W-bearing quartz veinlets and fractures in felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING: Zones of weak to moderate extension in cratons, particularly post-collisional zones in areas of tectonically thickened crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Paleozoic to Tertiary, but Mesozoic and Tertiary examples are more common.

HOST/ASSOCIATED ROCK TYPES: Highly variable; mineralized rocks may be predominantly genetically related intrusive rocks, but may also be related or unrelated sedimentary, volcanic, igneous and metamorphic rocks. Genetically related felsic intrusive rocks are commonly F-rich (fluorite and/or topaz bearing) and porphyritic; unidirectional solidification features, particularly comb quartz layers, may also be present. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits vary in shape from inverted cup-shaped, to roughly cylindrical, to highly irregular. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore minerals is structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets, breccias, disseminations and replacements.

ORE MINERALOGY (Principal and *subordinate*): Main ore mineral is generally either scheelite or wolframite, although in some deposits both are present. Subordinate ore minerals include molybdenite, bismuth, bismuthinite and cassiterite.

GANGUE MINERALOGY: Pyrite, pyrrhotite, magnetite, arsenopyrite, löllingite, quartz, K-feldspar, biotite, muscovite, fluorite, topaz.

ALTERATION MINERALOGY: Hydrothermal alteration is pervasive to fracture controlled and, at deposit scale, is concentrically zoned. It is commonly characterized by the presence of greisen alteration minerals, including topaz, fluorite and Li- and F-rich micas. At Mount Pleasant, for example, pervasive greisen alteration consisting of quartz + topaz ± sericite ± chlorite associated with high-grade W zones and grades laterally into fracture-controlled quartz- biotite-chlorite-topaz alteration associated with lower grade W zones. Propylitic alteration, mainly chlorite and sericite, extends as far as 1500 m beyond the mineralized zones. Potassic alteration, dominated by K-feldspar, occurs locally within the central areas of pervasive greisen alteration. Other deposits such as Xingluokeng (China) are characterized more by central zones of silicic and potassic alteration (K-feldspar and biotite); zones of weak greisen alteration consisting of muscovite and fluorite may be present. Sericitic alteration forms a broad aureole around the central potassic zone; irregular zones of argillic alteration may be superimposed on both the potassic and sericitic zones. In detail, alteration patterns may be complex; at Logtung, for example, different stages of mineralized veins and fractures are characterized by different assemblages of ore and alteration minerals.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite, if present, may produce yellow ferrimolybdenite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones surround or are draped over and are superimposed to varying degrees on small stocks (<1 km2); multiple stages of mineralization commonly present; felsic intrusions associated with the deposits are typically F-rich.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip W, Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore forming process.

ASSOCIATED DEPOSIT TYPES: Porphyry W deposits may be part of a spectrum of deposits that include Climax-type Mo deposits (L08) as one end-member and porphyry Sn deposits as the other (L06). Vein/replacement W, Sn, Ag deposits may be associated (I05, H07), e.g. Logjam Ag-Pb-Zn veins peripheral to the Logtung W-Mo deposit. Skarn (contact metamorphic) zones associated with genetically related felsic intrusions may be mineralized, but are not typical skarn W (i.e. contact metasomatic) deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: W, Mo and Sn are anomalous in hostrocks close to mineralized zones; anomalously high contents of F, Zn, Pb and Cu occur in wallrocks up to several kilometres from mineralized zones. W, Sn, Mo, F, Cu, Pb and Zn may be anomalously high in stream sediments and W, Sn and F (topaz) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite rather than magnetite dominant); contact aureole may be magnetic high if pyrrhotite or magnetite are present in associated skarn or hornfels zones. Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

OTHER EXPLORATION GUIDES: The presence of scheelite can be detected with an ultraviolet lamp.

ECONOMIC FACTORS

GRADE AND TONNAGE: Tens to more than 100 Mt at grades of 0.2 to 0.3 % W (Lianhushan is exceptional at 0.8 % W). Boya (British Columbia): limited size due to thrust fault truncation, no published resource data. Mount Pleasant (New Brunswick): Fire Tower zone: 22.5 Mt @ 0.21 % W, 0.10 % Mo, 0.08 % Bi, (includes 9.4 Mt @ 0.31 % W, and 0.12 % Mo), North zone: 11 Mt @ 0.2 % W, 0.1 % Mo. Logtung (Yukon): 162 Mt @ 0.10 % W, 0.03 % Mo. Xingluokeng (China): 78 Mt @ 0.18 % W. Lianhuashan (China): ~40 Mt @ 0.8 % W.

ECONOMIC LIMITATIONS: Low grades require high production volumes which may not be justified by current demand for tungsten.

IMPORTANCE: Not currently an important source of world W production; some W may be recovered from deposits in China (e.g. Lianhuashan), but none is recovered at present (1994) from deposits outside China. Mount Pleasant Tungsten in New Brunswick produced slightly more than 2000 t of concentrate grading 70 % WO3 from 1 Mt of ore mined from 1983 to 1985.

REFERENCES

Kirkham, R.V. and Sinclair, W.D. (1984): Porphyry Copper, Molybdenum, Tungsten; in Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, pages 51-52.
Kirkham, R.V. and Sinclair, W.D. (1988): Comb Quartz Layers in Felsic Intrusions and their Relationship to Porphyry Deposits; in Recent Advances in the Geology of Granite-related Mineral Deposits, Canadian Institute of Mining and Metallurgy, Special Volume 39, pages 50-71.
Kooiman, G.J.A., McLeod, M.J. and Sinclair, W.D. (1986): Porphyry Tungsten-Molybdenum Orebodies, Polymetallic Veins and Replacement Bodies, and Tin-bearing Greisen Zones in the Fire Tower Zone, Mount Pleasent, New Brunswick; Economic Geology, Volume 81, pages 1356-1373.
Liu, W. (1980): Geological Features of Mineralization of the Xingluokeng Tungsten (Molybdenum) Deposit, Fujian Province; in Tungsten Geology, China, Hepworth, J.V. and Lu, H.Z., Editors, ESCAP/RMRDC, Bandung, Indonesia, pages 338-348.
Noble, S.R., Spooner, E.T.C. and Harris, F.R. (1986): Logtung: A Porphyry W-Mo Deposit in the Southern Yukon; in Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 37, pages 274- 287.
Sinclair, W.D. (1986): Molybdenum, Tungsten and Tin Deposits and associated Granitoid Intrusions in the Northern Canadian Cordillera and adjacent parts of Alaska; in Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 37, pages 216-233.
Yan, M-Z., Wu, Y-L. and Li, C.-Y. (1980): Metallogenetic Systems of Tungsten in Southeast China and their Mineralization Characteristics; in Granitic Magmatism and Related Mineralization, Ishihara, S. and Takenouchi, S., Editors, The Society of Mining Geologists of Japan, Mining Geology Special Issue, No. 8, pages 215-221.

[Back to top]

PORPHYRY Mo (Climax-type)

L08
by W. David Sinclair

Geological Survey of Canada, Ottawa

Sinclair, W.D. (1995): Porphyry Mo (Climax-type), in Selected British Columbia Mineral Deposit Profiles, Volume 1 - Metallics and Coal, Lefebure, D.V. and Ray, G.E., Editors, British Columbia Ministry of Energy of Employment and Investment, Open File 1995-20, pages 105-108.

IDENTIFICATION

SYNONYMS: Granite molybdenite; Climax Mo; granite-related Mo.

COMMODITIES (*BYPRODUCTS*): Mo (W, Sn; pyrite and monazite have also been recovered from the Climax deposit).

EXAMPLES (British Columbia - *Canada/International*): No unequivocal Climax-type porphyry Mo deposits occur in British Columbia or other parts of Canada; *Climax, Henderson, Mount Emmons and Silver Creek (Colorado, USA), Pine Grove (Utah, USA), Questa (New Mexico), Malmbjerg (Greenland), Nordli (Norway).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks of molybdenite-bearing quartz veinlets and fractures in highly evolved felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING: Rift zones in areas of thick cratonic crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Paleozoic to Tertiary, but mainly Tertiary.

HOST/ASSOCIATED ROCK TYPES: Genetically related felsic intrusive rocks are high-silica (>75% SiO_2), F-rich (>0.1% F) granite/rhyolite; they are commonly porphyritic and contain unidirectional solidification textures (USTs), particularly comb quartz layers. Contents of Rb, Y and Nb are high; Ba, Sr and Zr are low. Mineralized country rocks may include sedimentary, metamorphic, volcanic, and older intrusive rocks. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits typically form an inverted cup or hemispherical shell; shapes may be modified by regional or local structures. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets and breccias; disseminations and replacements are less common.

ORE MINERALOGY (Principal and *subordinate*): Molybdenite; wolframite, cassiterite, sphalerite, galena, monazite.

GANGUE MINERALOGY: Quartz, pyrite, topaz, fluorite and rhodochrosite.

ALTERATION MINERALOGY: Potassic alteration (K-feldspar ± biotite) is directly associated with high-grade Mo (>0.2% Mo); pervasive silicic alteration (quartz ± magnetite) may occur locally in the lower parts of high-grade Mo zones. Quartz-sericite-pyrite alteration may extend hundreds of metres vertically above orebodies; argillic alteration may extend hundreds of metres beyond quartz-sericite-pyrite alteration, both vertically and laterally. Spessartine garnet occurs locally within quartz-sericite-pyrite and argillic alteration zones. Greisen alteration consisting of quartz-muscovite-topaz occurs as alteration envelopes around quartz-molybdenite veins below high-grade Mo zones. Propylitic alteration is widespread and may extend for several km.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite produces yellow ferrimolybdite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones surround or are draped over, and are superimposed to varying degrees on small, genetically related stocks (area <1 km^2); multiple stages of mineralization are commonly present; abundant comb quartz layers and other USTs characterize productive intrusions.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore-forming process.

ASSOCIATED DEPOSIT TYPES: Ag-base metal veins (I05), fluorspar deposits. Some porphyry W-Mo deposits (e.g. Mount Pleasant) may be W-rich Climax-type deposits. Mo may also be present in adjacent skarn deposits (K07). Climax-type porphyry Mo deposits may be related to rhyolite-hosted Sn deposits (H07, USGS model 25h).

COMMENTS: This model is based mainly on descriptions of Climax and Climax-type deposits in Colorado. These deposits tend to have more complex igneous- hydrothermal systems and higher average Mo grades than low-F-type porphyry Mo deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Mo, Sn, W, Rb, Mn and F may be anomalously high in hostrocks close to and overlying mineralized zones; Pb, Zn, F and U may be anomalous in wallrocks as much as several kilometres distant. Mo, Sn, W, F, Cu, Pb, Zn may be anomalous in stream sediments and Mo, Sn, W, and F (topaz) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite rather than magnetite dominant). Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

OTHER EXPLORATION GUIDES: Deposits occur in extensional tectonic settings in areas of thick continental crust. Genetically related felsic intrusive rocks generally have high contents of Nb (>75 ppm. Ag-Pb-Zn veins, topaz, fluorite and Mn- garnet may be present in peripheral zones. Yellow ferrimolybdite may be present in oxidized zones.

ECONOMIC FACTORS

GRADE AND TONNAGE: Deposits typically contain hundreds of millions of tonnes at 0.1 to 0.3 % Mo. Following figures are production plus reserves (from Carten et al., 1993): Climax, Colorado: 769 Mt @ 0.216% Mo (mineable), Henderson, Colorado: 727 Mt @ 0.171% Mo (geological), Mount Emmons, Colorado: 141 Mt @ 0.264% Mo (mineable), Silver Creek, Colorado: 40 Mt @ 0.310% Mo (geological), Pine Grove, Utah: 125 Mt @ 0.170% Mo (geological), Questa, New Mexico: 277 Mt @ 0.144% Mo (mineable), Malmbjerg, Greenland: 136 Mt @ 0.138% Mo (geological), Nordli, Norway: 181 Mt @ 0.084% Mo (geological).

ECONOMIC LIMITATIONS: Economic viability of these deposits is affected by Mo production from other types of deposits such as porphyry Cu-Mo deposits, which produce Mo as a coproduct or byproduct.

IMPORTANCE: Porphyry Mo deposits of the Climax type have been a major source of world Mo production and contain substantial reserves.

REFERENCES

Carten, R.B., White, W.H. and Stein, H.J. (1993): High-grade Granite-related Mo Systems: Classification and Origin: in Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Dute, J.M. Editors,: Geological Association of Canada, Special Paper 40, pages 521-554.
Kirkham, R.V. and Sinclair, W.D. (1984): Porphyry Copper, Molybdenum, Tungsten; in Canadian Mineral Deposit Types: A Geological Synopsis; Geological Survey of Canada, Economic Geology Report 36, pages 51-52.
Kirkham, R.V. and Sinclair, W.D. (1988): Comb Quartz Layers in Felsic Intrusions and their Relationship to Porphyry Deposits; in Recent Advances in the Geology of Granite-related Mineral Deposits, Canadian Institute of Mining and Metallurgy, Special Volume 39, pages 50-71.
Keith, J.D. and Christiansen, E.H. (1992): The Genesis of Giant Molybdenum Deposits; in Giant Ore Deposits, Whiting, B.H., Masong, R. and Hodgson, C.J., Editors, Proceedings of the Giant Deposits Workshop, Queen's University, Kingston, 11-13 May, 1992.
Ludington, S.D. (1986): Descriptive Model of Climax Mo Deposits; in Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, U.S. Geological Survey, Bulletin 1693, page 73.
Mutschler, F.E., Wright, E.G., Ludington, S. and Abbot, J. (1981): Granite Molybdenite Systems; Geology, Volume 13, pages 469-474.
Wallace, S.R., Muncaster, N.K., Jonson, D.D., MacKenzie, W.B., Bookstrom, A.A. and Surface, V.E. (1968): Multiple Intrusion and Mineralization at Climax, Colorado; in Ore Deposits of the United States, 1933-1967 (The Graton-Sales Volume), Ridge, J.D., Editor, American Institute of Mining, Metallurgy and Petroleum Engineers, New York, pages 605-640.
Westra, G. and Keith, S.B. (1981): Classification and Genesis of Stockwork Molybdenum Deposits; Economic Geology, Volume 76, pages 844-873.
White, W.H., Bookstrom, A.A., Kamilli, R.J., Ganster, M.W., Smith, R.P., Ranta, D.E. and Steininger, R.C. (1981): Character and Origin of Climax-type Molybdenum Deposits; Economic Geology, 75th Anniversary Volume, pages 270-316.

[Back to top]

** Note: All BC deposit profile #s with an asterisk have no completed deposit profile. USGS deposit model #s with an asterisk had no published model in the late 1990s.*

Examples of Porphyry Deposits

BC Profile #	Global Examples	B.C. Examples
L01	Lepanto (Philippines), Resck (Hungary), Kori Kollo (Bolivia)	Equity Silver, Thorn
L02	Mokrsko (Czech Republic), Timbarra (New South Wales, Australia)	- -
L03	*Tai Parit (Philippines)*	Afton, Copper Mountain, Galore Creek
L04	Chuquicamata & La Escondida (Chile)	Highland Valley, Gibraltar
L05	Quartz Hill (Alaska)	Endako, Kitsault, Glacier Gulch
L06	Llallagua (Bolivia), Potato Hills (Yukon)	- -
L07	Logtung (Yukon), Xingluokeng (China)	Boya
L08	Climax & Henderson (Colorado)	- -
L09*	Marte & Lobo (Chile), Lihir (Papua New Guinea)	Snowfields

Top

Appendix 3

2014 – 2015 Cost Statement

2014-2015 Cost Statement for Texada Project					
Exploration Work type	**Comment**	**Days**			**Totals**
Office Studies	**List Personnel (note - Office only, do not include field days**				
Literature search	J.Houle - late 2013	1.90	$831.60	$1,580.04	
Database compilation	J.Houle - Mar.19,20, 2014	1.10	$831.60	$914.76	
Computer modelling	J.Houle - Mar 24-26, Apr.4, 2014	1.25	$831.60	$1,039.50	
Reprocessing of data			$0.00	$0.00	
General research			$0.00	$0.00	
Report preparation	J.Houle - Feb.22-28, Mar.3-5, 2015	5.00	$831.60	$4,158.00	
				$7,692.30	**$7,692.30**
TOTAL Expenditures					**$7,692.30**