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Metal Zoning in the Ecstall VMS Belt, Northwest British Columbia (NTS 103H/103I)

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KEYWORDS: *Economic geology, mineral potential, geologic mapping, Central Gneiss Complex, Coast Plutonic Complex, Coast Crystalline Belt, Ecstall Metamorphic Belt, metavolcanic, greenstone, Devonian, VMS, sulphide, metal zoning, Ecstall, Scotia, Packsack, Prince Rupert, Tasmania, Iberian Pyrite Belt.*

INTRODUCTION

More than a century of prospecting within the Ecstall Greenstone Belt has located 40 sulphide mineral occurrences, including 3 deposits with combined reserves of 10 million tonnes grading 0.5% Cu and 2.1% Zn. The high mineral potential has justified a detailed mapping project, related mineral deposit studies, and a special regional geochemical survey. The third field season of this project focused on mapping and prospect visits in the southern portion of this belt.

The Ecstall belt is 80 kilometres long, 3 to 20 kilometres wide, and extends from the Douglas Channel fiord north northwesterly to the Skeena River (Figure 1). The belt lies midway between the northern port cities of Prince Rupert and Kitimat, and is close to tidewater, the Yellowhead Highway, the Skeena Railway line of VIA Rail and the national power grid (Table 1). Extensive logging road networks are established at the northern and southern ends of the belt (at the mouth of the Scotia River and at Kitkiata Inlet, respectively). Other favourable features of the Ecstall Greenstone Belt are listed in Figure 2.

TABLE 1
KEY DISTANCES FOR DEPOSITS IN THE ECSTALL BELT

Deposit:	Scotia	Ecstall	Packsack
Elevation	758 m	182 m	242 m
Distance to:			
Ocean	27	24	18
Estuary / Tidewater	15	6	15
Hydro Powerline	10	19	29
Highway	15	39	49
Railway	15	39	49
Prince Rupert	49	72	82
Kitimat	67	60	59
Terrace	84	93	98

Elevation ranges from sea level to 1760 metres. Steep-walled, glaciated valleys flank rounded ridgecrests. Despite the precipitous terrain, it is possible to traverse the belt from north to south without exceeding 125 metres elevation by following a route of interconnecting valleys. Rainfall is heavy; average annual precipitation at Prince Rupert is 244 centimetres (96 inches). The low elevation of

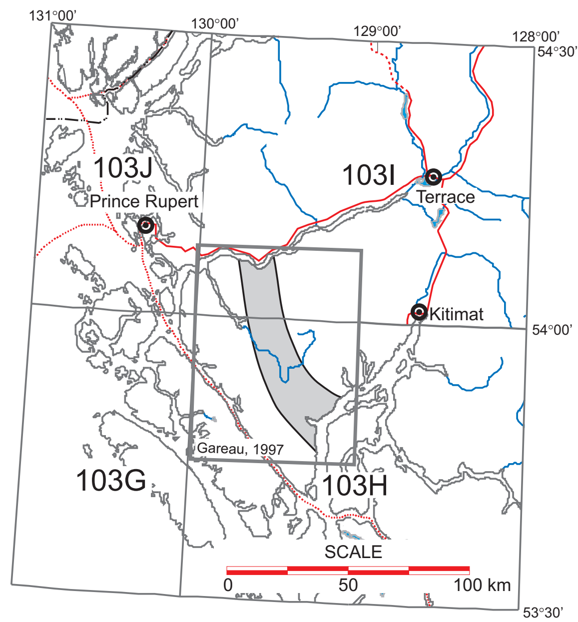

Figure 1. Location of the Ecstall belt in British Columbia.

- Admirable location and infrastructure
- Mid-Devonian metavolcanic belt
- Polymetallic Kuroko-type Zn-Cu VMS
- 3 deposits, all still open
- Coarse-grained sulphides
- Simple mineralogy and metallurgy
- Low levels of deleterious elements
- 40 other sulphide prospects and showings
- Several recent discoveries
- Multiple prospective felsic volcanic horizons
- Detectable by prospecting, geophysics and stream geochemistry
- High exploration / mineral potential
- Underexplored

Figure 2. Favourable features of the Ecstall belt.

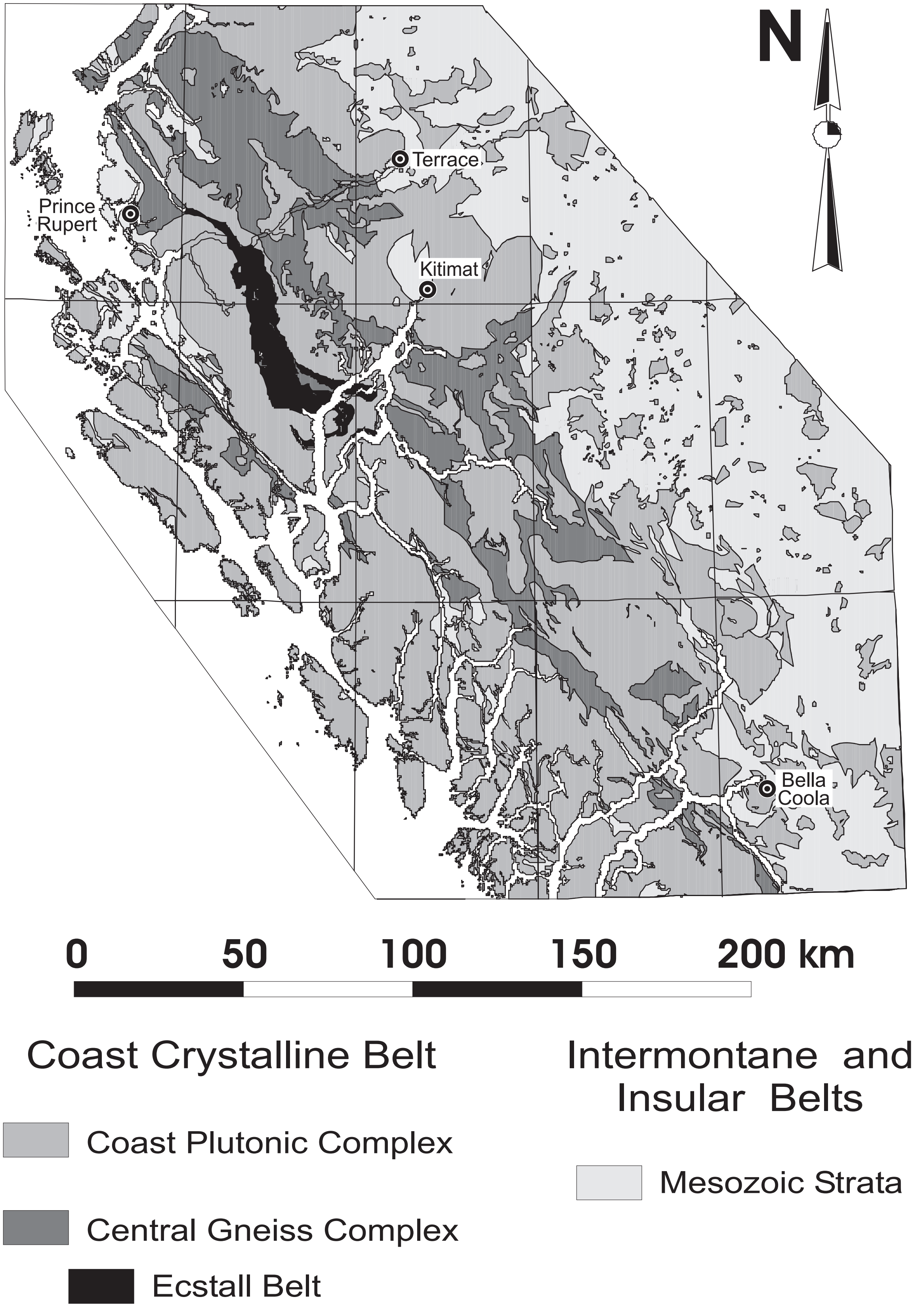

Figure 3. Geology of the mid-coast region of British Columbia, highlighting the location of the Ecstall metavolcanic belt within the Central Gneiss Complex and the Coast Plutonic Complex.

the valley bottoms and their proximity to the coast leaves them free of snow through most of the year. Dense coastal rainforest covers all but the steepest slopes, where bedrock is exposed in cliffs or along avalanche tracks. Terrain above 1100 metres elevation is free of trees and shrubs.

REGIONAL GEOLOGIC SETTING

The Ecstall Greenstone Belt is part of the Central Gneiss Complex, a 2000 kilometre long, anastomosing network of medium to high-grade metamorphosed volcanic, sedimentary and minor plutonic rocks enclosed by younger granitoid rocks of the Coast Plutonic Complex (Figure 3). These two complexes comprise the Coast Crystalline Belt or Coast Belt. The Coast Belt hosts the greatest number of volcanogenic massive sulphide deposits (18) of any of the five physiographic belts in the Cordillera. The following summary is adapted from Greenwood *et al.* (1992), Woodsworth *et al.* (1992), Read *et al.* (1991), Gareau (1991a,b) and Gareau and Woodsworth (2000).

Plutonic rocks of the Coast Plutonic Complex (CPC) make up more than 80% of the Coast Belt; the remainder is metavolcanic rocks, metasedimentary rocks and granitoid gneisses of the Central Gneiss Complex. Plutonic rocks of the CPC range in age from Late Silurian to Eocene. In general, the oldest plutons are exposed along the western edge of the CPC and the plutons young progressively to the east. Rocks range in composition from granite to gabbro, but 70% of all plutonic rocks are tonalite-quartz diorite-diorite. Among the circum-Pacific plutonic terranes, the Coast Plutonic Complex is the largest, the most mafic, and the most deficient in potassium feldspar.

The metamorphic rocks of the Central Gneiss Complex range in age from Proterozoic through Paleozoic and typically occur as screens or pendants surrounded or intruded by the plutonic rocks of the CPC (Figure 3). Evidence of Paleozoic regional metamorphism is preserved locally, but intense mid-Mesozoic and early Tertiary metamorphism, deformation and plutonism have obscured the record of earlier events in many places. Most recrystallization can be attributed to regional metamorphic events, but pluton emplacement can also generate a local contact metamorphic overprint.

The most extensively studied area of the Coast Crystalline Belt lies along the road and rail corridor between Prince Rupert and Terrace (Greenwood *et al.*, 1992; Stowell and McClelland, 2000). This is also the most deeply exhumed part of the Central Gneiss Complex; metamorphic grades range up to kyanite-amphibolite, sillimanite-amphibolite and granulite facies in different parts of this area (Read *et al.*, 1991). Within the Ecstall belt, Gareau (1991a,b) has documented a southwest to northeast progression from lower amphibolite facies to granulite facies, with most rocks falling within the kyanite-amphibolite (upper amphibolite) facies.

The mid-Devonian volcanic arc that evolved into the Ecstall Greenstone Belt (Figure 4) likely developed in a similar setting as the extensive volcanosedimentary successions of the Yukon-Tanana terrane (Gareau and Woodsworth, 2000). The regional geologic history of the Ecstall belt is outlined in Alldrick *et al.* (2001) and summarized in Figure 5; Devonian volcanism, sedimentation and intrusion were followed by four poorly-constrained phases of deformation and four well-dated plutonic episodes. The Jurassic to Eocene plutonic and metamorphic history of the Coast Crystalline Belt is consistent with a model of east-dipping subduction beneath a single, allochthonous Alexander-Wrangellia-Stikinia superterrane, emplaced against North America in Middle Jurassic time (van der Heyden, 1989).

GEOLOGY OF THE ECSTALL BELT

The Ecstall belt is a north-northwest trending, high-grade metamorphic belt bounded by the elongate mid-Cretaceous Ecstall pluton on the west and the Paleocene Quottoon pluton on the east (Figure 4). Gareau (1991a) divided stratified rocks of the belt into four principal units: metavolcanic rocks, metasedimentary rocks, quartzite and layered gneiss (Figure 4). Two new U-Pb zircon ages (Friedman *et al.*, 2001) confirm the stratigraphic succession established for these highly deformed strata (Gareau, 1991a,b and Alldrick *et al*., 2001) and improve the age constraints on the regional stratigraphy (Figure 5).

The mid-Devonian metavolcanic unit consists of mafic and intermediate metavolcanic rocks, interlayered with lesser felsic metavolcanic and clastic metasedimentary rocks and rare limestone and chert. Textures within this metavolcanic unit range from layered gneisses in the north, to pillow lavas and graded beds in the south of the belt. These latter units are too deformed to give reliable tops indicators. 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.

These mid-Devonian metavolcanic rocks are intruded by three large, elongate, mid-Devonian plutons called the Big Falls tonalite. These coeval, subvolcanic intrusions may be the exposed parts of a single large stock. The mid-Devonian intrusive and extrusive rocks are grouped together as the Big Falls Igneous Complex (Alldrick *et al.,* 2001). In many other greenstone belts, subvolcanic plutons provide camp-scale controls for localization of massive sulphide deposits (Campbell *et al.*, 1981, Galley, 1996 and 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.

The metavolcanic unit and its coeval subvolcanic stocks are overlain by a regionally extensive package of late Devonian clastic metasedimentary rocks, consisting of a lower metapelitic unit and an upper quartzite unit. The quartzite unit hosts 3 sulphide prospects (Amber, El Amino and Cheens Creek) in areas where minor limestone units are interbedded with the clastic metasedimentary rocks. Two

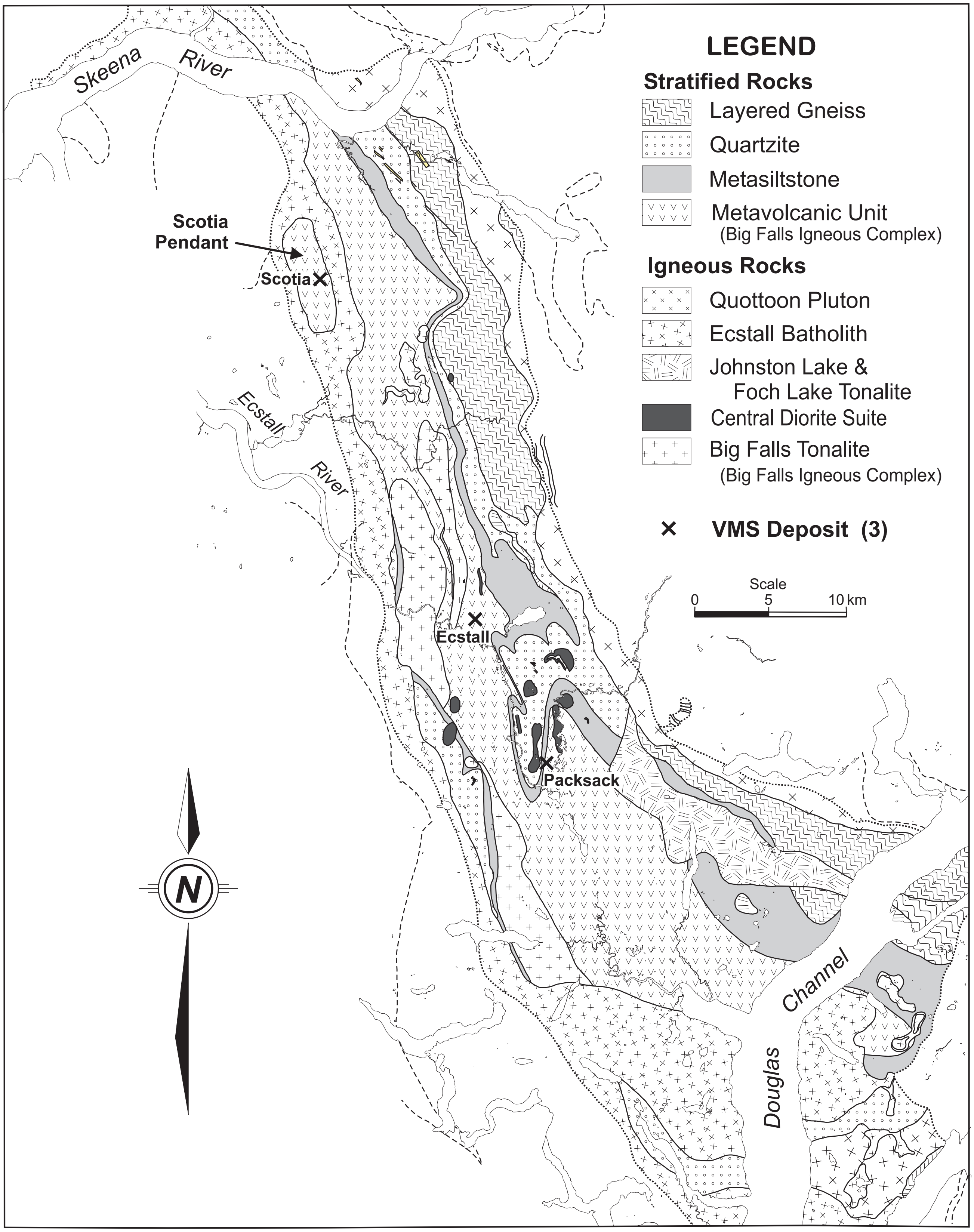

Figure 4. Simplified geology of the Ecstall belt (modified from Gareau, 1997).

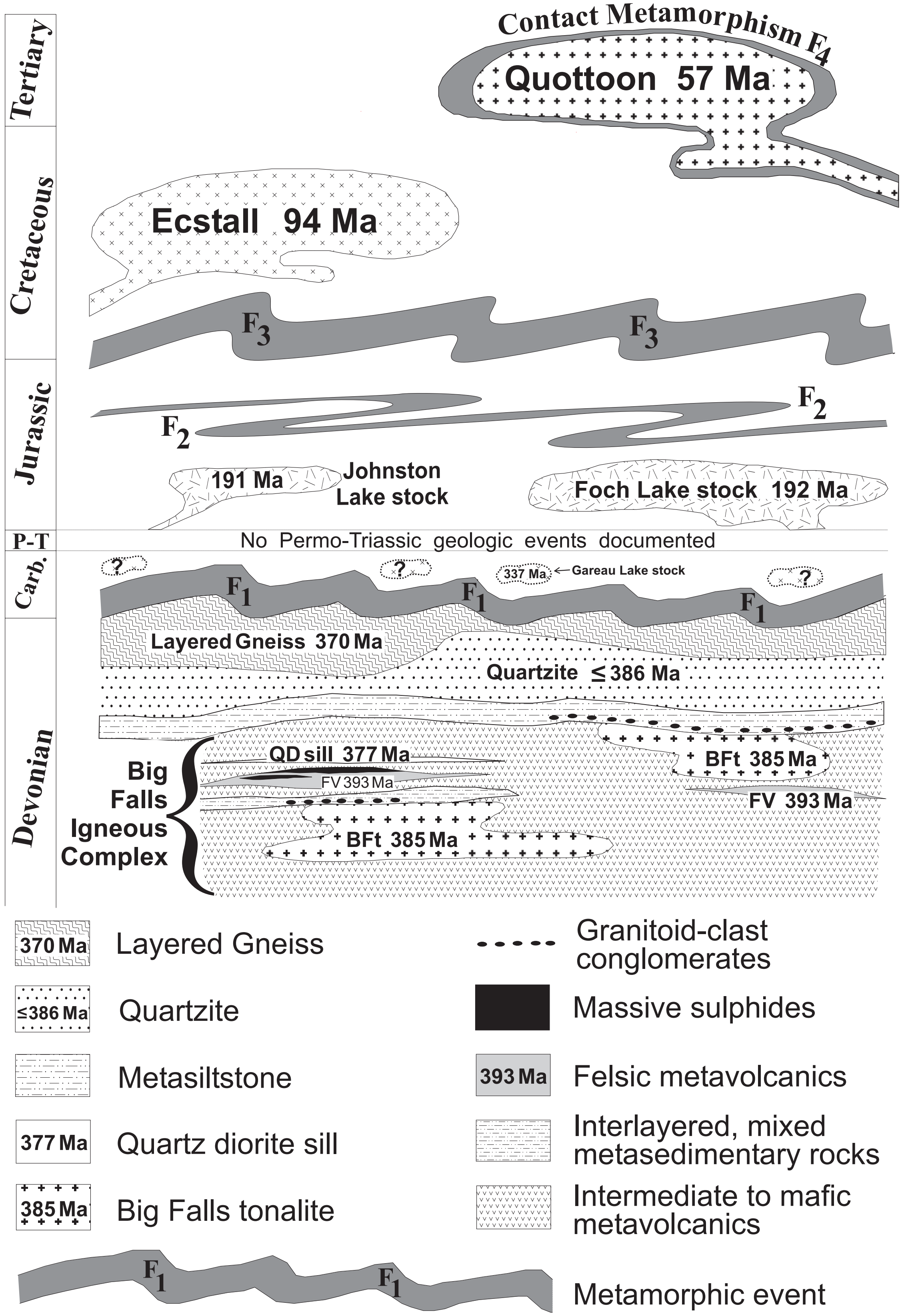

Figure 5. Schematic stratigraphy and geologic history of the Ecstall belt.

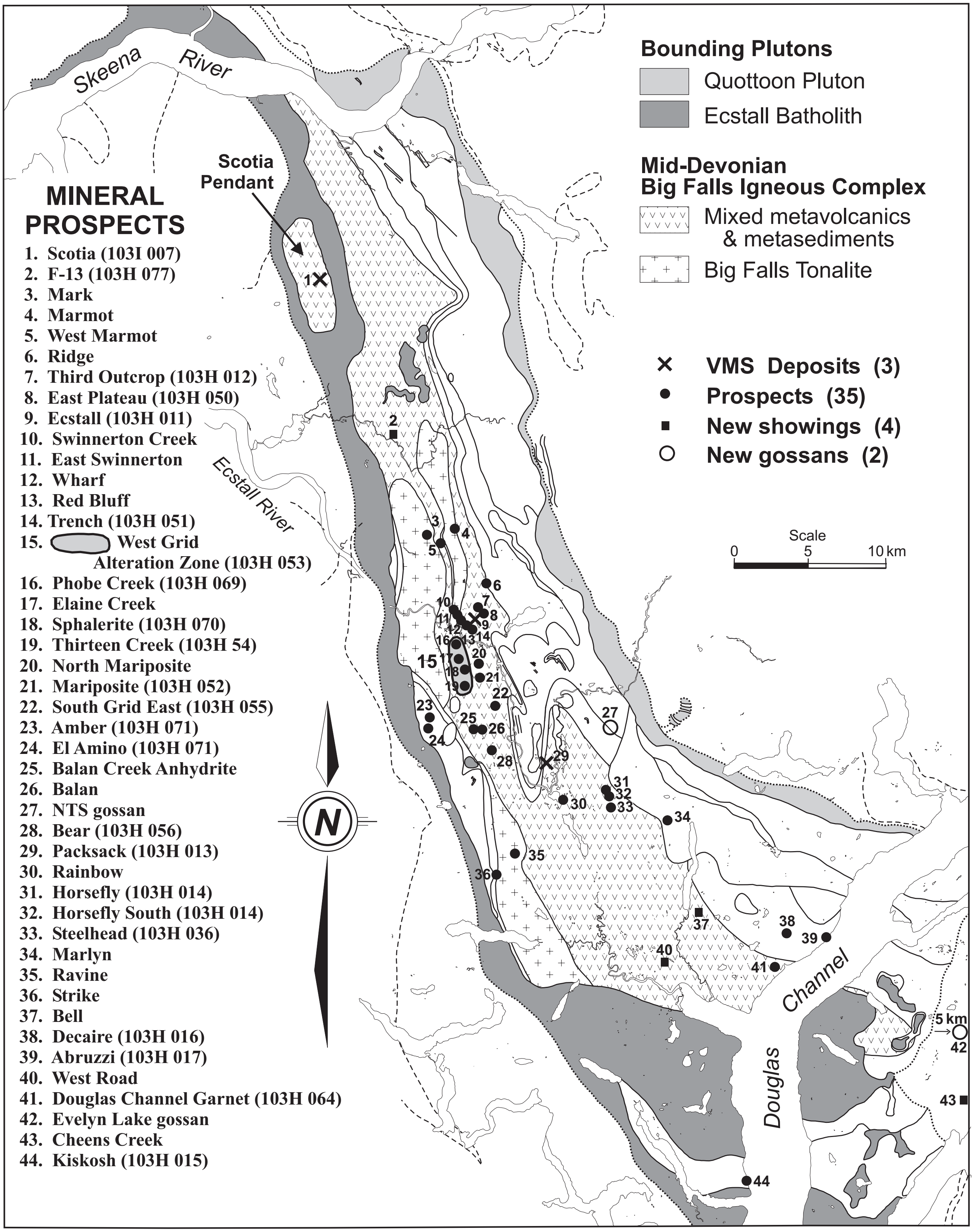

Figure 6. Mineral occurrences of the Ecstall belt.

large gossan areas were also discovered in these units during this season's mapping. Samples show only disseminated to semi-massive pyrite in well foliated quartzite; assay results are forthcoming.

These metasedimentary strata are overlain in turn along the eastern margin of the Ecstall belt by mafic gneiss. The protolith for this black and white banded gneiss is interpreted as a mafic volcanic package of Late Devonian age (Friedman *et al*., 2001).

At least four plutonic events post-date the middle to upper Devonian stratigraphic succession (Figures 4 and 5). An extensive suite of small, weakly deformed diorite stocks are scattered throughout the central Ecstall belt. One stock yielded an Early Mississippian age, which may indicate the age for all these plugs. In addition to Paleozoic intrusions, two elongate Early Jurassic plutons, the Johnston Lake and Foch Lake tonalites, intrude the eastern part of the belt. The two bounding plutons, the mid-Cretaceous Ecstall on the west and the Paleocene Quottoon on the east, have associated dikes, sills and small stocks that cut Ecstall belt rocks.

MINERAL DEPOSITS AND EXPLORATION

The Ecstall belt hosts 40 sulphide and 2 industrial mineral occurrences (Figure 6 and Table 2). These deposits and showings are described in Alldrick (2001a), Scott (2001) and this paper.

In 1890, the specte Ecstall belt (*see* Table 2).acularly exposed sulphide lenses of the Ecstall volcanogenic massive sulphide deposit were discovered in Red Gulch Creek. A series of companies have investigated and developed this deposit over the last 100 years. Prospecting work during the 1930s and 1940s located 12 additional sulphide showings within 8 kilometres of the Ecstall deposit. Regional mapping and exploration programs conducted by Texas Gulf Sulphur Company Limited in 1957 and 1958 discovered the Packsack (1957) and Scotia deposits (1958). Exploration work carried out by many companies and by independent prospectors over the last 30 years, resulted in the discovery of 25 more sulphide occurrences.

Figure 6 shows the location of the 3 deposits and 39 smaller showings in the belt, including four new discoveries. Most of the mineral prospects in the belt are hosted by the mid-Devonian metavolcanic package. These metavolcanic rocks offer the greatest exploration potential for the discovery of more deposits.

NEW CLAIMS

The southern part of the Ecstall belt has seen limited exploration interest and activity over the past century, but a

TABLE 2
RESERVES, RESOURCES, GRADES AND CU:ZN AND CU:PB RATIOS FOR DEPOSITS AND PROSPECTS IN THE ECSTALL GREENSTONE BELT

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

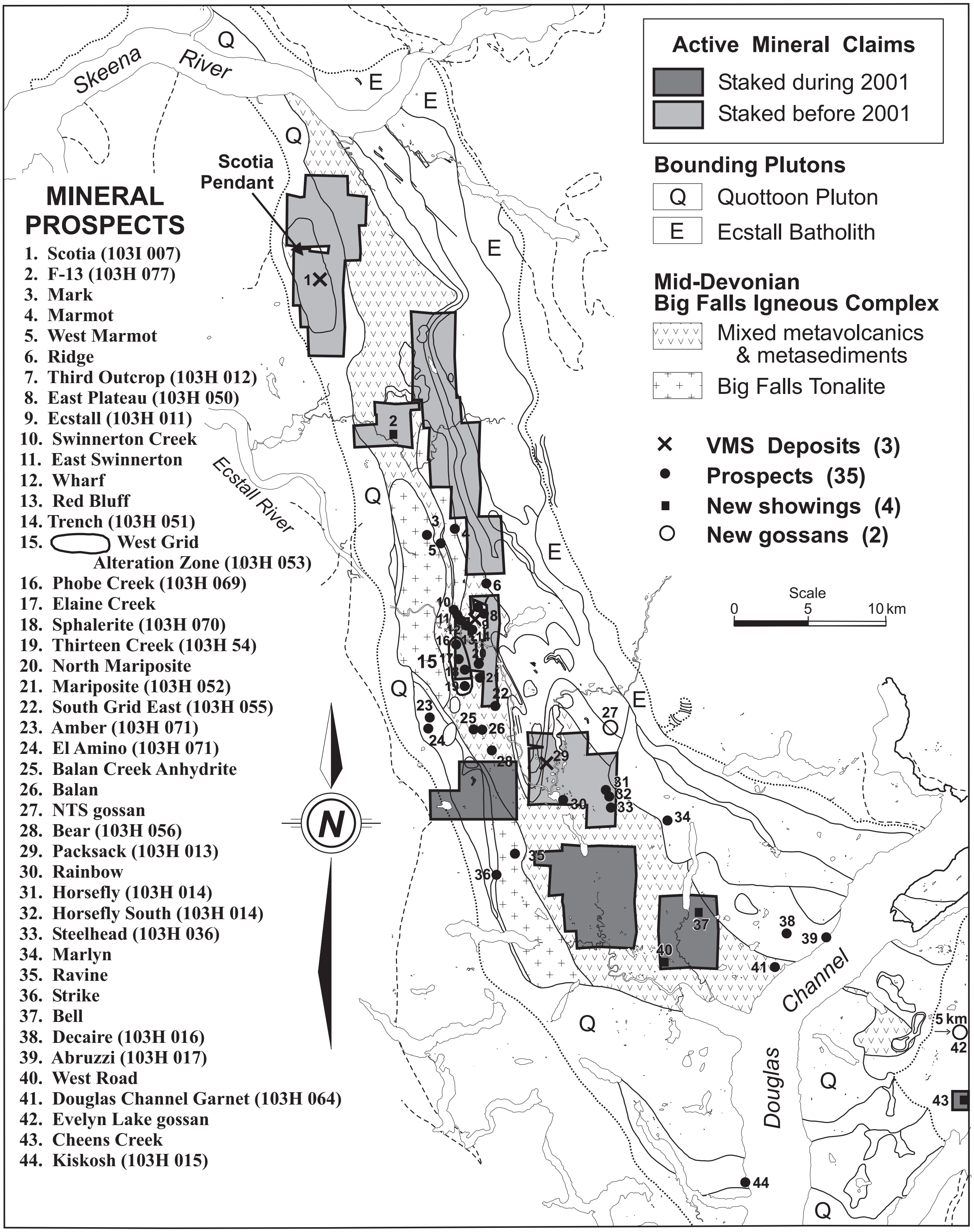

Figure 7. Mineral claims in the Ecstall belt - October, 2001.

number of new claims were staked in this area during 2001 (Figure 7). Staking was carried out just before the publication of Regional Stream Sediment Survey results (Jackaman, 2001) on June 1 to cover areas with known exploration potential. After June 1, claim blocks were staked over areas of multi-element stream sediment survey geochemical anomalies and over three newly discovered mineral showings.

NEW SHOWINGS

Prospectors Ralph Keefe and Shawn Turford have discovered three new polymetallic sulphide showings over the past three summers (Figure 6). These prospects all lie in the southern part of the Ecstall belt and all are exposed in rock cuts along logging roads. Two prospects are hosted by pyritic quartz-sericite schist within the main metavolcanic unit; the other showing is hosted by quartz-biotite schist with minor associated calc-silicate bands within the thick metasedimentary sequence.

The **Bell** prospect is exposed in a rock cut along an upper level logging road southeast of Kitkiata Lake. This zinc-lead-copper prospect is hosted by a 10 metre thick pyritic quartz-sericite schist that strikes 163°. The showing consists of several parallel seams, up to 3 centimetres thick, of medium-grained black sphalerite, with accessory galena and rare chalcopyrite, hosted in well-sheared, weakly to strongly pyritic (5-10 %) quartz-sericite schist. Base-metal-sulphide rich zones are silicified and more resistant, while intervening, less altered, quartz-sericite schist is well-weathered and readily crumbles away. The best assay from five grab samples is 6.24% Zn, 2.07% Pb, 0.163% Cu, 103.6 ppm Ag and 0.78 ppm Au and the average assay from the five samples is 2.63% Zn, 1.58% Pb, 0.106% Cu, 71.4 ppm Ag and 0.53 ppm Au.

This rock unit is exposed again several hundred metres to the northwest on an adjacent logging road. No base metal sulphides are visible in the pyritic quartz-sericite schist at this location and base metal assays are in the ppm range.

The **West Road** showing is a small (7 metres wide) rusty cliff face of pyritic quartz sericite schist exposed alongside a logging road located midway between Kitkiata Lake and the Quaal River valley. One seam of fine-grained black sphalerite, 2 centimetres thick, was exposed during sampling. The pyritic unit crops out for 80 metres subparallel to the road and then extends into the logged off area.

The **Cheens Creek** prospect is exposed in and around a bedrock borrow pit at the end of a new logging road on the south side of Hawkesbury Island, 3.5 kilometres west of Danube Bay (Photo 1). The showing is hosted in thinly laminated biotite-quartz schist with minor associated calc-silicate layers, within the main quartzite unit (Figures 4 and 5). No volcanic rocks have been noted in the area. These strongly foliated metasedimentary strata strike 055°. Mineralization in place consists of abundant disseminated pyrite exposed in the wall of the pit over a thickness of 3 to 4 metres (Photo 2). Large float boulders dispersed along the roadbed include massive sphalerite-magnetite-pyrite rock with minor galena and trace chalcopyrite. Several styles and textures of disseminated to semi-massive to massive sulphides are displayed in the float samples; some incorporate calc-silicate bands consisting of pale green diopside, rusty-red garnet and quartz. Chalcopyrite is more abundant in pyritic samples that have little or no sphalerite, galena and magnetite. One chalcopyrite-rich sample assayed 0.04% Zn, 0.02% Pb, 1.068% Cu, 14.7 ppm Ag, with gold values below detection limit. Assays from sphalerite-galena-rich samples range up to 14.27% Zn, 8.43% Pb, 0.068% Cu, 373.0 ppm Ag and 1.89 ppm Au. The average assay from five grab samples is 6.86% Zn, 2.15% Pb, 1.77% Cu, 99.8 ppm Ag and 0.6 g/t ppm Au. The metasedimentary host rocks, the variable sulphide textures and grades, the presence of magnetite and calc-silicate mineral assemblages and the proximity to stocks and dikes of the mid-Cretaceous Ecstall pluton to the west, all suggest that the mineralization is magmatic-hydrothermal in style. Close analogues in the Ecstall area are the Amber and El Amino prospects (Scott, 2001) which are also hosted by metasedimentary rocks. These three showings may be examples of polymetallic

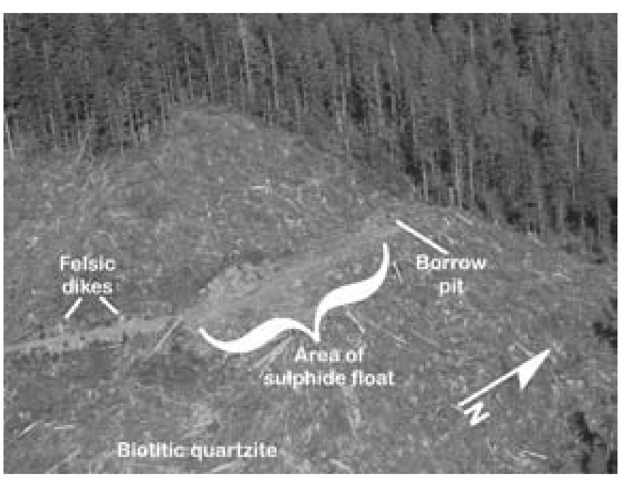

Photo 1. Aerial view of the Cheens Creek sulphide prospect, Hawkesbury Island .

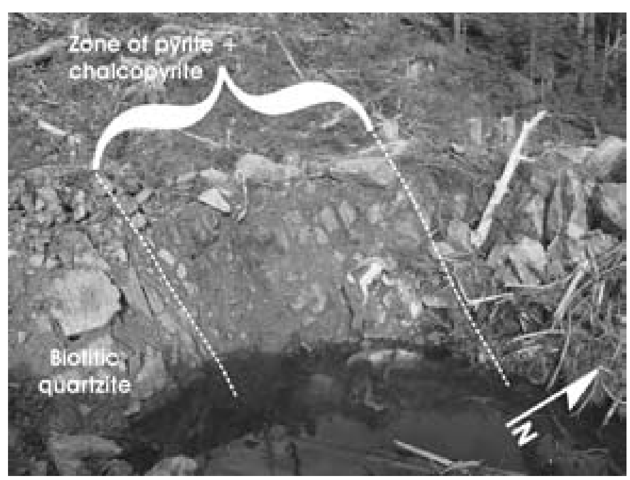

Photo 2. Paul Wojdak in the borrow pit, Cheens Creek prospect.

skarn mineralization developed proximal to the Ecstall batholith.

DISTRIBUTION OF MINERAL PROSPECTS

Sulphide prospects cluster in the central area of the Ecstall belt (Figure 6). Two explanations for this concentration of mineral showings are:

- Favourable geology: Current VMS genetic models emphasize the concentration of massive sulphide deposits on the seafloor in areas directly overlying shallow subvolcanic magma chambers that feed overlying lavas along conduits (Figure 8). Most mineral prospects in the Ecstall belt are concentrated close to the subvolcanic tonalite plugs, so the distribution of prospects at Ecstall fits the genetic model well. Since the model predicts that this type of mineral deposit is preferentially localised in lavas near to, and directly overlying, these buried granitoid bodies, the tonalite stocks become critically important prospecting guides.
- Degree of Exploration: Human factors may be the main influence for the present distribution pattern of mineral prospects in the Ecstall belt. For 20 years (1938-1958) most prospecting teams working in the belt set out on foot, or by boat, from the large mine development camp at the Ecstall deposit. One predictable result of this logistical arrangement is that more showings would be discovered in the immediate area of this base camp and the number of discoveries would drop off further out from the camp.

These two possible explanations raise the question whether the geological factors or the human factors are the dominant control for the obvious clustering of known deposits. The answer is important because, in the former case, future prospecting should concentrate around the tonalite stocks, while in the latter case, the mineral potential at the northern and southern ends of the belt deserve increased attention because they are relatively untested.

Metal Zoning in the Mount Read Volcanic Belt

Metal zoning in VMS deposits spatially related to a large, comagmatic subvolcanic pluton has been documented in the Mount Read volcanic belt of western Tasmania (Large *et al*., 1996). Prospects in this belt demonstrate clear, proximal-to-distal zoning from copper to gold to zinc, both up-section and laterally, away from the regional-scale pluton (Figure 9). Only two small stocks crop out, but the full extent of this buried batholith has been revealed by a recent aeromagnetic survey. These maps clearly illustrate that volcanogenic massive sulphide deposits are distributed throughout the Mount Read volcanics, and are not just concentrated near the coeval pluton.

Metal zoning in the Ecstall Greenstone Belt

The full extent of the exploration potential of the Ecstall belt is revealed in results of a geochemical stream sediment survey (Jackaman, 2001). During the 2000 field season, 228 samples were collected (Figure 10) at double the density of regular mapsheet-scale programs, since this is a well-mineralized district.

All prospects in this belt crop out, and creeks are actively eroding massive sulphide lenses at the Ecstall and Packsack deposits (Photos 3, 4 and 5). Before erosion, the Ecstall deposit is estimated to have been nearly twice its present size (Alldrick, 2001b); therefore, roughly six million tonnes of massive sulphides have been washed downstream. Silt samples from these creeks show high contents of copper, lead, zinc, silver and gold, as expected. However, these are not the most metal-rich samples collected in the survey. The three most metal-rich stream sediment samples collected in the belt come from three streams with no known

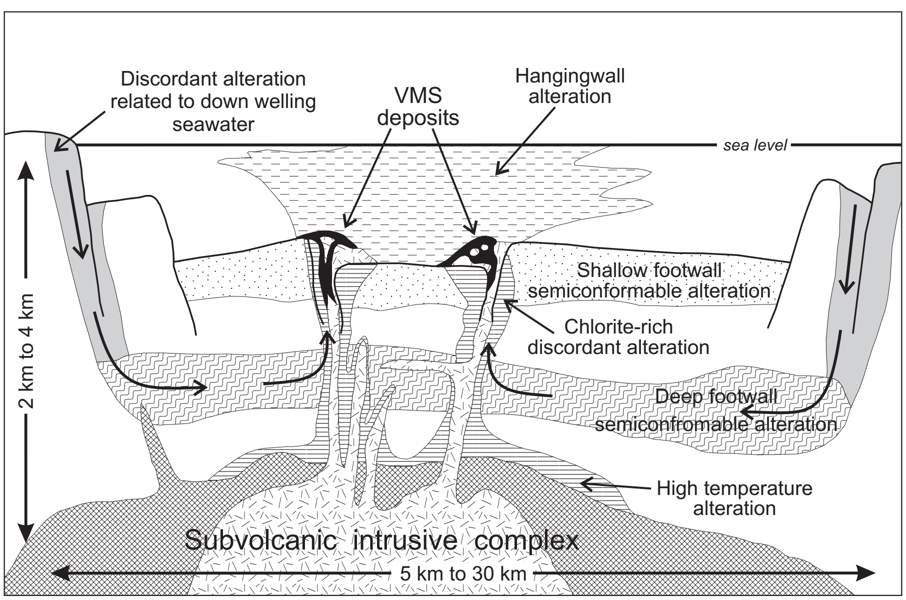

Figure 8. Generalized relationships between VMS deposits, alteration zones and an underlying subvolcanic intrusive complex (from Galley, 1995).

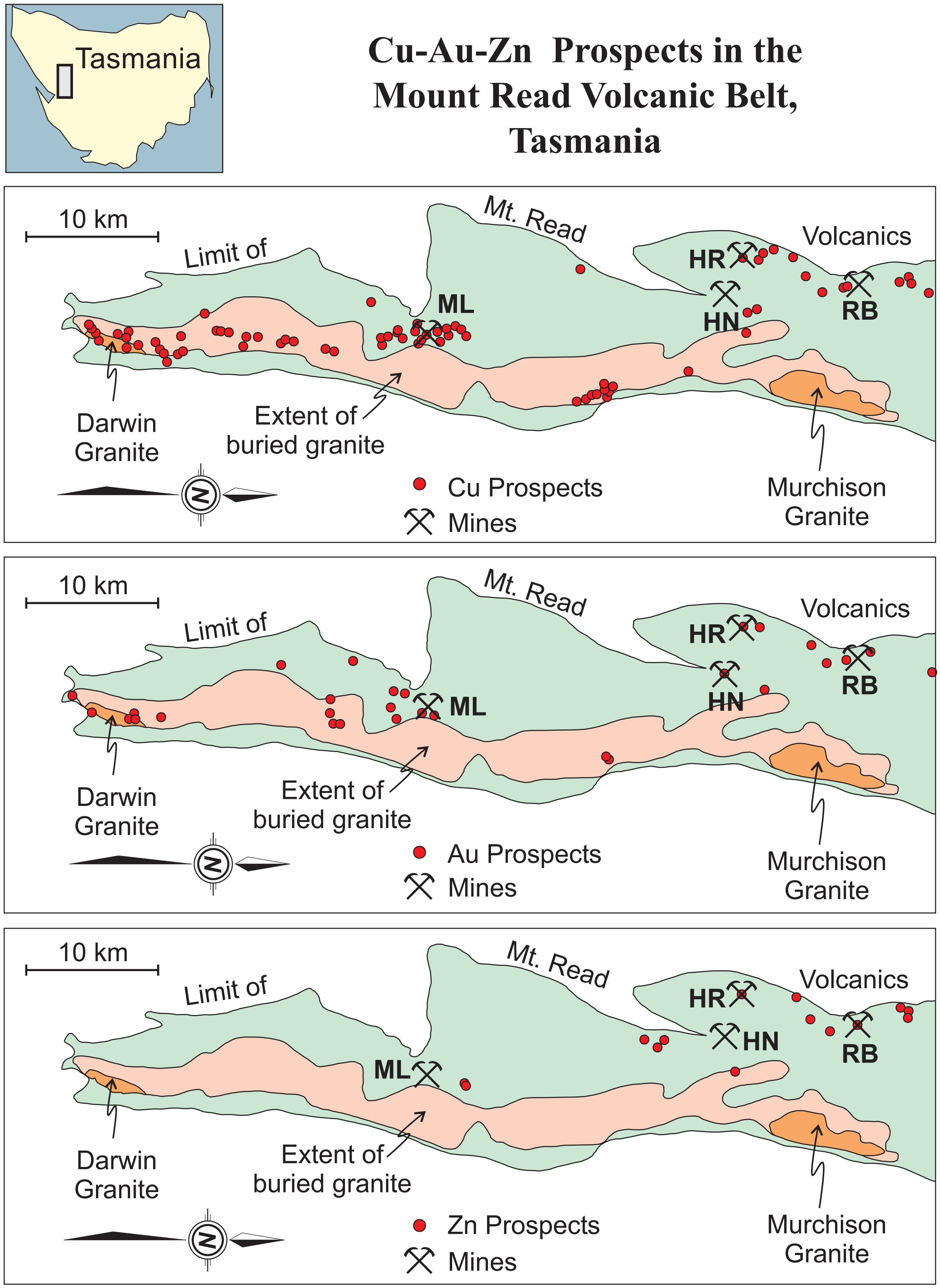

Figure 9. Metal zoning among mineral prospects of the Mount Read Volcanic Belt, western Tasmania (from Large *et al*., 1996). ML-Mount Lyell, HR-Hercules, HN-Henty, RB-Rosebery. Que River and Hellyer mines are off the map edge to the north.

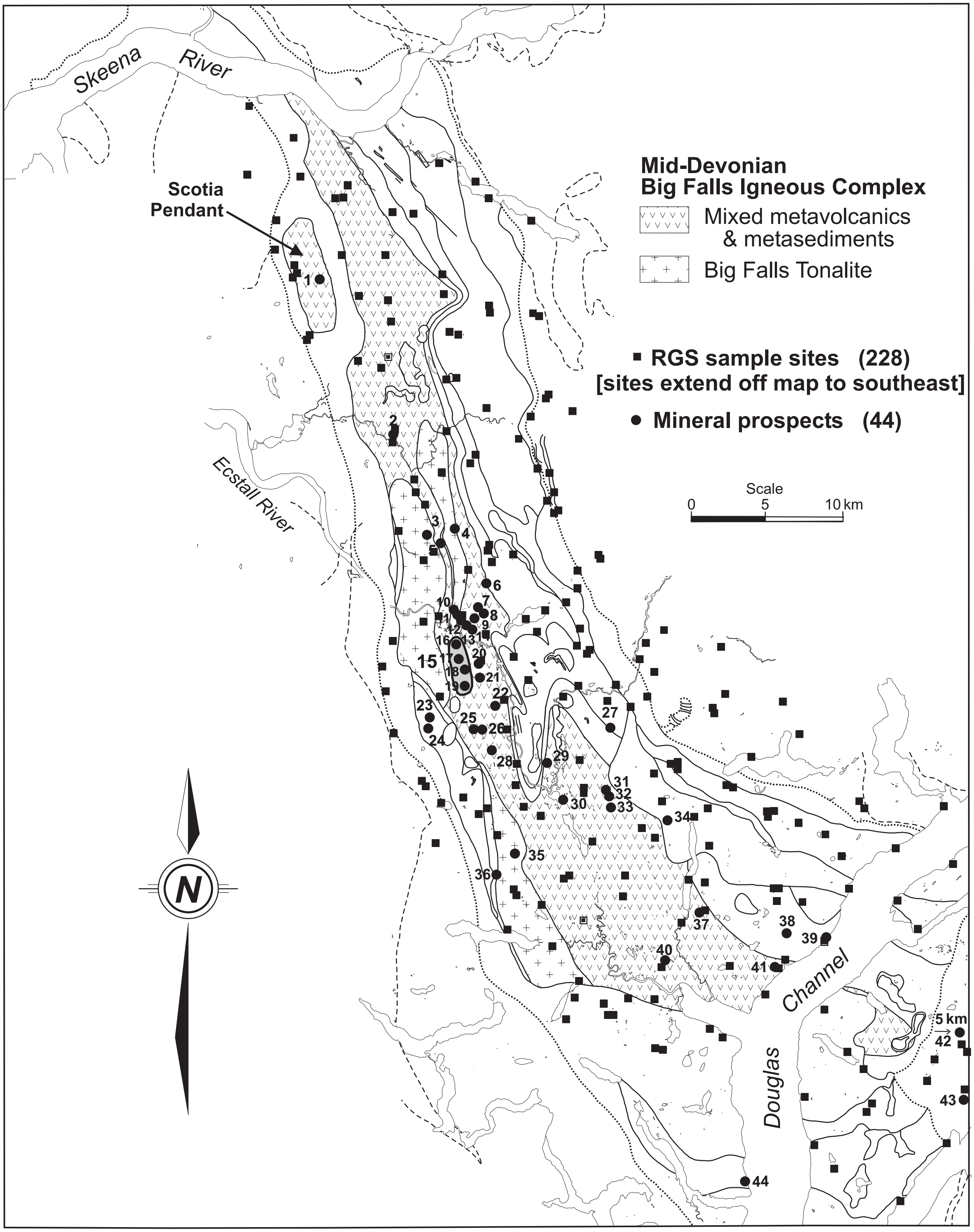

Figure 10. Regional Geochemical Survey sample sites in the Ecstall belt (from Jackaman, 2001).

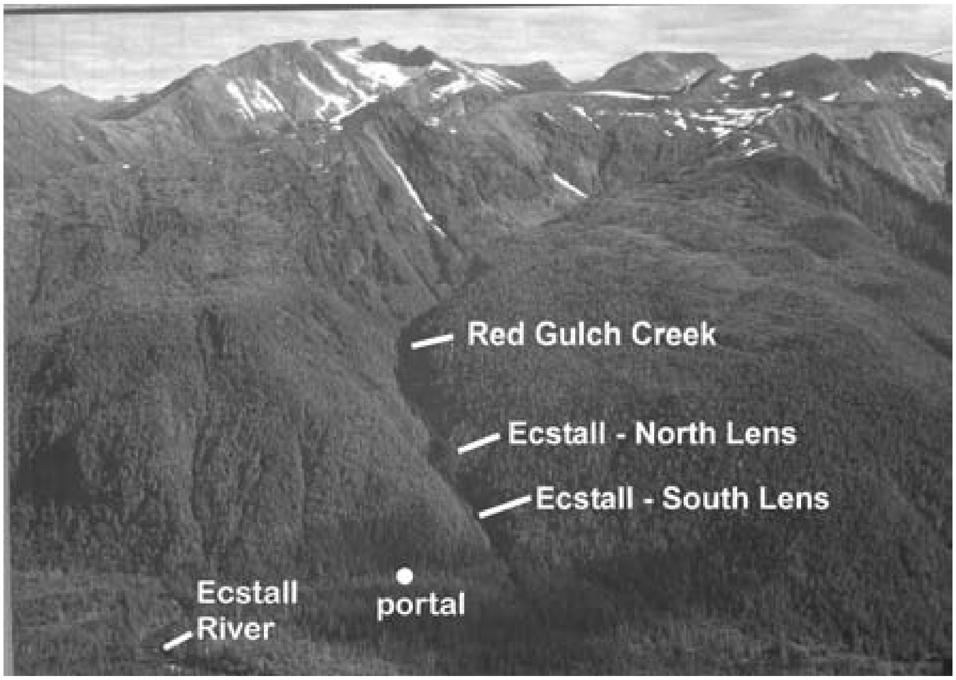

Photo 3. The Ecstall massive sulphide deposit crops out along the floor and canyon walls of Red Gulch Creek for 600 metres. View looking north-northeast.

Photo 4. Part of the continuous exposure of massive sulphides, 25 metres wide and 90 metres long, at the northern end of the Ecstall VMS deposit .

Photo 5. Packsack massive sulphide deposit. Shawn Turford and Paul Wojdak inspect the 5 metre thick lens of massive sulphides at the upper waterfall in Packsack Creek - one of four sulphide lenses exposed along this streambed.

mineral occurrences anywhere within their drainage basins (*see* Table 5 in Jackaman, 2001). And 12 more polymetallic anomalies have been identified from 12 more streams with no known mineral occurrences.

Stream sediment geochemistry results for copper, gold, zinc and lead are shown on the four maps in Figure 11. The strongest copper values are clustered close to the mid-Devonian tonalite bodies (Figure 11a); only a few high copper values are located well away from these intrusions. The highest stream sediment gold values (Figure 11b) overlap with the area of the highest copper values, but also extend further to the south from the high copper values. Thus, the strongest gold values are concentrated a little further outboard from the tonalite bodies than the high copper values.

The strongest zinc anomalies are broadly dispersed along the belt (Figure 11c) compared to the tighter clustering of the copper and gold values. There is also a small area in the center of the Ecstall belt with a noticeable absence of strong zinc values that coincides with an area primarily underlain by the tonalite stocks. The zinc-rich Scotia deposit lies within the northern area of high zinc values. Overall, the zoning pattern of copper, gold and zinc resembles the pattern discovered in the Tasmanian study (Figure 9).

Stream sediment sample results for lead are included in this study of regional metal zoning because they also fit the pattern of lateral zoning well (Figure 11d). The strongest lead values are well dispersed along the whole of the belt. Proximal to the tonalite bodies, there is a conspicuous absence of the strong lead concentrations in the stream sediment samples.

These results from the new stream sediment survey, and the patterns revealed in the Tasmania study, indicate that the

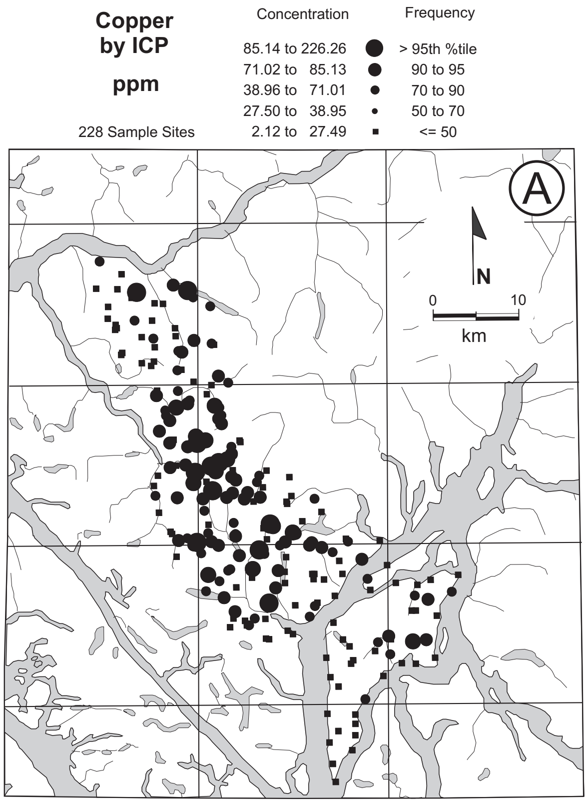

Figure 11a. Copper concentrations in stream sediment samples from the Ecstall belt.

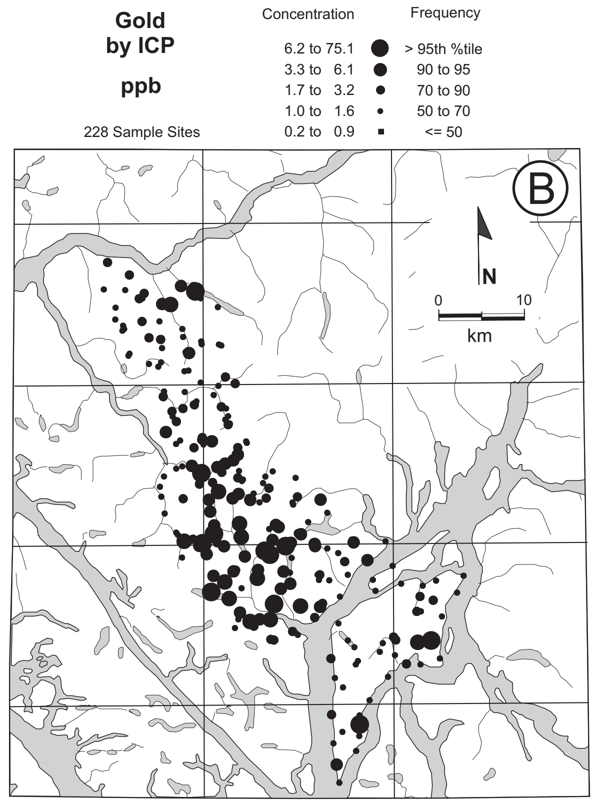

Figure 11b. Gold concentrations in stream sediment samples from the Ecstall belt.

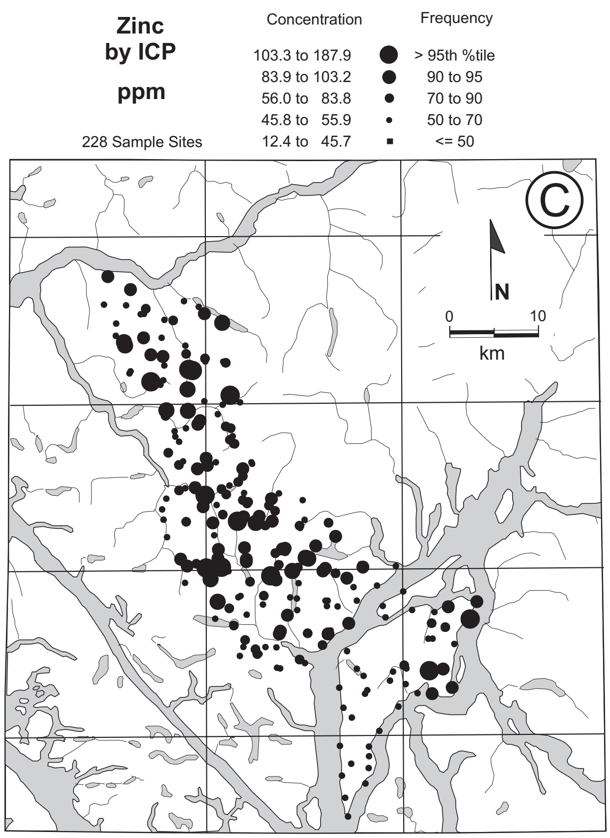

Figure 11c. Zinc concentrations in stream sediment samples from the Ecstall belt.

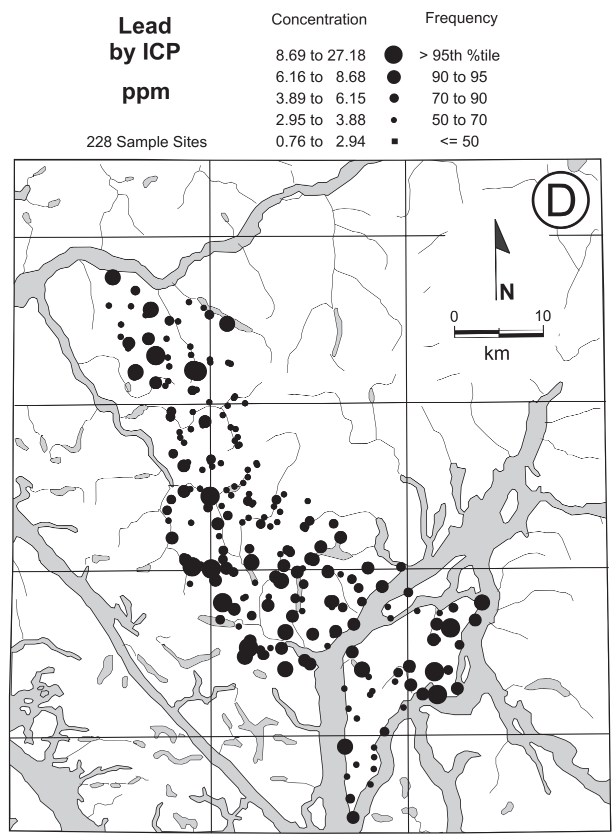

Figure 11d. Lead concentrations in stream sediment samples from the Ecstall belt.

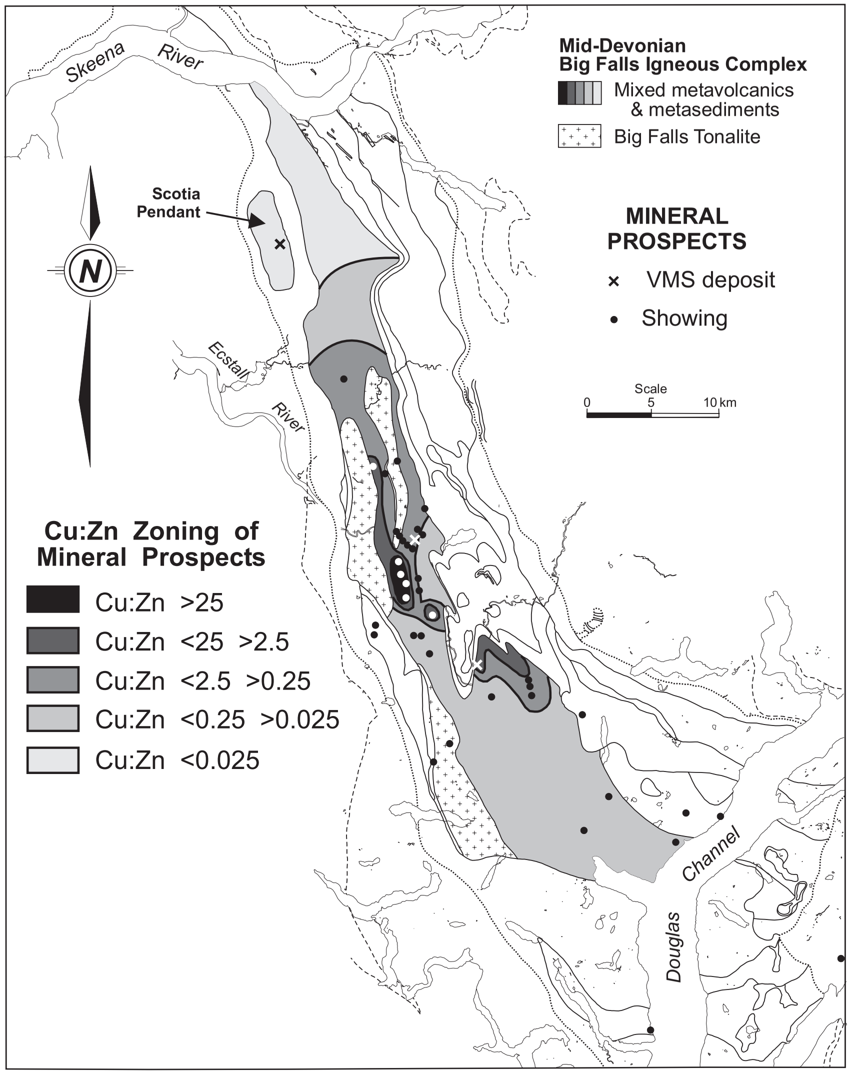

Figure 12a. Contoured Cu:Zn ratios for mineral prospects in the Ecstall belt (*see* Table 2).

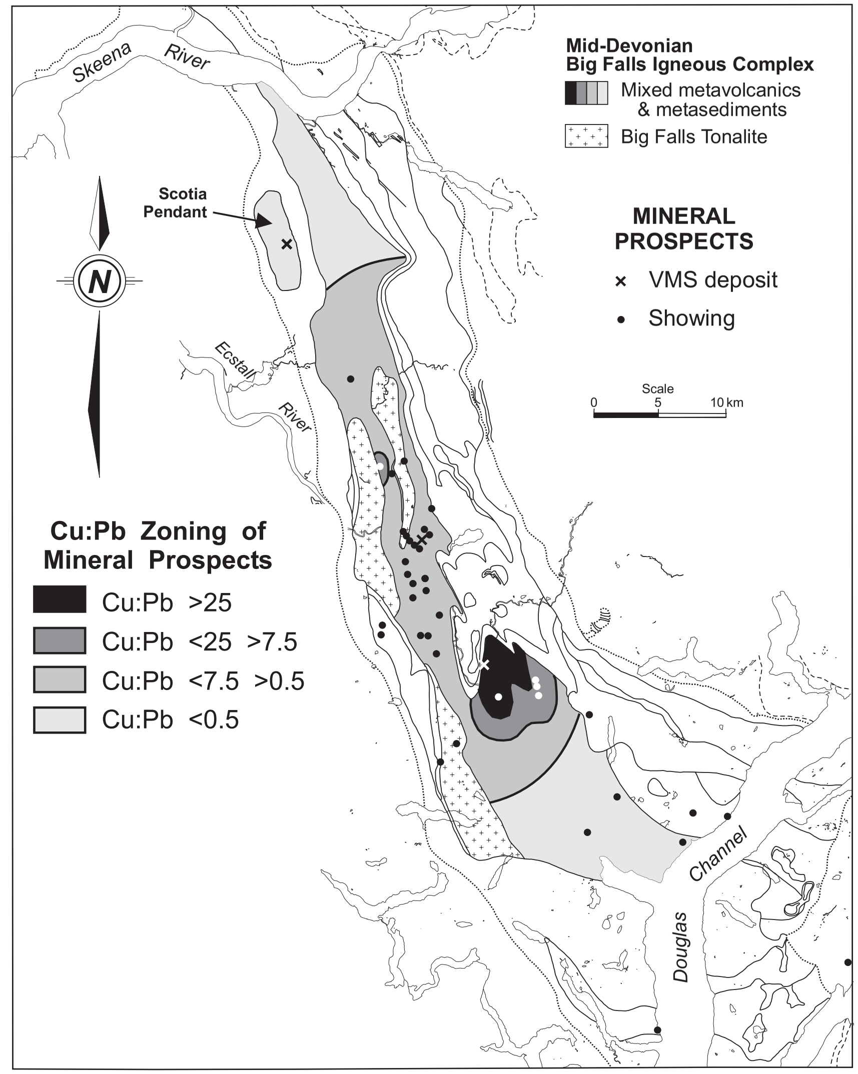

Figure 12b. Contoured Cu:Pb ratios for mineral prospects in the Ecstall belt (*see* Table 2).

high concentration of mineral prospects in the central part of the Ecstall Greenstone Belt is probably an artifact of 20 years of intensive prospecting and exploration work that was based out of the camp at the Ecstall deposit. The exploration potential throughout this belt is high everywhere, but copper-rich deposits will be most abundant near the central tonalite bodies and gold, zinc and lead-rich deposits will be concentrated progressively further away, but still hosted by the metavolcanic rocks of the belt.

The clear pattern of metal-zoning evident in the stream sediment geochemistry results suggested that the same pattern of metal zoning might also be discernible by calculating the Cu:Zn and Cu:Pb ratios for assays from the deposits and prospects in the Ecstall belt (Table 2); these values could then be contoured. In most mining camps, assay data is more readily available than high quality stream sediment survey results, so it offers a more universal database for applying this technique. Nevertheless, there are problems and restrictions encountered when calculating and contouring data derived from assay results:

Just 36 showings in the Ecstall belt are hosted in volcanic strata.

For smaller showings, assays are not always carried out for `accessory' metals such as zinc or lead (Table 2). Copper and zinc analyses are available for 24 prospects; but copper, zinc and lead analyses are only available for 15 prospects.

For very small prospects, the `best assay' is typically reported. This features the highest copper or gold grade, rather than the most representative assay or the average assay.

Showings are unevenly distributed, clustering near the Ecstall deposit (Figure 6).

In general, the contoured maps (Figure 12) show concentric zoning of Cu:Zn and Cu:Pb ratios decreasing outward from the central coeval stocks. An important feature is the presence of a copper-rich zone in the area of the Packsack deposit, despite the apparent absence of mid-Devonian stocks. Tonalite (quartz diorite) intrusions may be present along this part of the valley of the upper Ecstall River where early mapping work (Padgham, 1958; Holyk *et al.,* 1958) identified several small bodies of "diorite". A second significant feature is the absence of any copper-rich zone in the southwest part of the Ecstall belt (Figure 11a, 12a and 12b) where a large tonalite body is shown on the maps by Gareau (1991c, 1997) (Figure 4). The tonalite intrusion in this area was extrapolated from a small exposure mapped far to the north. The absence of any copper-rich geochemical signature, combined with the presence of two relatively low-copper mineral occurrences hosted in schist (Figure 6), suggest that the tonalite body is much less extensive than shown on existing maps. The prominent Cu:Zn high centred over the West Grid Alteration Zone (Phobe, Elaine and Thirteen Creeks prospects) contrasts with a conspicuous absence of a Cu:Pb high at the same location. This reflects the

TABLE 2
RESERVES, RESOURCES, GRADES AND CU:ZN AND CU:PB RATIOS FOR DEPOSITS AND PROSPECTS IN THE ECSTALL BELT

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

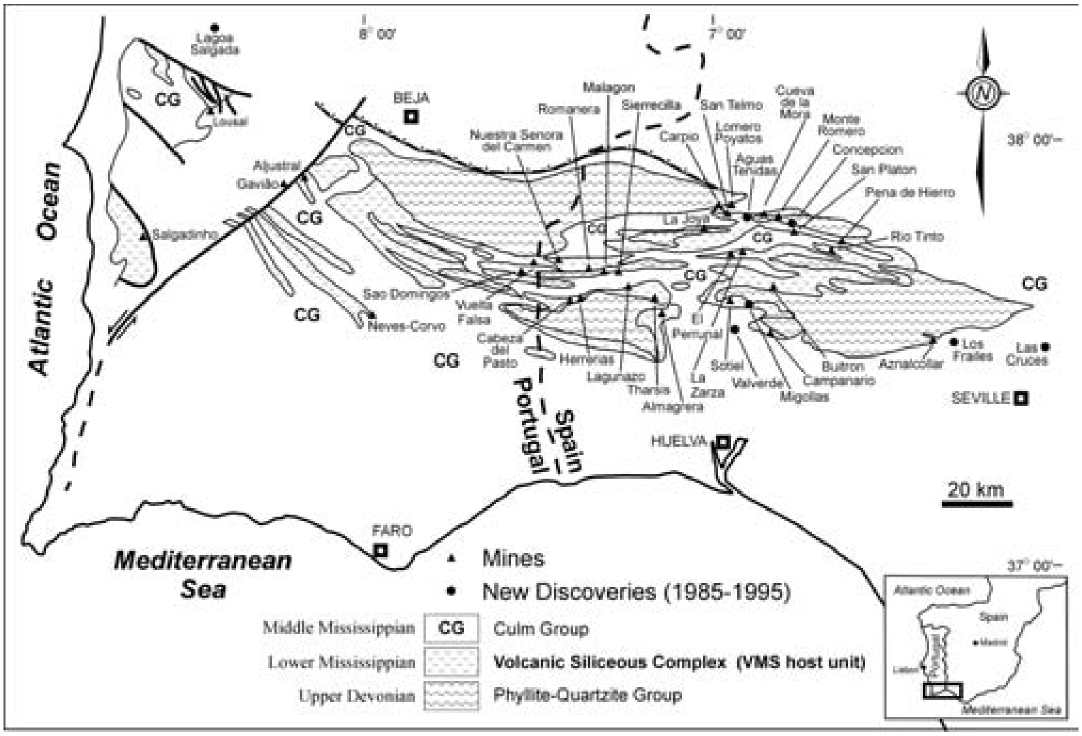

Figure 13. Volcanogenic massive sulphide deposits of the Iberian Pyrite Belt (modified from Leistel *et al.,* 1998).

TABLE 3
PRODUCTION, RESERVES AND CU:ZN AND CU:PB RATIOS FOR DEPOSITS AND PROSPECTS IN THE IBERIAN PYRITE BELT

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

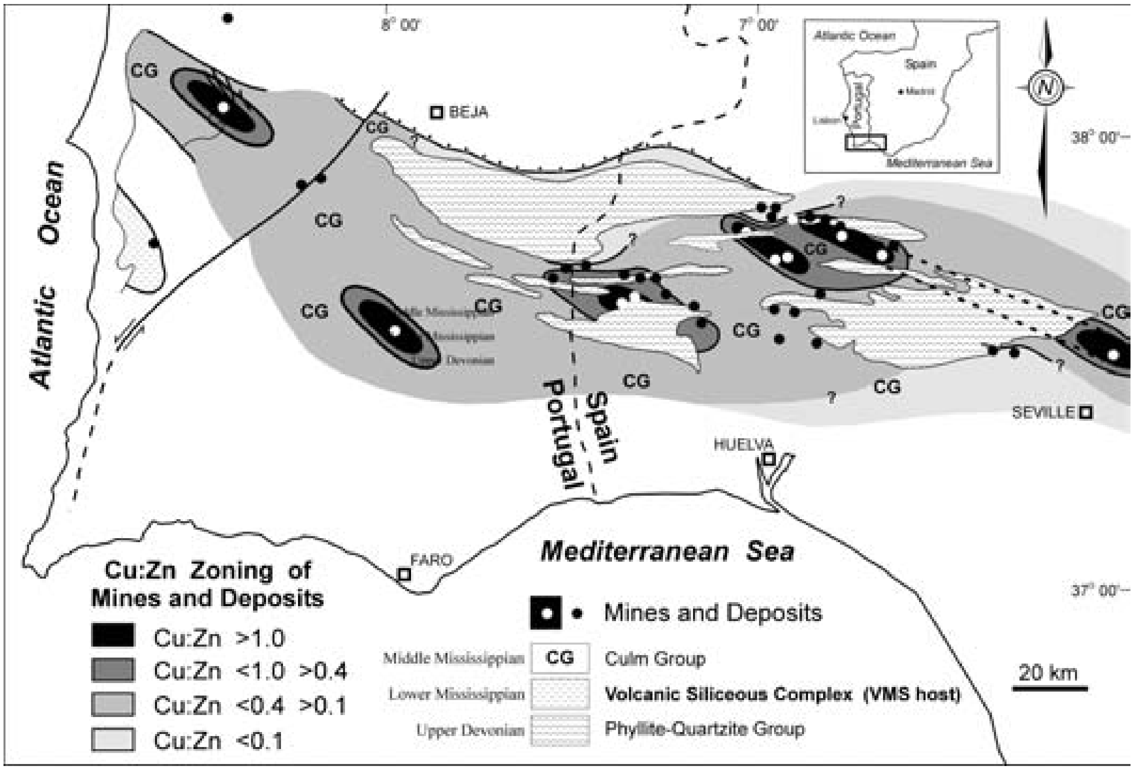

Figure 14a. Contoured Cu:Zn ratios for VMS deposits in the Iberian Pyrite Belt (*see* Table 3).

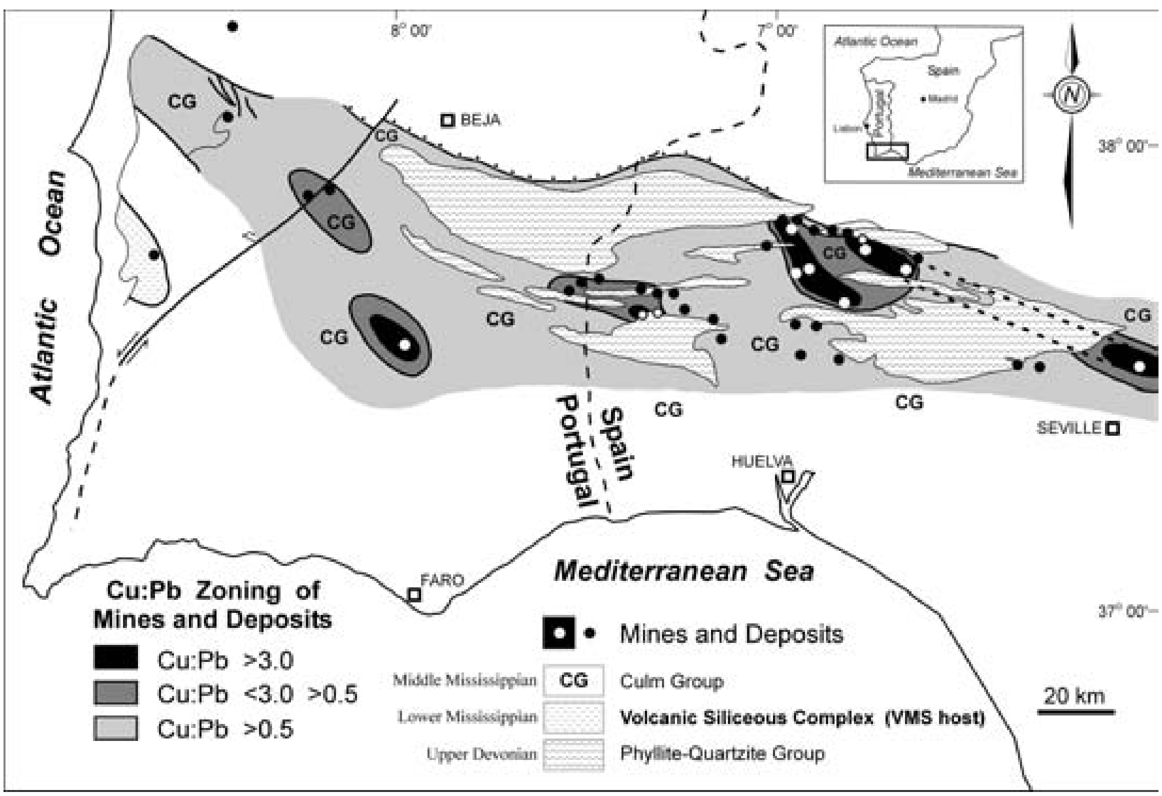

Figure 14b. Contoured Cu:Pb ratios for VMS deposits in the Iberian Pyrite Belt (*see* Table 3).

lack of lead analyses from these showings despite three seasons of exploration work.

Metal Zoning in the Iberian Pyrite Belt

Measuring just 250 kilometres east-west by 20-70 kilometres north-south, the Iberian Pyrite Belt (IPB) straddles the border between southern Portugal and Spain (Figure 13) and hosts more than 140 volcanogenic exhalative massive sulphide deposits within the Late Devonian-Early Mississippian strata of the Volcanic-Siliceous Complex, an average of more than one deposit per 2 km of strike length. The IPB is the setting for the Rio Tinto and Neves-Corvo mines, the second and third largest VMS deposits in the world after the Windy Craggy deposit of British Columbia.

The geology of the IPB is profiled in a special double issue of Mineralium Deposita (Marcoux and Leistel, 1998). No coeval subvolcanic intrusions have been documented through most of this large district. Boulter (1993) describes undated dolerite sills and felsic quartz-feldspar porphyry sills in the Rio Tinto area, and presents textural evidence that the felsic units are synvolcanic.

The technique for contouring Cu:Zn and Cu:Pb ratios was applied to the dataset of assay values for the deposits of the IPB. Published reserves (Leistel *et al.*, 1998) and calculated Cu:Zn and Cu:Pb ratios are listed in Table 3. As in the Ecstall belt, deposit locations are unevenly distributed. Contours are projected up through the unmineralised slates of the Culm Group, which rest as a thin veneer on the VMS host strata in the Volcanic-Siliceous Complex. Many recent discoveries are blind deposits located by drilling through this barren cover sequence (Figure 13).

Contoured maps of Cu:Zn and Cu:Pb ratios (Figure 14) show seven copper-rich centres located around the Lousal, Aljustrel, Neves-Corvo, Cabeza del Pasto, La Zarza, Rio Tinto and Las Cruces massive sulphide deposits. Significantly, other large VMS deposits, such as Tharsis, Aznalcollar and Los Frailes, have relatively low Cu:Zn and Cu:Pb ratios. Contour distributions indicate favourable areas within this extensive belt to search for copper-, gold-, zinc- or lead-rich VMS deposits. These patterns also reveal high Cu:Zn and Cu:Pb areas where coeval plutonic rocks might be preserved and exposed.

Other exploration applications are possible. The Rio Tinto mine and Las Cruces deposit are 55 kilometres apart. They may represent deposits formed near two separate thermal or magmatic centres, shown as separate Cu:Zn and Cu:Pb highs in Figure 14. However, they may lie within one elongate Cu:Zn and Cu:Pb contour high (shown as a dashed outline on Figure 14) that is now dissected where erosion has removed the favourable stratigraphy and exposed the unmineralised footwall strata. In the latter scenario, the area of volcanic rocks immediately east-southeast of the Rio Tinto mine is especially prospective for deposits with relatively high copper and gold grades.

DISCUSSION AND CONCLUSIONS

The high exploration potential and the partially explored status of the Ecstall Greenstone Belt are underscored by the recent discovery of four base metal showings in rock cuts along existing logging roads (Bell, West Road, Cheens Creek and F-13). Stream sediment sampling results from the new Regional Geochemical Survey reliably detect the geochemical signature of the major prospects in the belt, but also reveal 15 more drainage basins where the bedrock sources for the anomalous base metal concentrations in stream sediment samples have yet to be discovered.

The distribution of base metal and gold values in the stream sediment data in the Ecstall region show progressive, overlapping Cu>Au>Zn>Pb zoning outward from coeval subvolcanic plutons. Contours of Cu:Zn and Cu:Pb ratios calculated from assays from mineral prospects and deposits reproduce this same lateral zoning. These two independent lines of data suggest that copper-rich prospects are concentrated near the synvolcanic tonalite stocks while zinc-rich and lead-rich prospects are deposited far from these plutons. This pattern matches the metal zoning sequence demonstrated in an earlier study of the Mount Read volcanic belt in Tasmania (Large *et al*., 1996). Results in the Ecstall belt point to a copper-rich area around the Packsack deposit where synvolcanic plutons are not documented but are likely present. Results also suggest that the large tonalite stock postulated in the southwestern Ecstall belt may be an area primarily composed of volcanic rocks well-removed from the nearest coeval tonalite pluton.

Application of this technique to the world's largest VMS belt in southwestern Spain reveals a simple pattern for the assorted copper-rich and copper-poor deposits of the Iberian Pyrite Belt. Multiple copper-rich centres are present. Each represents an area where coeval subvolcanic plutons might be exposed. The easternmost Las Cruces deposit lies within a copper-rich, `pluton-associated' centre, so exploration potential for proximal copper-rich deposits and then distal zinc- and lead-rich deposits will extend for still farther to the east. The area east-southeast of the Rio Tinto mine is particularly favourable for undiscovered copper- and gold-rich deposits.

In summary, analysis of base metal distributions and contouring of base metal ratios from VMS camps can be accomplished using readily available reserve and assay data. Resolution and reliability can be improved by using an evenly distributed, higher density database, such as a regional geochemical survey. In combination, these two techniques can reveal the location and extent of coeval subvolcanic intrusive rocks, key components of the volcanic complex and the ore-forming process. Identification and delineation of synvolcanic plutons by these methods can be particularly helpful during the early years of exploration and mining in greenstone belts when geochronological confirmation is often lacking. Such analysis can help clarify the original geometry of volcanic belts in highly deformed terranes. Applied during exploration programs, these analytical tools effectively highlight underexplored areas and permit the selection of metal-specific target areas.

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