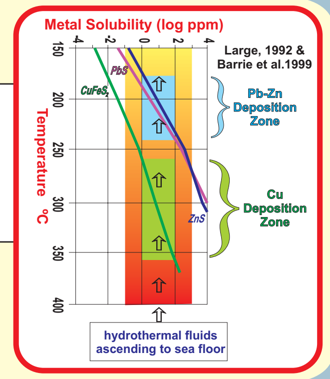
TARGETING HOTSPOTS — Metal Zoning in VMS Belts

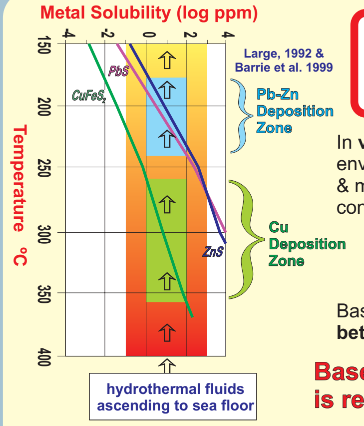
BC Geological Survey

by Dani Alldrick

GEOFILE 2002-3



Concept



In **volcanogenic massive sulphide (VMS)** environments, variations in the temperature & metal solubilities of hydrothermal fluids control the zonation of base metals:

1. within single VMS lenses
2. between adjacent VMS lenses
3. along volcanic belts

Base metal zoning **within** lenses and **between** lenses has long been recogised.

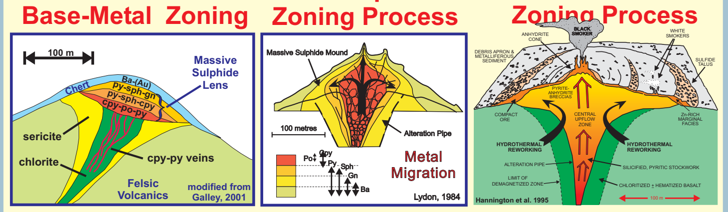
Base metal zoning at belt scale is reported here for the first time.

Deposit-scale Zoning

Base-metal zoning within VMS deposits was documented before the syngenetic nature of these deposits was recognised. Metal zoning results from selective dissolution of metals & the progressive cooling of the metal-bearing hydrothermal fluids as they combine with cold seawater within newly formed sulphide mounds.

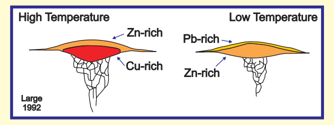
The process of selective dissolution & redeposition of Zn & Pb has been termed **"hydrothermal reworking"**, **"metal migration"** & **"zone refining"**.

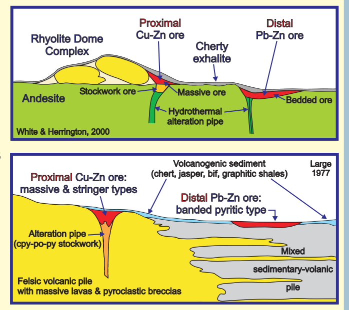
Observed Base-Metal Zoning — Conceptual Zoning Process — Observed Zoning Process



Volcano-scale Zoning

Base-metal zoning **between** sulphide lenses at volcano scale (> 1 km) has been recognised in several mining camps. This zoning is attributed to differences in temperature of the enclosing rock packages, with proximal, **Cu-Au**-rich deposits hosted by felsic volcanics & distal **Zn-Pb-Ag**-rich deposits hosted by tuffaceous metasediments.



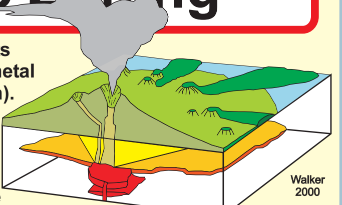


Belt-scale Zoning

Recent studies in Tasmania & new results from the Ecstall Belt confirm that base metal zoning also exists at belt scales (> 10 km).

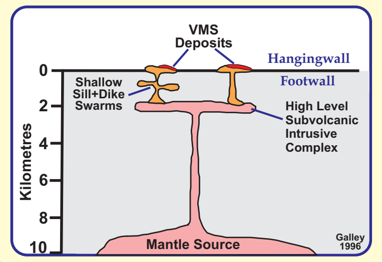
Belt-scale base metal zoning is driven by the large subvolcanic plutons commonly associated with VMS belts.

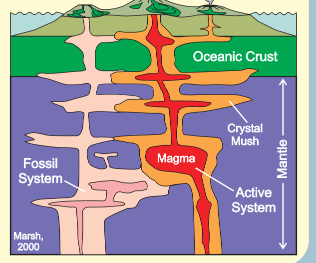
The latent heat of crystallisation of these batholith-scale plutons sets up a long-lived, regional-scale geothermal gradient.



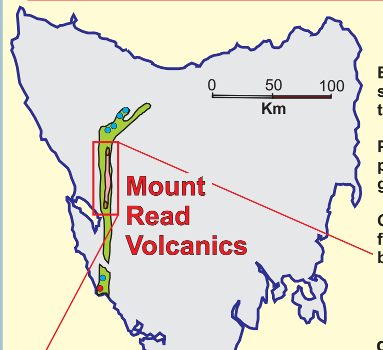
Subvolcanic magma plumes can:
- Migrate with time
- Feed multiple volcanoes

Study of belt-scale zoning during exploration programs can highlight underexplored areas & permit selection of metal-specific target areas.





Mount Read Belt



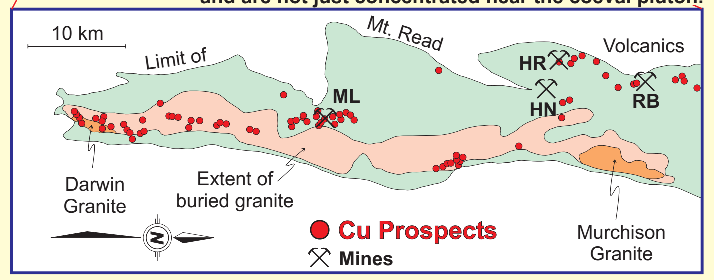
TASMANIA

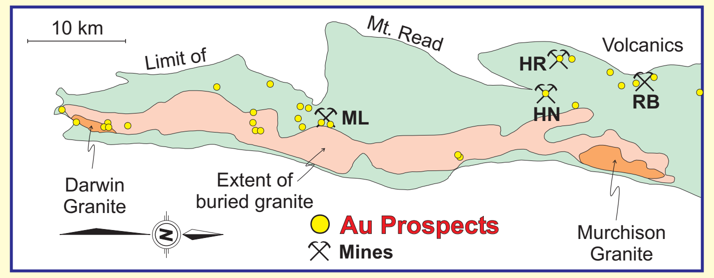
Base metal zoning among VMS deposits is spatially related to a subvolcanic pluton in the Mount Read volcanic belt of Tasmania.

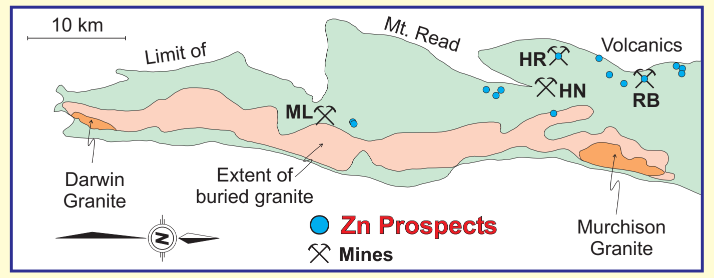
Prospects in this belt demonstrate clear, proximal-to-distal zoning from copper to gold to zinc, both up-section and laterally.

Only two small stocks crop out, but the full extent of this buried batholith has been revealed by an aeromagnetic survey.

These maps (Large et al., 1996) demonstrate that VMS deposits are distributed throughout the Mt. Read volcanics, and are not just concentrated near the coeval pluton.

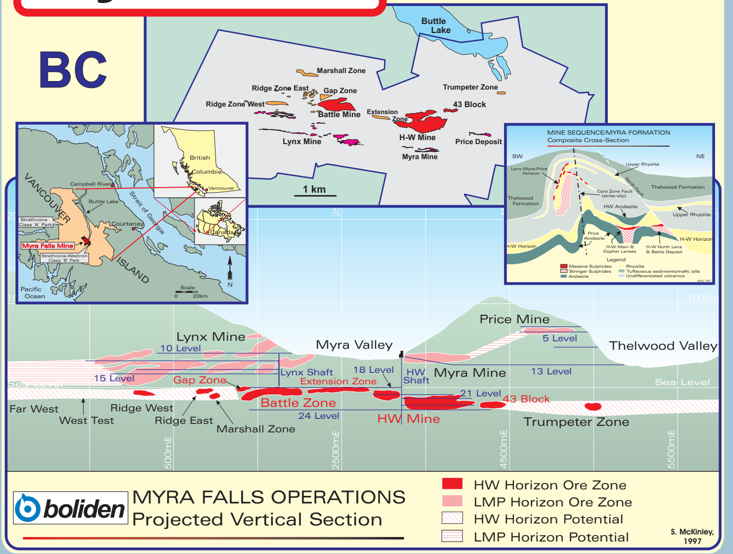




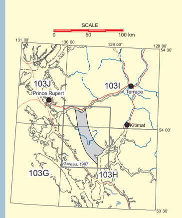


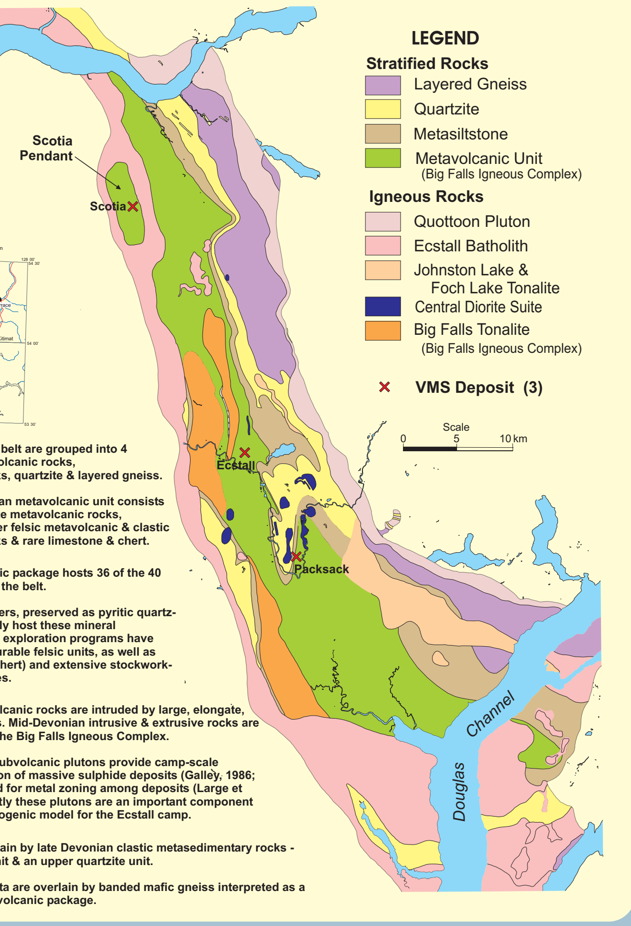
Myra Falls

NB: There can be multiple prospective horizons within one volcanic succession.



GEOLOGY





Stratified rocks of the belt are grouped into 4 principal units: metavolcanic rocks, metasedimentary rocks, quartzite & layered gneiss.

The basal mid-Devonian metavolcanic unit consists of mafic & intermediate metavolcanic rocks, interlayered with lesser felsic metavolcanic & clastic metasedimentary rocks & rare limestone & chert.

This main metavolcanic package hosts 36 of the 40 sulphide prospects in the belt.

Felsic volcanic members, preserved as pyritic quartz-sericite schist, typically host these mineral occurrences. Industry exploration programs have traced out many favourable felsic units, as well as exhalative horizons (chert) and extensive stockwork-style mineralized zones.

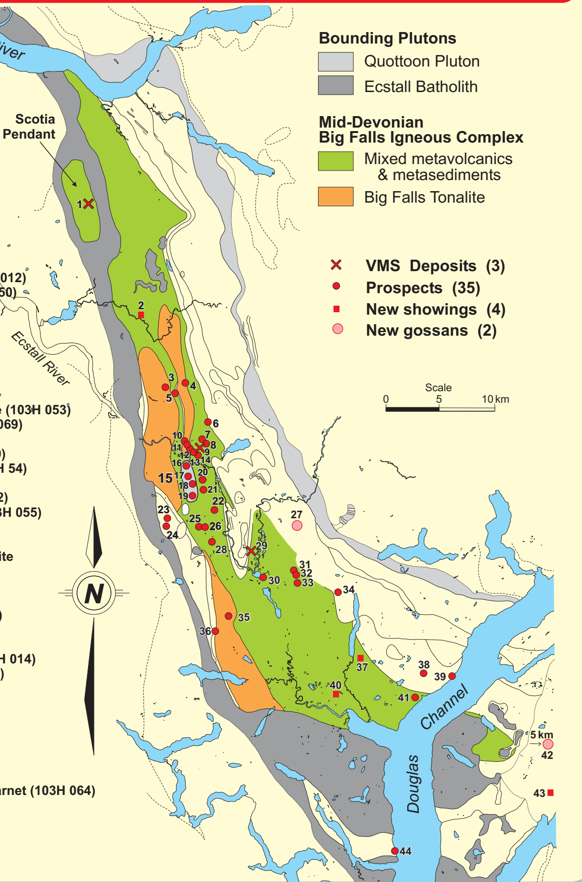
Mid-Devonian metavolcanic rocks are intruded by large, elongate, mid-Devonian plutons. Mid-Devonian intrusive & extrusive rocks are grouped together as the Big Falls Igneous Complex.

In greenstone belts, subvolcanic plutons provide camp-scale controls for localization of massive sulphide deposits (Galley, 1986; Barrie et al., 1999) and for metal zoning among deposits (Large et al., 1996). Consequently these plutons are an important component of the evolving metallogenic model for the Ecstall camp.

These rocks are overlain by late Devonian clastic metasedimentary rocks - a lower metapelitic unit & an upper quartzite unit.

Metasedimentary strata are overlain by banded mafic gneiss interpreted as a Late Devonian mafic volcanic package.

MINERAL DEPOSITS



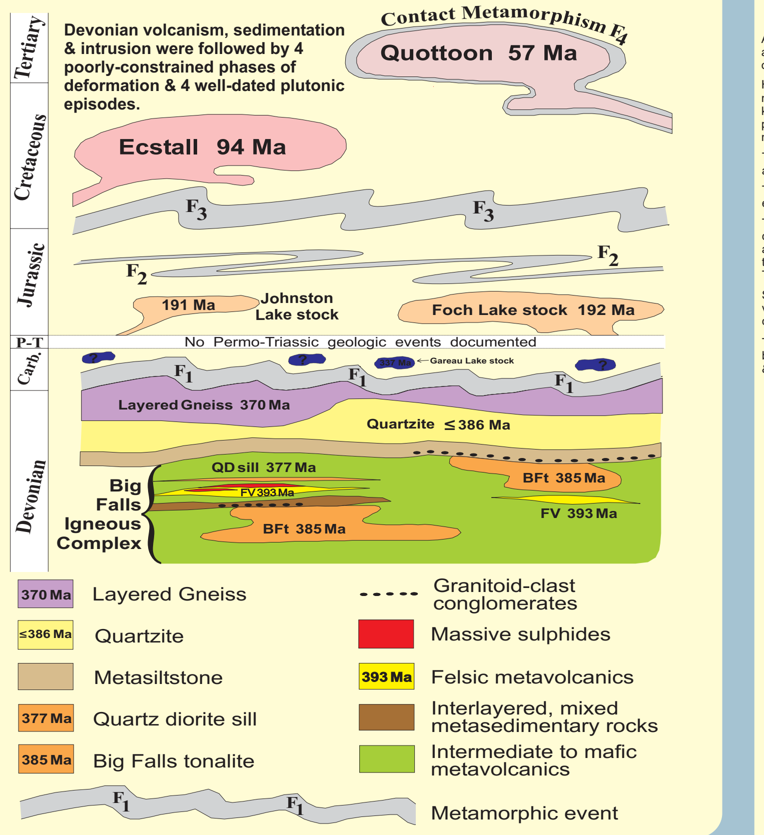
MINERAL PROSPECTS

1. Scotia (103I 007)
2. F-13 (103H 077)
3. Mark
4. Marmot
5. West Marmot
6. Ridge
7. Third Outcrop (103H 012)
8. East Plateau (103H 050)
9. Ecstall (103H 011)
10. Swinnerton Creek
11. East Swinnerton
12. Wharf
13. Red Bluff
14. Trench (103H 051)
15. West Grid Alteration Zone (103H 053)
16. Phobe Creek (103H 069)
17. Elaine Creek
18. Sphalerite (103H 070)
19. Thirteen Creek (103H 54)
20. North Mariposite
21. Mariposite (103H 052)
22. South Grid East (103H 055)
23. Amber (103H 071)
24. El Amino (103H 071)
25. Balan Creek Anhydrite
26. Balan
27. NTS gossan
28. Bear (103H 056)
29. Packsack (103H 013)
30. Rainbow
31. Horsefly (103H 014)
32. Horsefly South (103H 014)
33. Steelhead (103H 036)
34. Marlyn
35. Ravine
36. Strike
37. Bell
38. Decaire (103H 016)
39. Abruzzi (103H 017)
40. West Road
41. Douglas Channel Garnet (103H 064)
42. Evelyn Lake gossan
43. Cheens Creek
44. Kiskosh (103H 015)

ECSTALL BELT

GEOLOGIC HISTORY

Devonian volcanism, sedimentation & intrusion were followed by 4 poorly-constrained phases of deformation & 4 well-dated plutonic episodes.



METAL ZONING — RESERVES & ASSAYS

Cu:Zn & Cu:Pb ratios were calculated & contoured for assays from deposits & prospects in the Ecstall belt.

In most mining camps, assay data is more readily available than high quality stream sediment survey results, so it offers a more universal database.

Reserves, Assays and Cu:Zn & Cu:Pb ratios

PROPERTY	SIZE (mT)	Cu %	Pb %	Zn %	Ag g/T	Au g/T	Cu:Zn Ratio	Cu:Pb Ratio
Scotia	1,240,000	0.10	0.40	3.80	13.00	0.250	0.03	0.25
Amber		0.01		0.02			0.56	
Bell		0.24	2.56	3.36	112.30		0.07	0.09
Cheens Creek		0.15	0.50	3.74	23.40		0.04	0.31
East Plateau		0.03		0.18			0.17	
Ecstall	6,878,539	0.65		2.45	17.00	0.500	0.27	
El Amino		0.50		0.60	70.00		0.83	
Elaine Creek		3.04		0.09	11.70	1.525	33.78	
Horsefly		1.16	0.13	4.60	39.00	0.500	0.25	8.92
Horsefly South		5.60	0.09	1.65	30.00	0.860	3.39	62.22
Mariposite		0.03	0.04	0.12	5.50	0.110	0.24	0.66
Mark		0.14	0.01	0.02	0.06	0.002	7.00	14.00
Marlyn		0.01	0.01	0.05	0.05	0.020	0.10	0.50
Marmot		0.01	0.01	0.02	0.01	0.002	0.30	0.60
Packsack	2,700,000	0.50	0.01	0.20	34.00	0.300	2.50	50.00
Phobe Creek		0.69		0.01	2.22	0.251	104.55	
Rainbow		0.04	0.00	0.31	1.80		0.13	40.00
South Grid East		0.12		0.02			5.00	
Sphalerite		0.06	0.00	6.00	1.50	0.015	0.01	20.68
Steelhead		0.03	0.13	0.04	13.80	0.024	0.75	0.21
Strike		0.17	0.27	2.83	1.13	0.010	0.06	0.63
Third Outcrop		0.63		2.30			0.27	
Thirteen Creek		8.05		0.05	350.00	2.400	151.89	
Trench		0.03	0.00	0.12			0.28	7.17

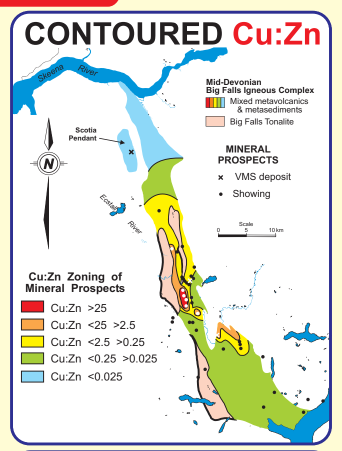
Concentric zoning of Cu:Zn & Cu:Pb ratios decreases outward from the central coeval stocks.

A Cu-rich zone occurs near the Packsack deposit, despite the apparent absence of mid-Devonian tonalite stocks. However, early mapping work identified several small bodies of "diorite" along this part of the valley.

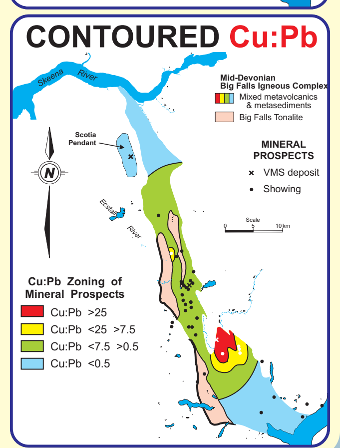
There is no Cu-rich zone in the SW part of the belt, where a large tonalite body is shown. The tonalite intrusion in this area was extrapolated from a small exposure mapped far to the north. The absence of any Cu-rich signature, combined with the presence of two low-Cu mineral occurrences hosted in schist, suggest that the tonalite is much less extensive than shown on maps.

A prominent Cu:Zn high at the West Grid Alteration Zone contrasts with a conspicuous absence of a Cu:Pb high at the same location. This reflects the lack of Pb analyses from these showings.

CONTOURED Cu:Zn

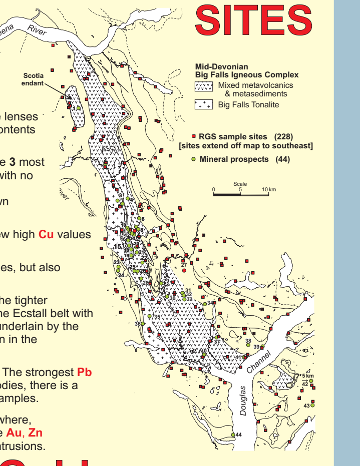


CONTOURED Cu:Pb



METAL ZONING — RGS SAMPLE SITES

RGS DATA (Jackaman, 2001)



All prospects in this belt crop out. Creeks are actively eroding massive sulphide lenses at the Ecstall & Packsack deposits. Silt samples from these creeks show high contents of Cu, Pb, Zn Ag & Au, as expected.

However, these are not the most metal-rich samples collected in the survey. The **3** most metal-rich stream sediment samples collected in the belt come from 3 streams with no known mineral occurrences anywhere within their drainage basins. **12** more polymetallic anomalies have been identified from 12 more streams with no known mineral occurrences.

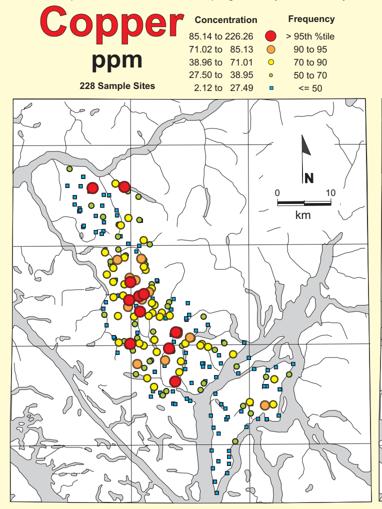
The strongest Cu values are clustered close to mid-Devonian tonalite bodies; few high Cu values are located away from these stocks.

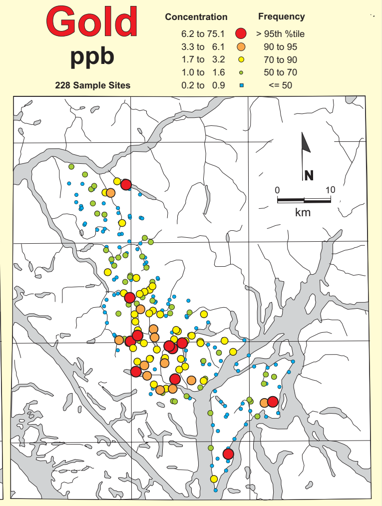
The highest stream sediment Au values overlap the area of the highest Cu values, but also extend further to the south.

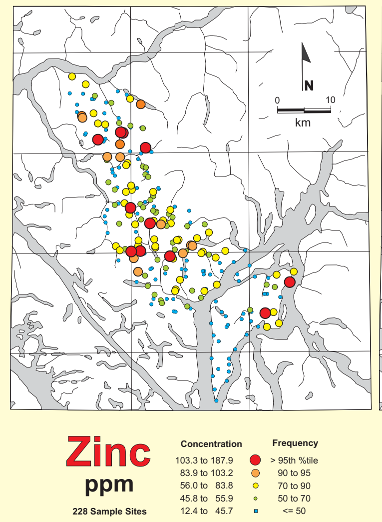
The strongest Zn anomalies are broadly dispersed along the belt compared to the tighter clustering of the Cu and Au values. There is also a small area in the center of the Ecstall belt with a noticeable absence of strong Zn values that coincides with an area primarily underlain by the tonalite stocks. Overall, the zoning pattern of Cu, Au & Zn resembles the pattern in the Tasmanian study.

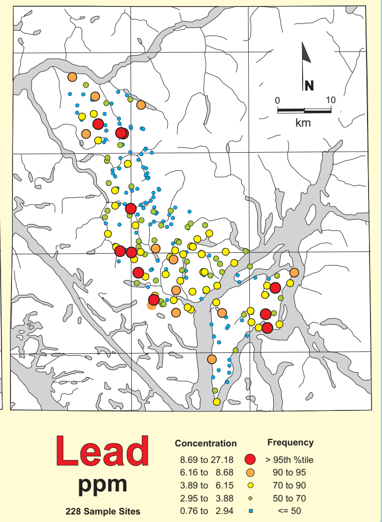
Stream sediment sample results for Pb also fit the pattern of lateral zoning well. The strongest Pb values are well dispersed along the whole of the belt. Proximal to the tonalite bodies, there is a conspicuous absence of the strong Pb concentrations in the stream sediment samples.

These results reveal that exploration potential throughout this belt is high everywhere, but Cu-rich deposits will be most abundant near the central tonalite bodies while Au, Zn & Pb-rich deposits will be concentrated progressively further away from these intrusions.









REFERENCES

Ecstall Belt

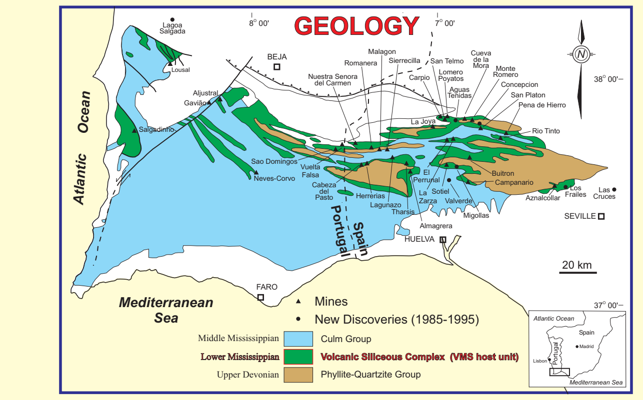
Alldrick DJ & Jackaman W (2002): Metal zoning in the Ecstall VMS Belt; BCMEM, GF 2001, Paper 2002-1, p151-170
Alldrick DJ (2001a): Geology & mineral deposits of the Ecstall greenstone belt; BCMEM, GF 2000, Paper 2001-1, p279-305
Alldrick DJ (2001b): Geology & mineral potential of the Ecstall VMS belt; BCYCM, Cordilleran Roundup, January, 2001, Abstracts, p3-4
Alldrick DJ Friedman RM & Childe FC (2001): Age & geologic history of the Ecstall belt; BCMEM, GF 2000, Paper 2001-1, p269-278
Alldrick DJ & Gallagher CS (2000): Geology & mineral potential of the Ecstall VMS belt; BCMEM, GF 1999, Paper 2000-1, p249-265
Friedman RM Gareau SA & Woodsworth GJ (2001): U-Pb dates from the Scotia-Quaal metamorphic belt; Radiogenic Age & Isotopic Studies 14, GSC, CR 2001-F9, 11p
Gareau SA (1991): The Scotia-Quaal metamorphic belt; CJES, v28, p870-880
Gareau SA (1997): Geology of the Scotia-Quaal metamorphic belt; GSC, Map 1868A, scale 1:100 000, 1 sheet
Jackaman W (2001): Stream sediment & water geochemistry of the Ecstall Greenstone Belt; BCMEM, OF 2001-13, 216p
Scott B (2001): Geology of the Amber-El Amino area; BCMEM, GF2000, Paper 2001-1, p307-312

VMS & General

Barrie CT et al (1999): Heat & fluid flow in VMS-forming hydrothermal systems; in Volcanic-associated massive sulphide deposits, SEG, Reviews in Economic Geology, v8, p201-219
Galley AG (1995): Target vectoring using lithogeochemistry: applications to exploration for VMS deposits; CIMM, v88, n990, p15-27
Galley AG (1996): Subvolcanic intrusions associated with massive sulphide districts; GAC Short Course 12, p239-278
Galley AG (2001): Characteristics of VMS deposits; Kamloops Exploration Conference, Short Course Notes, 56p
Hannington MD et al (1995): Processes of seafloor mineralisation at mid-ocean ridges; AGU Geophysical Monograph 91, p115-157
Large RR (1992): Australian VHMS deposits - features, styles & genetic models; Economic Geology, v87, p471-510
Large RR et al (1996): Evaluation of Cambrian granites in the genesis of VHMS deposits in Tasmania; OGR, v10, p215-230
Leistel JM et al (1998): VMS deposits of the Iberian Pyrite Belt; Mineralium Deposita, v33, n1-2, p2-30
Lydon, JL (1984): Volcanogenic massive sulphide deposits; in Genetic Models, Geoscience Canada, v15, p43-65
Marsh BD (2000): Magma Chambers; in Encyclopedia of Volcanoes, Academic Press, London, p191-206
Walker GPL (2000): Basaltic Volcanoes & Volcanic Systems; in Encyclopedia of Volcanoes, Academic Press, London, p283-289
White NC & Herrington RJ (2000): Mineral Deposits Associated with Volcanism; Encyclopedia of Volcanoes, Academic Press, p897-912

Iberian Pyrite Belt

This technique reveals underexplored areas and highlights metal-specific target areas.



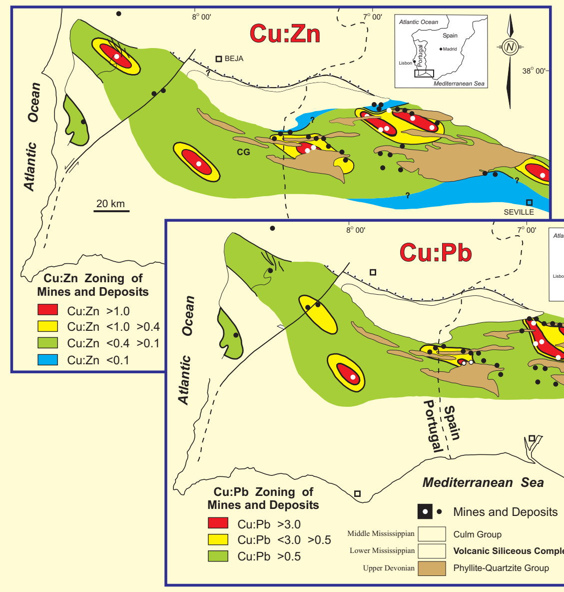
The Iberian Pyrite Belt hosts 140 VMS deposits in the Early Mississippian Volcanic-Siliceous Complex.

The IPB includes the Rio Tinto & Neves-Corvo mines, the 2nd & 3rd largest VMS deposits in the world, after Windy Craggy.

Favourable volcanic strata are covered by a thin veneer of unmineralized slates. Recent discoveries include deposits located by drilling through these cover rocks. So the Cu:Zn & Cu:Pb contours were drawn to project up through overlying strata.

Published Reserves & Cu:Zn & Cu:Pb ratios

Mine	Size (mT)	% Cu	% Pb	% Zn	g/t Ag	g/t Au	% Sn	Cu:Zn	Cu:Pb
Aguas Tenidas	41	1.3	0.9	3.1	37	0.5		0.42	1.44
Aljustrel	130	1.2	1.2	3.2	36	1		0.38	1.00
Almagrera	10	0.65	0.8	1.35	40	0.7		0.48	0.81
Aznalcollar	90	0.51	0.85	1.8	37	0.48		0.28	0.60
Cabeza del Pasto	0.6	1	3	1				1.00	0.33
Campanario	0.41	0.97	2	2.58				0.38	0.49
Carpio	3.35	0.5	0.12	2.77				0.18	4.17
Castillo Buitron	0.5	0.6	0.28	1.13				0.53	2.14
Concepcion	55.85	0.57	0.19	0.48	6.68	0.21		1.19	3.00
Cueva de la Mora	4.2	1.45	0.26	0.73				1.99	5.58
El Perrunal	7.55	0.5	0.1	0.2				2.50	5.00
Grupo Malagon	1	1.85	2	4				0.46	0.93
Herrerias	5	0.9	0.54	0.43				2.09	1.67
La Joya	1.19	0.5	0.65	0.2				2.50	0.77
La Romanera	34	0.42	1.18	2.3	44	0.8		0.18	0.36
La Zarza	100	0.7	0.6	1.5				0.47	1.17
Lagunazo	6	0.57	1.1	1.5	65	1.1		0.38	0.52
Las Cruces	42.7	2.95	1	2.14	5	0.2		1.38	2.95
Lomero Poyatos	1.71	0.5	4.5	7.5	120	4		0.07	0.11
Los Frailes	70	0.34	2.25	3.92	62			0.09	0.15
Lousal	50	0.7	0.8	1.4				0.50	0.88
Migollas	57.6	0.88	1.12	2.23				0.39	0.79
Monte Romero	0.8	2	2.5	5				0.40	0.80
Neves Corvo	80.81	3.12	0.74	4.11	37		0.22	0.76	4.22
Nuestra Senora del Carmen	0.04	1.3	10.3	29	153	1		0.04	0.13
Pena de Hierro	5	1.3	0.42	1.39				0.94	3.10
Rio Tinto	334.5	0.39	0.12	0.34	22	0.36		1.15	3.25
San Platon	1.13	1.16	0.53	12.3	69	2.05		0.09	2.19
San Telmo	4	1.2	0.4	12	60	0.8		0.10	3.00
Sao Domingos	27	1.25	1	2				0.63	1.25
Sierrecilla	1	1.5	5	12	500			0.13	0.30
Sotiel	75.2	0.56	1.34	3.16	24	0.21		0.18	0.42
Tharsis	110.06	0.5	0.6	2.7	22	0.7		0.19	0.83
Vuelta Falsa	1	1.27	8.8	20.7	307	9		0.06	0.14



Application of this contouring technique reveals a simple pattern for the assorted Cu-rich & Zn-rich deposits of the Iberian Pyrite Belt.

Seven Cu-rich centres are present around the Lousal, Aljustrel, Neves-Corvo, Cabeza del Pasto, La Zarza, Rio Tinto & Las Cruces massive sulphide deposits. Other large VMS deposits, such as Tharsis, Aznalcollar & Los Frailes, have relatively low Cu:Zn & Cu:Pb ratios. Contour distributions indicate favourable areas within this extensive belt to search for Cu-, Au-, Zn- or Pb-rich VMS deposits.

Each high Cu:Zn & Cu:Pb area represents a region where coeval plutonic rocks might be preserved & exposed.

The Rio Tinto mine & Las Cruces deposit are 55 km apart.

They may represent deposits formed near two separate thermal or magmatic centres - shown as separate Cu:Zn and Cu:Pb highs on the maps.

However, they may lie within one elongate Cu:Zn and Cu:Pb contour high - shown here as a heavy black outline - and now dissected where erosion has removed favourable stratigraphy and exposed unmineralised footwall strata.

In the latter scenario, volcanic strata immediately east-southeast of the Rio Tinto mine (arrow) are particularly favourable for undiscovered Cu-rich & Au-rich deposits.