Geology and Mineral Potential of the Ecstall VMS Belt (NTS 103H, 103I)

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KEYWORDS: *Economic geology, mineral potential, geologic mapping, Central Gneiss Complex, Coast Belt, VMS, sulphide, metavolcanic, greenstone, Devonian, Scotia, Ecstall, Packsack, Prince Rupert.*

INTRODUCTION

The mid-coast region of British Columbia, extending between Prince Rupert and Bella Coola, hosts 31 volcanogenic massive sulphide (VMS) deposits (BC MINFILE; Massey, 1999). A multi-year project will investigate the geologic setting of many of these prospects, starting in the Ecstall VMS belt near Prince Rupert (Figure 1). The Ecstall belt is part of the Central Gneiss Complex, an anastomosing network of high-grade metamorphic rocks enclosed by younger granitoid rocks of the Coast Plutonic Complex (Figure 2).

The Ecstall belt extends 80 kilometres from the estuary of the Skeena River to the Douglas Channel fiord (Figures 2 and 3); width of the belt varies from 3 to 20 kilometres. The belt is equidistant from the northern communities of Prince Rupert, Terrace and Kitimat (Table 1). In addition to its proximity to tidewater and to these communities, the Ecstall belt is close to the Yellowhead Highway, the Skeena Railway line of VIA Rail and the national

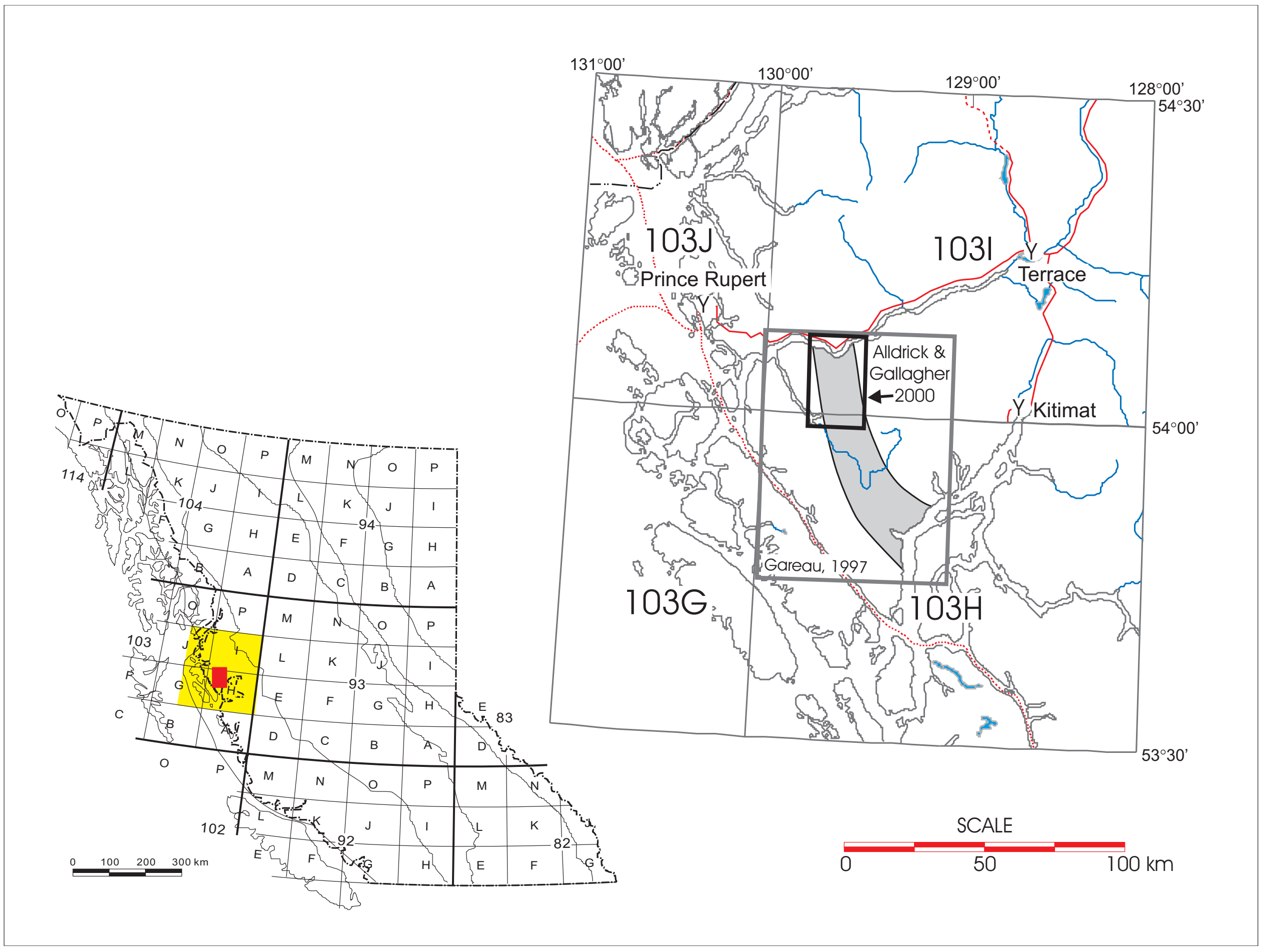

Figure 1. Location of the Ecstall belt in British Columbia.

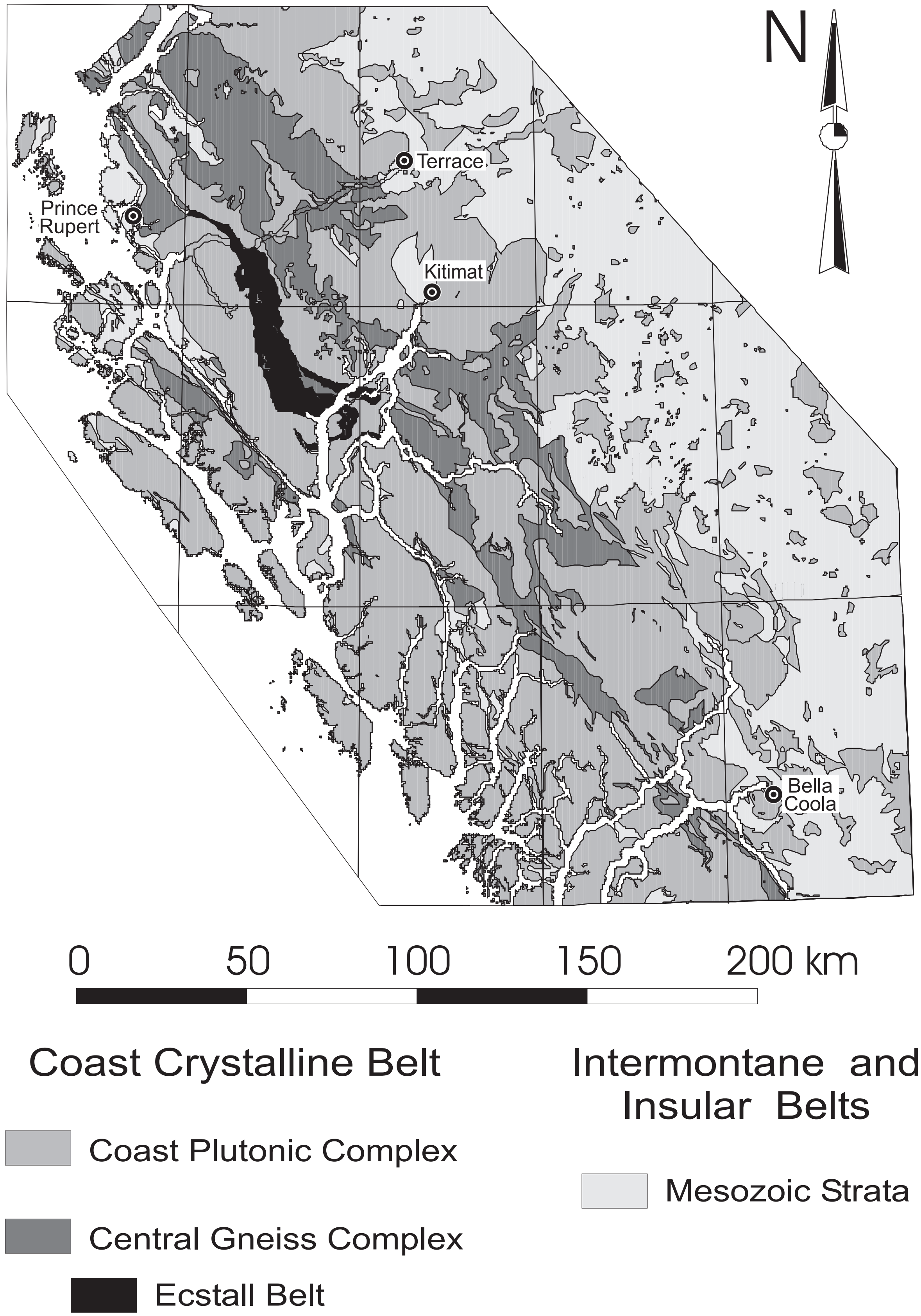

Figure 2. Geology of the mid-coast region of British Columbia, highlighting the location of the Ecstall metavolcanic belt within the Central Gneiss Complex and the Coast Plutonic Complex.

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

power grid. The northern and southern ends of the belt have established networks of logging roads.

Elevation ranges from sea level to 1760 metres. Smooth undulating ridgecrests are flanked by steep slopes characteristic of glaciated valleys. Despite this precipitous terrain, it is possible to traverse the entire belt from north to south without exceeding 125 metres elevation by traveling up the Scotia River valley and through the pass at Big Falls Lake, then up the Ecstall River valley and through the pass at Ecstall Lake and finally down the Quaal River valley.

Rainfall is heavy; average annual precipitation at Prince Rupert is 244 centimetres (96 inches). The combination of low elevation and proximity to the coast leaves the valley bottoms 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 shoots. Ridgecrests above 1100 metres elevation are free of trees and shrubs.

In the late 1890s local Indians lead prospectors to the exposed sulphide lenses of the Ecstall deposit in Red Gulch Creek. This deposit was investigated intermittently from 1900 to 1952 by a variety of companies. A regional exploration program conducted by Texasgulf Inc. in 1958 discovered the Scotia and Packsack deposits and the Horsefly showing. For the last 20 years there has been continuous exploration work on the properties in this belt, carried out by a series of companies. Discovery of the 14 other sulphide occurrences in the Ecstall belt are the result of these recent exploration efforts.

Regional scale mapping in this area was conducted by the Geological Survey of Canada from 1962 to 1966 (Roddick 1970a, 1970b; Hutchinson 1970, 1979, 1982) and from 1987 to 1989 (Gareau, 1991a,b,c, 1997). Woodsworth, Crawford and Hollister (1983) produced a geological field trip guidebook for the Terrace - Prince Rupert corridor.

University research projects within, adjacent to and along strike from the Ecstall belt have investigated a wide variety of geological features. These studies are reported in theses by Padgham (1959), Money (1959), Eldridge (1983), Krage (1984), van der Heyden (1989), Heah (1991) and Gareau (1991a) as well as in published reports by Hutchinson (1970), Brew and Ford (1978), Crawford and Hollister (1982), Sutter and Crawford (1985), Rubin *et al*. (1990), Heah (1990), Crawford and Crawford (1991), McClelland *et al*. (1991a), McClelland *et al*. (1991b), Gehrels *et al*. (1991a), Gehrels *et al*. (1991b), Gehrels *et al*. (1991c), Samson *et al*. (1991), Gareau (1991c), Drinkwater *et al*. (1993), Dusel-Bacon *et al*. (1996), Gehrels and Kapp (1998), Gehrels and Boghossian (in press) and Boghossian and Gehrels (in press).

Regional scale studies of VMS deposits have recently been completed by Newberry *et al*. (1997) and Massey (1999). Property scale maps and reports prepared by industry geologists between 1912 and 1999 are listed with the individual property descriptions in the BC MINFILE database.

Objectives of the current mapping program include: establish a more detailed lithological breakdown within the four stratigraphic packages documented by Gareau (1997), study the relationships between this detailed lithostratigraphy and the many mineral occurrences of the belt, trace out prospective felsic volcanic strata, and investigate a possible coeval relationship between the Big Falls orthogneiss and the metavolcanic package. In the 1999 field season, three weeks mapping was completed by a team of two. Work concentrated on mapping rock-cuts along the extensive logging road network at the north end of the Ecstall belt and along the Yellowhead Highway and Skeena Railway.

REGIONAL GEOLOGIC SETTING

The geologic setting of the Ecstall belt is shown in Figures 2, 3, 4 and 5. The Ecstall metamorphic belt is part of the Central Gneiss Complex, an anastomosing network of high-grade metamorphic rocks enclosed by younger granitoid rocks of the Coast Plutonic Complex (CPC; Figure 2). Together, these two complexes comprise the Coast Belt. The following summary is adapted from Greenwood *et al*. (1992) and Woodsworth *et al*. (1992).

Plutonic rocks make up more than 80% of the Coast Belt; the remainder is granitoid gneiss, metasediments and metavolcanics. 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 ages of plutons young progressively to the east. Rocks range in composition from granite to gabbro, but 70% of all plutonic rocks lie within the compositional range of tonalite-quartz diorite-diorite. Among the circum-Pacific plutonic terranes, the CPC is the largest, the most mafic, and the most deficient in K-feldspar.

In the Prince Rupert - Terrace region, intrusions of different ages have extensive flat-lying `sills' developed along their eastern margins (Figure 4). In the Ecstall belt north of Big Falls Creek and on Hawkesbury Island, these sill-like apophyses are preserved as erosional remnants

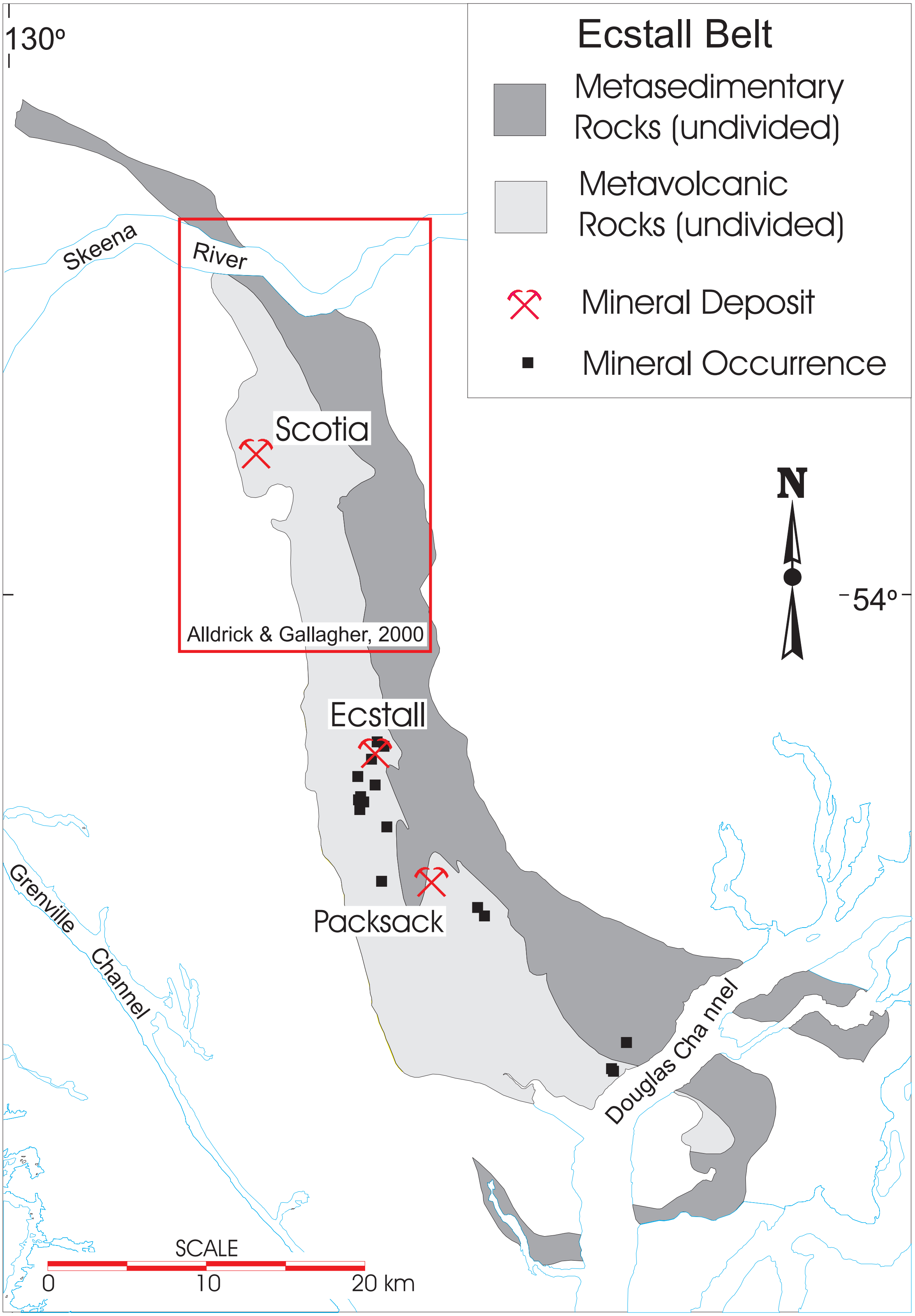

Figure 3. Geology and volcanic-associated massive sulphide occurrences of the Ecstall belt (simplified from Gareau, 1997).

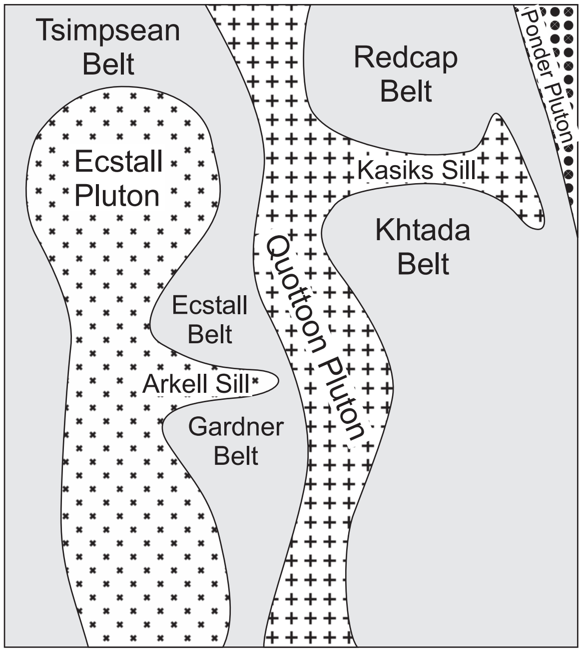

Figure 4. Schematic section showing the relationships between intrusive rocks of the Coast Plutonic Complex and metamorphic rocks of the Central Gneiss Complex in the Ecstall area.

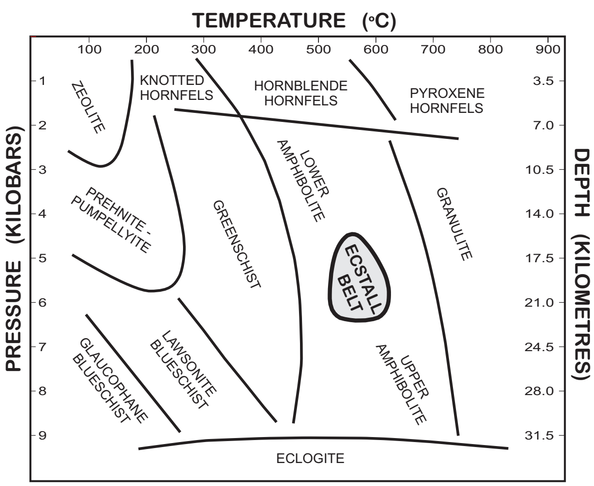

Figure 5. Metamorphic pressure-temperature conditions in the Ecstall belt (modified from Greenwood *et al*., 1992 and Gareau, 1991c).

on hilltops and ridgecrests (Gareau, 1997), where they overlie and obscure prospective metavolcanic strata.

Metamorphic rocks of the Coast Belt typically occur as screens or pendants surrounded or intruded by the plutonic rocks (Figure 2). The Central Gneiss Complex is composed of rocks ranging and age from Proterozoic through Paleozoic. Remnants of Paleozoic metamorphism are preserved locally, while most regional metamorphic overprints are Mesozoic and early Tertiary in age. Intense Cretaceous and early Tertiary metamorphism, deformation and plutonism have obscured evidence of earlier events in many places. Most metamorphic effects can be attributed to regional metamorphism, but contact metamorphism from the adjacent plutons can also create a late metamorphic overprint.

The Prince Rupert - Terrace corridor is the most extensively studied and best understood area of the Coast Belt**.** This is the most deeply exhumed part of the Coast Plutonic Complex, and metamorphic grades range up to kyanite-amphibolite, sillimanite-amphibolite and granulite facies in different parts of this area. Within the Ecstall metavolcanic belt, Gareau (1991a,c) 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 (Figure 5).

The Devonian volcanic arc that evolved into the Ecstall metamorphic belt likely developed in a similar pericratonic tectonic setting as the extensive volcanosedimentary rocks of the Yukon-Tanana terrane (Gareau, 1991a,c). The regional geologic history of the Ecstall belt is summarized in Figure 6; Devonian volcanism and sedimentation and comagmatic intrusions, are followed by three poorly-constrained phases of deformation and four well-dated plutonic episodes. The Jurassic to Eocene plutonic and metamorphic history of the CPC is consistent with a model of east-dipping subduction beneath a single, allocthonous Alexander-Wrangellia-Stikinia superterrane, emplaced against North America in Middle Jurassic time (van der Heyden, 1989).

GEOLOGY OF THE NORTHERN ECSTALL BELT

Mapping in the 1999 field season covered road networks within the area outlined on Figure 3. Figure 7 shows the simplified geological map and legend.

Stratified Rocks

Unit 1 - Metavolcanics

Metavolcanic rocks of the Ecstall belt host all the known mineral occurrences (Figure 3). This sequence is the largest unit defined by Gareau (1991a), and extends the entire length of the belt, averaging four kilometres in thickness. Metavolcanic rocks are in gradational contact with the Big Falls orthogneiss (Unit C) and with metasedimentary rocks; contact relationships with other units were not determined. The metavolcanic unit is heterogeneous. Biotite schist, hornblende-biotite schist and semi-schist comprise 70% of the unit. Interlayered with these lithologies are 100-metre-thick heterogeneous lenses of pyrite-quartz-sericite schist, amphibolite, quartzite and calcareous muscovite-biotite schist. The continuity of these smaller lenses has not been confirmed, but they may extend along strike for several kilometres.

Unit 1a - Mafic Metavolcanics

The hornblende-biotite schist is a black to greenish black recessive rock that is fissile and commonly highly

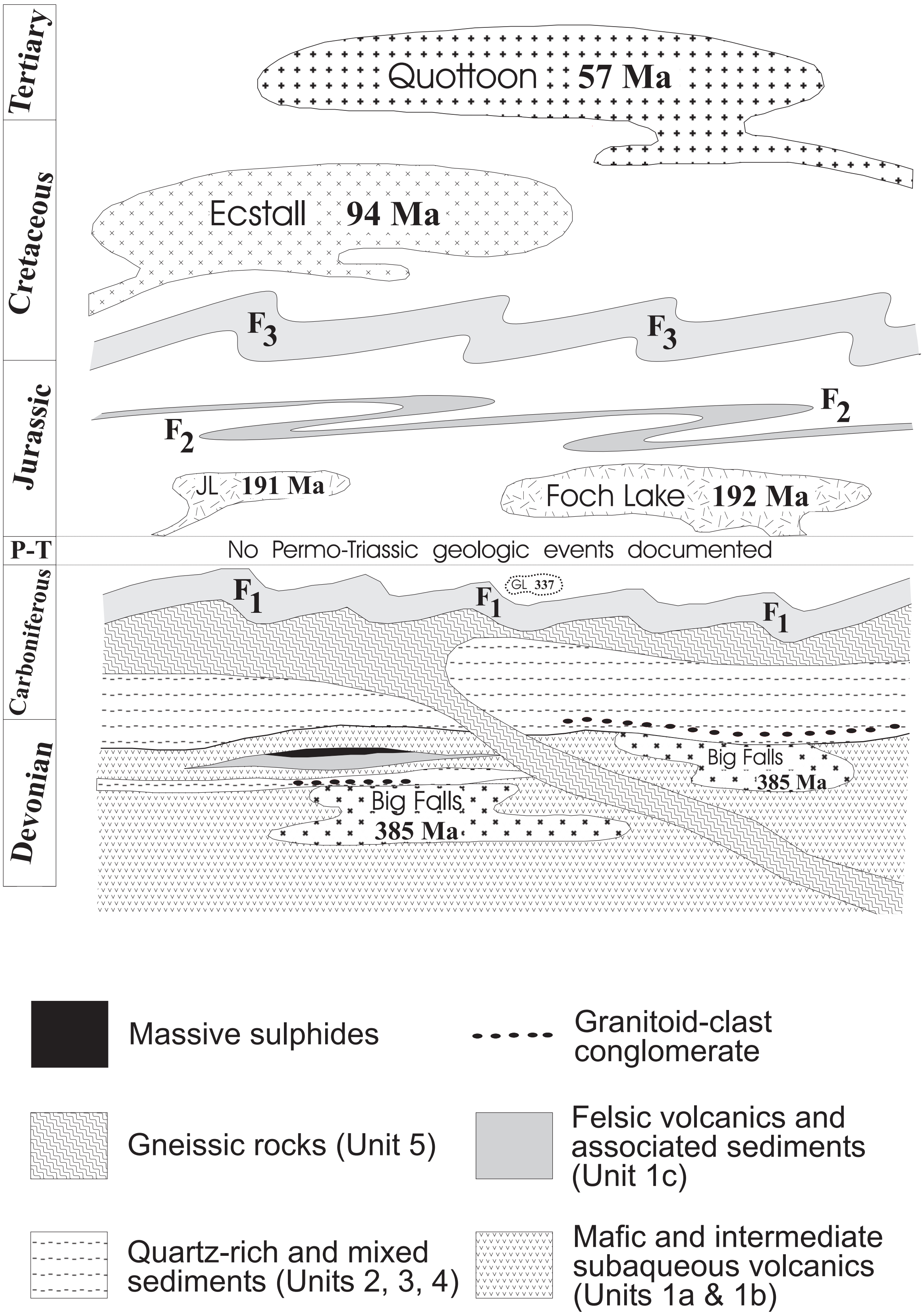

Figure 6. Geologic history of the Ecstall belt. F-1, F-2 and F-3 are successive episodes of folding. JL is the Johnson Lake stock; GL is the Gareau Lake stock (adapted from Gareau, 1991a,b,c and 1997).

weathered. It is the thickest of the metavolcanic units, averaging several hundred meters thickness, and displays gradational boundaries with surrounding metavolcanic and metasedimentary lithologies. Also present within the mafic metavolcanics are lenses of resistant, homogeneous, black to rusty-coloured, garnet-hornblende amphibolite interlayered on a 5 to 20 metre scale.

Compositional layering is typically non-existent, or is very weak and defined by discontinuous millimetre-thick laminae. The rock contains more than 50% medium-grained biotite and 10% to 20% hornblende. Granular, fine to medium grained plagioclase comprises up to 20% of the rock and is typically polygonal. Disseminated pyrite locally constitutes up to 5% of the rock and accessory skeletal garnet porphyroclasts are preserved. Euhedral titanite, that makes up to 10% of some thin sections, is a common mineral associated with sulphide grains. Titanite occurs as well defined layers, as radial masses cored by pyrite, or as interstitial clusters or individual grains. Epidote-hornblende knots or pods are common within this unit; when present these knots make up 5% to 15% of the rock. The schist locally displays discontinuous, orange, medium-grained, calcareous lenses that are highly recessive.

The abundance of hornblende and biotite and the lack of quartz is consistent with a mafic volcanic protolith. The lithologic heterogeneity observed in the unit suggests a highly dynamic depositional environment. Discontinuous carbonate lenses appear to be primary and are indicative of a subaqueous environment.

Unit 1b - Intermediate Metavolcanics

Hornblende-diopside-biotite-quartz-plagioclase semi-schist is common along the east side of the Scotia Main logging road (Unit 1b in Figure 7). The unit has a minimum structural thickness of 200 metres and unknown contact relationships with surrounding lithologies. Gareau (1991a) concluded that this is the dominant lithology in the northern part of the Ecstall belt. Semi-schist is fine to medium grained, granular, well indurated and weathers dark grey to black.

This quartz-plagioclase rock has medium-grained biotite partings spaced 1 to 5 centimetres apart. Plagioclase and diopside microlithons have 5% to 10% interstitial biotite. Titanite occurs as euhedral interstitial grains making up less than 2% of the rock. Fine to medium grained prismatic hornblende, ranging from 5% to 10% by volume, is concentrated along biotite parting surfaces.

The presence of biotite semi-schist members within the mafic metavolcanic schists marks a decrease in mafic minerals, and an increase in quartz from near zero to 10% to 20%. This mineral assemblage suggests that the protolith was a metamorphosed intermediate volcanic rock, or a volcaniclastic sedimentary rock.

Unit 1c - Felsic Metavolcanics

This heterogeneous unit is composed of pyritic quartz-muscovite schist interlayered with 10 to 20 metre thick bands of muscovite-bearing quartzite and hornblende-biotite schist. The unit is shown in Figure 7 as two discontinuous lenses a few hundred metres in thickness that have gradational boundaries with the surrounding metavolcanic unit. These two lenses are roughly on strike with one another and may be a continuous layer. Contacts with adjacent lithologies are typically sharp but may be gradational over half a metre to a metre. Both bands of felsic metavolcanics lie well east of the Scotia VMS deposit; however, the southern lens of this unit is host to the Friday the 13th showing.

Quartz-muscovite schist is a medium to coarse-grained rock with significant sulphides, containing on average 10% to 15% pyrite. These rocks also locally display relict clastic or fragmental volcanic textures. Primary compositional layering, on a 1 to 10 centimetre scale, is defined by alternating quartz and phyllosilicate layers. Pyrite seams or layers, up to 4 millimetres thick, are concordant with compositional layering and characterize the lithology. Subhedral garnet, with an average diameter of 5 millimetres, is commonly associated with the sulphides, as is biotite. Chlorite can be seen in handsample surrounding the garnet porphyroblasts. Quartz-rich metasediments associated with the felsic metavolcanic rocks are similar in composition and relationships as those described in Unit 2.

Pyritic quartz-sericite schists are interpreted as metamorphosed felsic volcanic flows, tuffs and fragmental rocks associated with subaqueous extrusion. Local thin units (1 to 5 metres) of thinly laminated (1 to 2 centimetres) quartz-rich rock that grades into the sericite schist likely share a volcanic origin and are likely metamorphosed chert.

Unit 2 - Quartzite and Quartz Schist

Metasedimentary rocks mapped in this study consist dominantly of muscovite-bearing quartzite. This unit may be correlative with the quartzite of Gareau (1991a,b,c; 1997), shown as Unit 3 in Figure 7. The unit rarely exceeds 200 metres thickness, but attains a maximum structural thickness of one kilometre in one location. Quartzite is in gradational contact with the surrounding metavolcanic unit.

Quartzite contains greater than 95% quartz and is very well indurated, resistant, homogeneous, light to medium grey, and fine to very fine grained. The rock typically weathers light grey, but is rusty red when pyrite is present. The unit locally contains lenses of matrix-supported conglomerate composed of stretched metatonalite and other granitoid cobbles with an aspect ratio of 10:2:1 or more. Finely laminated compositional layering is defined by light grey quartz-rich layers alternating with dark grey to black layers of quartz, biotite and graphite(?). Pyrite commonly occurs along partings as dissemi-

LEGEND

STRATIFIED ROCKS

PALEOZOIC (Devonian?)

GNEISS

5 Mafic to intermediate gneiss. Biotite epidote hornblende mafic gneiss. Resistant, black to greenish black rock. Commonly migmatitic in northern areas. Medium grained, granular. Locally contains pyrite-, garnet- and diopside-rich boudins and lenses. Medium grained, granular, light grey weathering biotite q-f gneiss is present in southern portions of unit.

METASEDIMENTARY ROCKS

4 Mixed metasedimentary rocks of the Khtada Lake area. Not mapped in this study. See Hollister (1977, 1982) for description.

3 Quartzite Unit of Gareau (1997). Not mapped in this study. May be correlative with unit 2.

2 Quartzite and Quartz Schist: Quartzite is a light grey, resistant rock, >95% quartz. Fine grained to very fined grained. Laminations of muscovite with trace to minor pyrite. Interlayered with garnet-biotite-quartz schist in the southern map area

METAVOLCANIC ROCKS

1c Felsic Volcanic Rocks: Pyritic quartz-muscovite schist to semi-schist; ± biotite, ± garnet. Fissile and recessive. Forms prominent gossans which can be traced across terrain. Commonly associated with quartz-rich metasedimentary members within the metavolcanic unit: garnet-biotite-quartz schist to phyllite, and muscovite quartzite interlayered on the 5-to-10 metre scale with mafic and felsic metavolcanic rocks.

1b Intermediate Volcanic Rocks: Hornblende biotite quartz feldspar semi-schist ± epidote. Dark grey to black medium grained rock. Resistant. Hornblende biotite rich partings on cm-

1a Mafic Volcanic Rocks: Hornblende biotite plagioclase schist ± pyrite ± garnet; dark black to rusty red recessive and commonly fissile, rare discontinuous carbonate lenses, homogeneous on outcrop scale, locally displays relict volcaniclastic tecture.

INTRUSIVE ROCKS

TERTIARY - 56.8 +6/-0.1 Ma (Late Paleocene)

C **Quottoon Pluton**: hornblende ± biotite tonalite to quartz diorite with abundant screens of gneiss and common rafts of metasedimentary rock. Medium to coarse grained. Strongly foliated throughout and locally lineated along western margin.

CRETACEOUS - 93.5 ± 1 Ma (early Late Cretaceous)

B **Ecstall Pluton**: Epidote hornblende biotite metadiorite (**Bd**) to metaquartzdiorite (**Bqd**) and granodiorite, with minor biotite hornblende quartz diorite. Medium to coarse grained. Moderately foliated. Up to 5% fine to medium grained epidote is a characteristic feature.

DEVONIAN - 385 ± 4 Ma (Middle Devonian)

A **Big Falls Orthogneiss**. Biotite hornblende meta-tonalite/trondhjemite ± garnet ± epidote. Light grey, fine to medium grained. Texture varies from plagioclase augen gneiss to fine grained plagioclase porphyritic gneiss to mylonite. Probably co-magmatic with the volcanic

Highway

Synform Axis

Logging Road

Antiform Axis

Mountain Peak

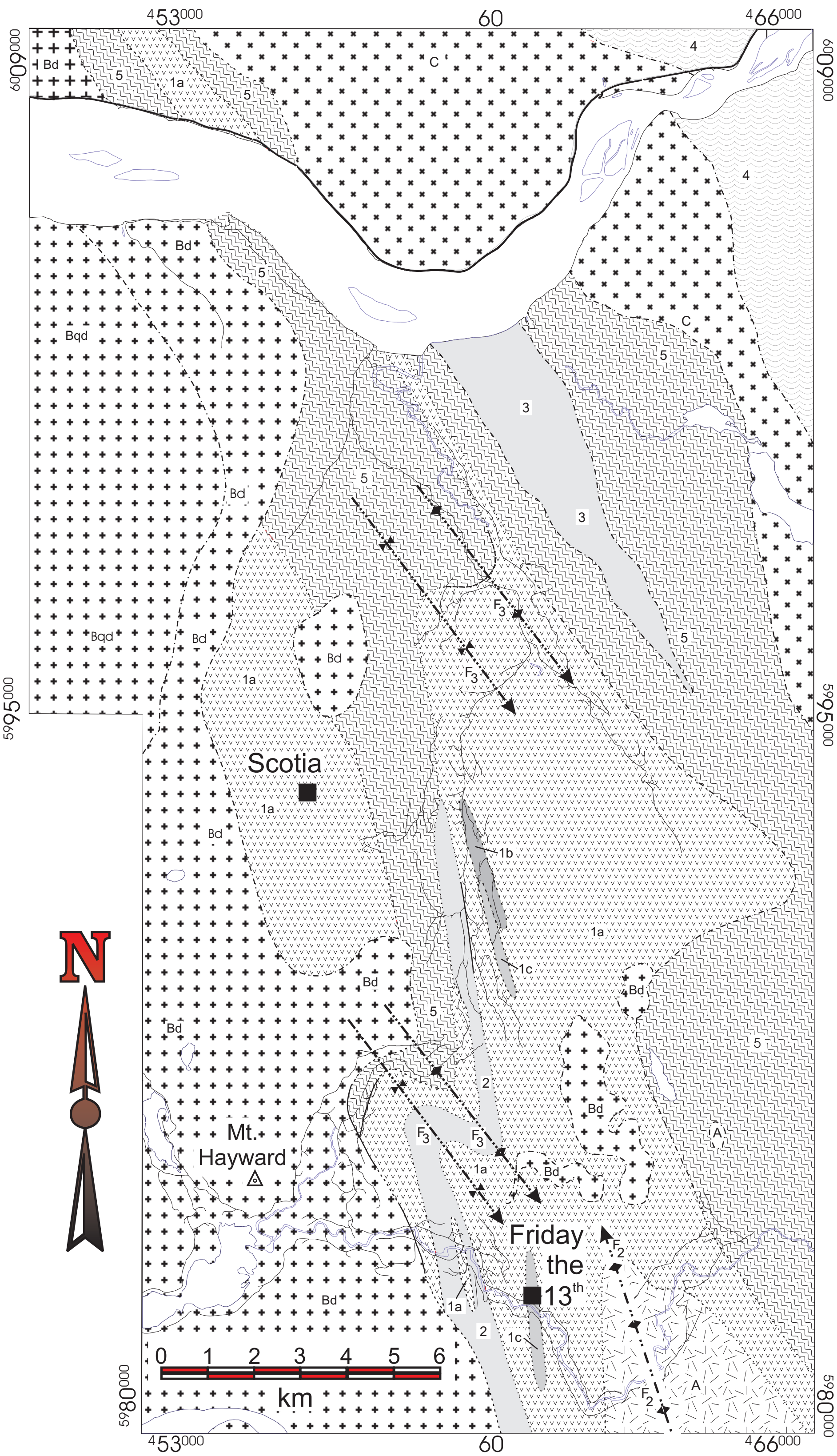

Figure 7. Geology of the northern Ecstall belt.

nations or semi-continuous laminae, not exceeding 5% of the rock.

South of Big Falls Creek, quartzite is interlayered with lenses of fine to very fine grained garnet-biotite-quartz schist. The gradational contact between the quartzite and schist is marked by quartz-rich rock with partings of medium-grained biotite and rare subhedral garnets ranging from 0.3 to 1.0 centimetres in diameter..

Unit 3 - Quartzite unit (from Gareau, 1991a)

This unit crops out northeast of the 1999 map area (Figure 7). The quartzite is a large lens, up to two kilometres thick, hosted entirely within the gneissic unit (Unit 5). Quartzite is in sharp contact with the surrounding gneissic rocks. The map unit is described as a "white to grey, locally pyritic quartzite, interlayered with lesser amounts of biotite-hornblende gneiss, fissile mica schist, black phyllite to meta-argillite, semi-pelite to pelite and marble" (Gareau, 1991a, p.14). The quartzite is a granoblastic rock; biotite is present in thin layers or partings less than 1 millimetre thick, or as minor interstitial grains. Accessory minerals are plagioclase, zoisite, cummingtonite, muscovite and carbonate. Gareau (1991a, p.14) concluded that these potassium and calcium-rich accessory minerals are consistent with a protolith of quartz arenite rather than chert.

Unit 4 - Metasedimentary rocks

Intensely deformed (Crawford *et al.*, 1987) high-grade metasedimentary rocks of the Khtada Lake area have been metamorphosed to granulite facies (Kenah and Hollister, 1983). These are the highest grade metamorphic rocks of the Central Gneiss Complex (Greenwood *et al.*, 1992). No stratigraphic correlation has been proposed for these rocks.

Unit 5 - Gneiss

A substantial belt of gneissic and locally migmatitic rocks are exposed along the western margin of the Ecstall metamorphic belt. Composition varies from buff weathering, grey, quartz gneisses in the south to migmatitic biotite-hornblende mafic gneisses in the north. Transition between the two lithologies is gradational over 300 metres.

Intermediate Gneiss

These light grey, well indurated and resistant gneisses are most common in the central western portion of the mapped area, northeast of Mt. Hayward. They occur as a north-northwest-trending belt with a maximum structural thickness of one kilometre.

Gneissic layering is defined by alternating medium grey and light grey layers averaging 10 centimetres thickness. Medium grey layers consist of medium grained, granular quartz-plagioclase matrix with substantial biotite and chlorite that make up 40% of the rock by volume. Light grey layers consist of approximately 60% quartz and minor plagioclase with up to 30% interstitial biotite. Sparse pyritic laminae are associated with the light grey layers.

Mafic Gneiss

Homogeneous, black to greenish black biotite hornblende plagioclase gneiss occurs as a northwest-trending belt with an average thickness of two kilometres. Along the southern bank of the Skeena River an extensive exposure of mafic gneiss is intruded by a swarm of discordant pegmatite dikes and sills (Woodsworth *et al.*, 1983, p.27-29).

Gneissic layering is well defined and typically 10 to 15 centimetres thick, with sharp boundaries. Compositional layering alternates between mafic biotite-diopside-hornblende to felsic biotite- quartz-plagioclase layers. Mafic layers consist of medium grained hornblende rock (60% amphibole) with interstitial plagioclase and minor biotite and garnet porphyroblasts. Light grey layers consist of 20% quartz, 60% plagioclase with interstitial biotite and hornblende. Minor bands and pods of hornblendite and epidote-garnet-pyrite-diopside and bands of migmatite were also noted. Hornblende amphibolite (hornblendite) layers, averaging 30 centimetres thick, consist entirely of medium to coarse grained, black, subhedral hornblende. Locally present are discontinuous pods of pyrite, garnet, epidote and diopside, typically 10 to 15 centimetres thick. Light grey to white migmatitic layers, several centimetres thick, occur as wavy discontinuous bands within the gneiss and consist of coarse to very coarse grained plagioclase and quartz.

The gneissic rocks lack relict igneous textures, such as flow banding and porphyroclasts, that would indicate an igneous protolith. The mineral assemblage of plagioclase, biotite, hornblende and minor quartz is consistent with a protolith of intermediate to mafic volcanic rock or immature volcanic sediment.

Intrusive Rocks

Ponder Pluton

The Ponder Pluton crops out to the northeast beyond the study area, but it is shown schematically in Figure 4. This is a mid-Eocene (47 Ma) hornblende-biotite granite to granodiorite, that may have been emplaced at a relatively high level (Hutchison, 1982; Sisson, 1985).

Unit A - Quottoon Pluton

This major pluton was mapped north of the Skeena River along the Yellowhead Highway. It is a long narrow body that extends north through southeastern Alaska, where it is called the "foliated tonalite sill" (Brew and Ford, 1978; Gehrels *et al.*, 1991a). The Quottoon Pluton is a medium to coarse grained hornblende quartz diorite to tonalite and is intensely foliated close to its contact with the gneissic rocks of the Ecstall belt. Age determinations from this extensive pluton span Late Cretaceous (80 Ma) to mid-Eocene (43 Ma) time (van der Heyden, 1989, p.158-160), with Gareau's (1991a, p.184-185) age of 56.8 Ma collected from a site closest to the present study area.

Unit B - Ecstall Pluton

The Ecstall pluton is the largest of a series of magmatic-epidote-bearing plutons (Zen and Hammarstrom, 1984; Zen, 1985) in the western Cordillera called the Ecstall Suite (Woodsworth *et al.,* 1992, p.518-519). Along the western margin of the map area (Figure 7), the early Late Cretaceous Ecstall pluton is a large homogeneous biotite-hornblende diorite to quartz diorite. Age determinations span 98 Ma to 64 Ma (Gareau, 1991a, Figure 3-1) with the six most recent analyses averaging 93.5 Ma (unpublished data from van der Heyden, 1991, cited in Gareau, 1991a, p.161-164). The rock is weakly foliated, medium to coarse grained and weathers to a black and white, granular-textured surface. Foliation is defined by preferentially oriented biotite and hornblende. The rock is commonly equigranular, but locally displays plagioclase porphyroclasts. Prominent crystals and aggregates of magmatic epidote comprise 5% of the rock and are associated with knots of biotite. Dark grey to black mafic schlieren are common and parallel the foliation within the rock. Medium grained, euhedral, transparent titanite is also present. Contacts are sharp and discordant to the foliation. The eastern contact of the pluton is also discordant to the regional trend of map units. No chilled margin or contact metamorphic aureole was noted.

Unit C - Big Falls Orthogneiss

The Big Falls Orthogneiss is a Middle Devonian (385 Ma; Gareau, 1991a) medium to coarse grained epidote-biotite-hornblende metatonalite exposed in the southeastern corner of the mapped area. It crops out as homogeneous and resistant light grey rock with a maximum structural thickness of 3.5 kilometres. The unit is in gradational contact with the surrounding metavolcanic unit. This contact zone is several hundred metres wide and characterized by decreasing grain size and increasing biotite content outward from the orthogneiss.

Textural variations range from gneissic to porphyroclastic to mylonitic. Gneissic zones are tens of metres thick with 5 to 10 centimetre bands of alternating quartz-plagioclase and biotite-hornblende layers. Porphyroclastic orthogneiss consists of 0.5 to 1 centimetre diameter plagioclase porphyroclasts in a medium grey fine to medium grained matrix consisting of biotite, hornblende, quartz and plagioclase. Minor epidote pods and layers are common. Up to 2% garnet is locally present. A 20-metre-thick mylonite zone crops out south of Big Falls Creek. Within this zone, millimetre-scale plagioclase porphyroclasts are set in a very fine grained matrix.

The composition, homogeneity, and presence of clear, colourless, euhedral zircons led Gareau (1991a) to conclude that this tonalite orthogneiss is an intrusion. The gradational contacts, showing a variation from medium to fine grainsize, and incorporating an exposure of fragmental volcanic rock at one location, are consistent with a large coeval subvolcanic pluton which fed the surrounding and overlying volcanic pile.

Structure

Rocks of the Ecstall belt are highly deformed and characterized by a northwest-striking, steeply dipping to vertical, transposition foliation that is defined by near-parallel compositional layering and cleavage. Coaxial, map-scale, upright, F_1 and F_2 isoclinal folds and upright to inclined F_3 open folds are identified in the belt. Hornblende mineral lineations and stretching lineations are steeply northwest to southeast plunging and have been rotated through the vertical. Stereographic projections of structural data collected during the 1999 field season are plotted in Figure 9. The relative timing of thermal and dynamic metamorphic events deduced from analysis of textures and mineralogy are shown in Table 2.

Foliation

The oldest foliation preserved is S_0, defined by sub-centimetre to centimetre scale compositional layering that is interpreted to be primary. Within metasedimentary and metavolcanic units, S_0 is characterized by quartz-plagioclase layers alternating with phyllosilicate layers. Within intrusive bodies, S_0 is locally preserved as alternating centimetre-scale mafic and felsic layering (interpreted as primary flow-banding), mafic schlieren and rafts or sheets of country rock.

S_1 foliation is a penetrative cleavage defined by preferentially oriented biotite, muscovite and possibly chlorite within metasedimentary and metavolcanic rocks and by preferentially oriented biotite within intrusive rocks. S_1 cleavage is axial planar to F_1 isoclinal folds and therefore is parallel to S_0 compositional layering in F_1 limbs, but S_1 cleavage remains at a high angle to S_0 within F_1 hinge areas (Figure 8).

Together these two foliations define a composite transposition foliation known as S_t (Figure 8). This transposition foliation is defined by near-parallel S_0 and S_1 foliations, and by centimetre-scale intrafolial isoclinal F_1 folds. Transposed metatonalite dikes, epidote-diopside seams and pods, and sulphide seams also define S_t. S_t is the northwest-trending regional foliation observed in the belt, characterized by near-vertical to steeply southeast or steeply northwest dips (Figure 9a). Along the Skeena River, this regional foliation swings to a west-northwest trend.

An S_2 crenulation cleavage, defined by biotite and minor chlorite, is observed in thin section in the hinges of F_2 minor folds. This cleavage is not visible in handsample (or is not distinguishable from S_t in handsample) and is not considered to be regionally significant.

The youngest foliation identified in the map area, S_3, is a local, medium grained, crenulation cleavage axial

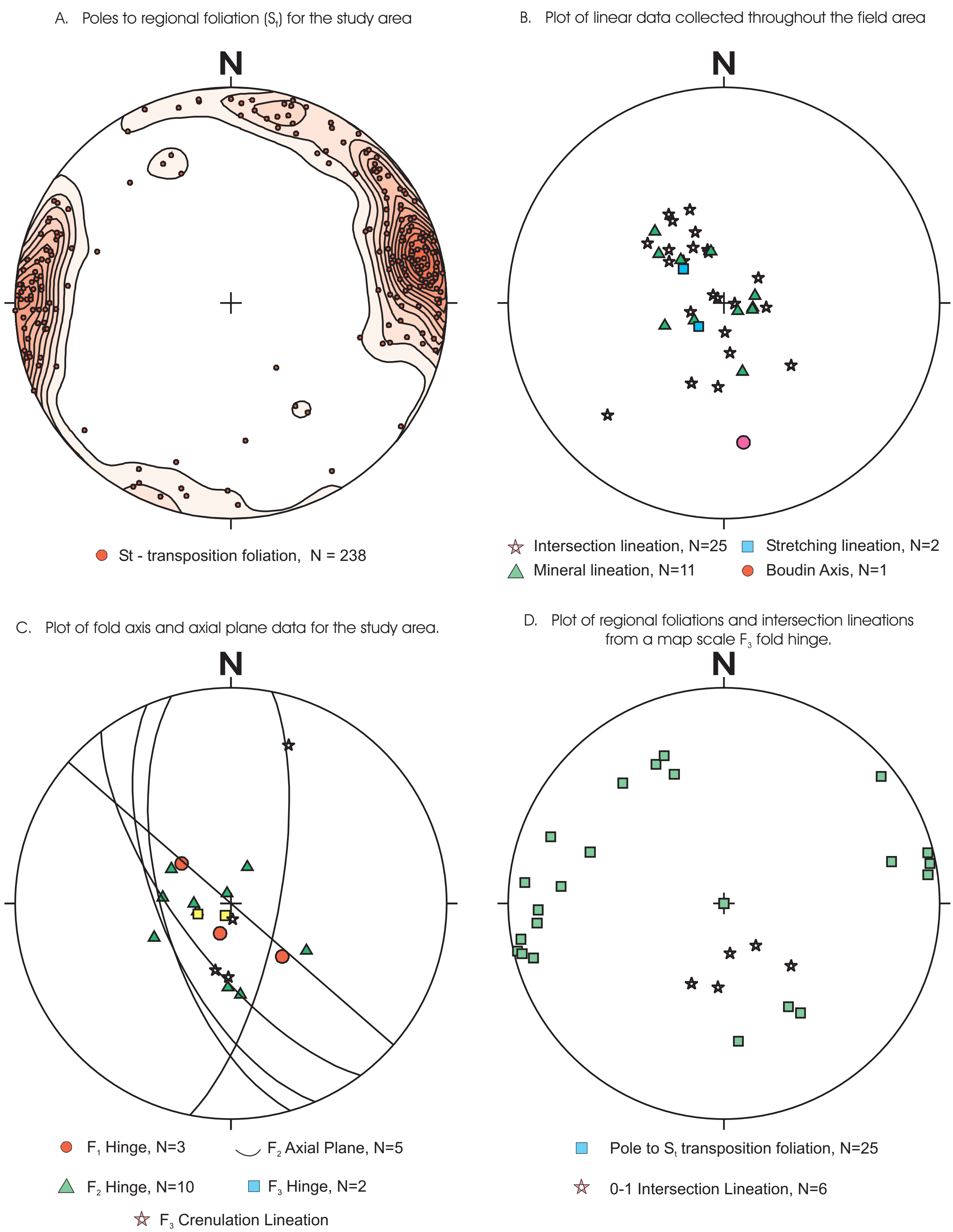

Figure 9. Stereonet plots for the northern Ecstall belt

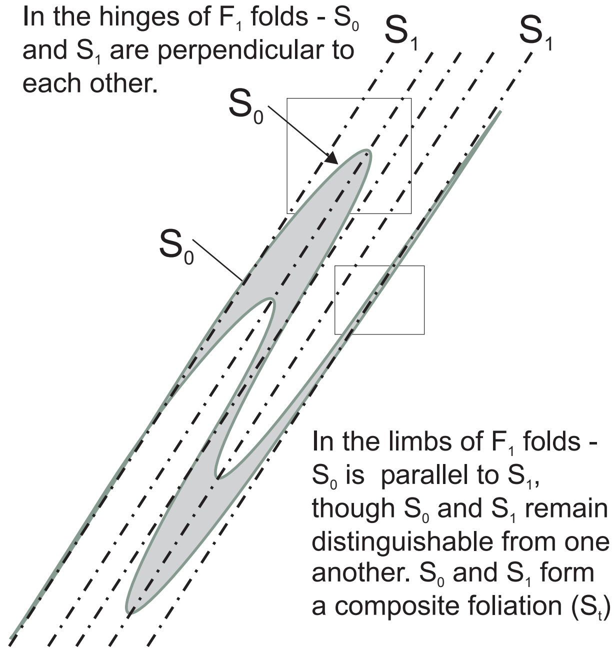

Figure 8. Geometric relationships between S_0, S_1, and S_t in an F_1 isoclinal fold.

TABLE 2
RELATIVE TIMING OF METAMORPHIC EVENTS

Geologic Time	Folding	Metamorphism	Foliation Development	Transposition Foliation
↑	F_3	M_2	S_3	
	F_2		S_2	
	F_1	M_1	S_1	S_t
			S_0	

planar to F_3 crenulations. This foliation was only identified in outcrops of quartz muscovite schist (felsic metavolcanics) near the Friday the 13th showing in the southern portion of the map area (Figure 7). S_3 is defined by preferentially oriented muscovite and minor biotite with an average spacing of 1 to 2 centimetres.

Folds

Minor Folds

F_1 minor folds are preserved as rare, rootless, intrafolial, isoclinal hooks and sheared hinges that fold S_0 compositional layering. They are near-vertical upright folds with steeply northwest-plunging hinge lines and near-vertical northwest-striking axial planes (Figure 9c). These folds are subtle and are most readily observed on highly weathered surfaces, or on folded veins or dikes. S_1 cleavage is axial planar to these folds.

F_2 minor folds are the most common folds recorded and are preserved as near-vertical, upright, tight to isoclinal folds with a one centimetre to half-metre wavelength. They fold S_t (both S_0 compositional layering and S_1 cleavage) and have steep northwest-plunging hinge lines and steep west-dipping to vertical axial planes (Figure 9c). F_2 folds differ from F_1 folds by the lack of axial planar cleavage in the F_2 hinge zones at outcrop or handsample scales.

F_3 minor folds occur as open to tight, asymmetric, parallel folds that fold S_t and the axial planes of F_2 folds. The scale of these folds ranges from 15 centimetres to several metres. Hinge lines of the F_3 folds are vertically plunging (Figure 9c) with near-vertical axial planes that are oblique to the regional foliation trend.

Major Folds

Vergence reversals of both F_1 and F_2 minor folds are consistent with major folds. Two upright, steeply north-plunging kilometre-scale F_2 closures have been outlined in the southern part of the map area near Big Falls Creek (Figure 7). Half-kilometre scale F_3 folds are well documented throughout the study area. These folds define a fold belt of northeast-vergent tight to open folds with an average wavelength of 500 metres. They are upright to inclined folds with moderately southeast-plunging hinge lines and moderately northeast-dipping axial planes. Hinge zones of these folds are characterized by moderately southeast-dipping S_t foliations and common F_3 m-folds (Figure 9d). These folds are responsible for the shifts in the northwest-striking regional foliation.

Lineations

Intersection lineations within the belt are preserved as S_0-S_1 bedding-cleavage lineations that are interpreted to be parallel to F_1 hinge lines. They are typically steeply northwest plunging, but do shallow up and plunge moderately to the north-northwest in the northern section of the map area (Figure 9b). Intersection lineations appear to be folded by F_3 map-scale folds in hinge areas.

Mineral lineations are the second most common lineation. These are best displayed in the metavolcanic unit where hornblende is abundant. These lineations are defined by fine to medium grained elongate to prismatic hornblende present on biotite partings and on S_t surfaces. The orientation of these lineations tends to mimic that of the intersection lineations (Figure 9b).

Stretching lineations are recorded from elongate clasts in the metasedimentary and metavolcanic units near Big Falls Creek. The near-vertical clasts have a minimum aspect ratio of 10:2:1. Stretched clasts illustrate the high degree of strain that these rocks have undergone. It is unlikely that stretching lineations defined by individual minerals could have survived the annealing that these rocks have undergone.

Faults

Northwest-striking faults with relative sinistral offset have been identified in a few outcrops. These exposures lie along northwest-trending linear topographic depressions that are readily evident on airphotos and which divert sections of stream drainages. There are many more northwest-trending topographic lineaments that have no confirmed association with faults, but these lineaments are suspected to be localized along similar northwest-striking sinistral faults.

Metamorphism

Evidence for two metamorphic episodes has been documented (Table 2). The peak M_1 mineral assemblage within mafic rocks consists of garnet, biotite, hornblende and titanite. Plagioclase compositions range from An_{40} to An_{45}. Siliceous and metasedimentary rocks have an M_1 mineral assemblage of muscovite, biotite and garnet. Kyanite and cordierite were identified in one pelitic layer within the metavolcanic unit. These assemblages are consistent with peak metamorphic conditions of upper amphibolite facies (Figure 5).

A regional retrograde metamorphic event (M_2), is interpreted from microscopic textures. Biotite is typically surrounded by wispy, fine grained, randomly oriented chlorite; remnant skeletal garnet porphyroblasts commonly display rims of matted chlorite.

Matrix grains of quartz and plagioclase lack any sub-grains and undulatory extinction within quartz is rare. Plagioclase feldspar noticeably lacks polysynthetic strain twins in thin section. Triple-point boundaries are common in quartz and plagioclase grains. Hornblende also displays polygonal grain boundaries in one section. The presence of polygonal matrix grains and the absence of microstructures indicating ductile deformation is consistent with a strong annealing event. This metamorphic event is most likely Cretaceous to Eocene in age, synchronous with intrusion of the Ecstall pluton or Quottoon pluton.

Relative timing of metamorphic and deformation events are constrained by an array of textural features. In the hinges of F_1 folds, M_1 biotite and muscovite grains are undeformed and are preferentially oriented parallel to F_1 axial planes. In F_2 hinges, the same mineral assemblage is kinked and has been rotated parallel to F_2 axial planes. Relative timing of garnet growth with respect to S_1 cleavage development remains ambiguous; garnets are observed truncating S_1 foliation, although S_1 foliation most commonly wraps around garnet porphyroblasts. Skeletal garnets also commonly display sinusoidal inclusion trails consisting of titanite and quartz grains.

Retrograde chlorite is randomly oriented. Chlorite is also common on brittle fault surfaces suggesting that late faulting occurred at greenschist facies conditions. The exact relationship between retrograde chlorite growth and D_2 and D_3 deformation could not be determined.

MINERAL DEPOSITS

Six styles of sulphide mineralisation were noted during this initial field season:

- volcanogenic massive sulphide deposits: VMS lenses, footwall stockworks and distal exhalite horizons have been described in the Ecstall belt
- felsic metavolcanics: pyritic quartz-muscovite schist
- pyritic cert
- quartzite: greater than 95% granoblastic quartz, with minor pynated along muscovite partings
- intrusive contacts: disseminated pyrite is distributed for a few to hundreds of metres into country rock
- faults: minor pyrite is commonly disseminated for 1 to 3 metres into the wallrock trace to minor disseminated pyrite is typical of most lithologies. In gneissic rocks, sulphides are concentrated in bands or boudins

In addition to these types of sulphide occurrences, some potential may exist for intrusion-related gold veins (Au-lithophile element deposits; Pogo - Fort Knox type deposits) associated with the mid-Cretaceous plutons and plugs that intrude the Ecstall belt at several locations (Gareau, 1997).

There are 18 mineral occurrences identified within Ecstall belt rocks; three of these are deposits with reserves. Seventeen of these are described in MINFILE, the remaining showing was discovered by Bishop Resources Ltd. during the 1999 field season. Industry geologists have classified all these occurrences as volcanogenic massive sulphides or related deposits such as footwall stockwork zones or distal exhalite horizons. These occurrences are spread over a 42 kilometre strike length, but all lie within the metavolcanic rock sequence of the Ecstall belt (Figure 3, and Unit 1 of Figure 7).

The following descriptions of the three largest deposits are summarized from MINFILE; reserves for these deposits are summarized in Table 3.

TABLE 3
RESERVES FOR ECSTALL BELT DEPOSITS

PROPERTY	SIZE (mT)	Cu %	Pb %	Zn %	Ag g/T	Au g/T
Scotia	1,240,000	0.1	0.4	3.8	13.0	0.25
Ecstall	6,349,700	0.6		2.5	20.0	0.5
Packsack	2,700,000	0.5	0.01	0.2	34.0	0.3
TOTAL RESOURCE	10,289,700	0.5	0.05	2.1	22.8	0.4

Scotia (103I 007)

The Scotia property is underlain by felsic gneiss, mafic gneiss and amphibolite. Deformed Zn-Ag-Pb-Au volcanogenic massive sulphide mineralization occurs in three stacked lenses extending over a 230-metre strike length, mainly within felsic gneiss. These three lenses may lie within parallel limbs of an overturned isoclinal fold. Massive sulphide widths range up to 11 metres. The sulphide zones strike 160 degrees, dip 40 degrees southwest and plunge 9 degrees south. Exposed in a south-facing cliff, the deposit is open along strike to the northwest and down dip to the southwest. Sulphide minerals include sphalerite, galena, pyrite, pyrrhotite, bornite and chalcopyrite.

Ecstall (103H 011)

The Zn-Cu-Ag-Au Ecstall deposit occurs in hydrothermally altered metavolcanic rocks. Two tabular, concordant, en echelon bodies, the North Lens and South Lens, consist of pyrite with minor chalcopyrite and sphalerite and lesser pyrrhotite, marcasite and galena. The two lenticular bodies of massive pyrite strike north, dip steeply east and plunge steeply south. The North Lens measures 300 x 150 x 30 metres. The South Lens measures 400 x 360 x 7 metres. A smaller deposit occurs 760 metres north of the North Lens, where a 30 x 2.4 metre lens of massive pyrite is exposed.

Property-scale exploration by Falconbridge in 1986 indicated significant stockwork copper mineralization in felsic rocks south of the Ecstall River in the Thirteen Creek area. This stockwork mineralization was interpreted as a possible feeder zone to a volcanogenic massive sulphide deposit.

Packsack (103H 013)

Two massive sulphide bodies, 170 metres apart along strike, occur within quartz-sericite schist associated with a 30-metre-wide shear zone. Disseminated pyrite is common throughout the quartz-sericite schist which has been traced continuously for 600 metres along strike. The deposits average 4 metres in thickness. The southern lens, up to 6 metres thick and traced for 365 metres, consists of massive pyrite with minor chalcopyrite, chalcocite and sphalerite. The northern lens is up to 0.6 metres thick

EXPLORATION AND MINERAL POTENTIAL

All eighteen VMS prospects of the Ecstall belt crop out. These showings have been located despite the fact that rock exposure throughout this belt is limited, thus the potential for discovery of additional deposits in the overburden-covered areas of this highly prospective belt are excellent. All discoveries have been achieved without the aid of regional-scale geological maps, geophysical surveys or geochemical surveys - standard exploration tools which have been particularly successful in the search for blind (subcropping or deeply buried) VMS deposits elsewhere.

Most showings have been discovered over the last 15 years from follow-up of property-scale stream sediment geochemical surveys. These geochemical surveys have not yet covered the whole of the prospective metavolcanic rocks of the belt. Moss-mat geochemical surveys conducted for the past three years have returned superior results compared to duplicate samples collected from stream sediments (A. Birkeland, Arnex Resources Ltd, personal communication).

Geological reconnaissance work and prospecting programs by companies have been intermittent and cover only portions of the belt. This point is exemplified by the Friday the 13th Zn-Cu showing, discovered this season during follow-up of stream sediment and moss-mat survey anomalies. The prospect was located in an eight-year-old logging road-cut where it is exposed as a 50-metre-long highly gossanous band, now heavily overgrown by roadside brush. For most of the last decade the three major deposits and adjacent ground have been held by three separate, competing companies and no comparison or synthesis of the detailed geological information collected around each deposit has been attempted. A company program designed to trace prospective pyritic quartz-sericite units through the central and northern parts of the belt commenced this season, but has limited funding.

No reference to chert has been found in geologic reports reviewed to date, yet two exposures were identified during the short 1999 field season - both exposures were strongly (> 5%) pyritic and part of the felsic metavolcanic package. These units record periods of prolonged exhalative activity in quiescent conditions and deserve careful follow-up.

Recent global research into the geologic setting of VMS deposits have stressed the importance of subvolcanic plutons of tonalite/trondhjemite as the heat source which concentrates VMS deposits at the overlying paleosurface (Galley, 1996; Large, 1996). An exploration program could be designed to investigate Gareau's (1991a,c) conclusion that the major Middle Devonian tonalite/trondhjemite pluton within the Ecstall belt, the Big Falls orthogneiss, is the coeval subvolcanic magma chamber that fed the volcanic pile.

Ground electromagnetic (EM) surveys carried out over known deposits generate clear anomalies that have been used to guide drilling on the prospects. This confirms that regional airborne geophysical surveys can also be effective in this belt, in contrast to many of the VMS districts of the Cordillera where highly conductive carbonaceous sedimentary rock masks the expected responses from sulphide accumulations.

Deposits discovered to date have significant tonnage but overall low base metal grades (Table 3). However, the higher grade section of the Scotia deposit has reserves of 224,000 tonnes grading 12.2% Zn, 1.2% Pb, 0.2% Cu, 23 g/t Ag and 0.55 g/t Au, indicating good potential in this belt for VMS deposits of economic size and grade.

CONCLUSIONS

The Ecstall metavolcanic belt is a classic VMS-rich greenstone belt. This Devonian age volcano-sedimentary complex is clearly underexplored with excellent potential for discovery of additional prospects and good potential for discovery of economic Zn-Cu-Ag-Au VMS deposits. With regional exploration work still at a relatively early stage, exploration success can be expected from programs ranging from prospecting, to regional stream geochemistry, to airborne geophysics, to regional-scale and property-scale geologic mapping. Despite its location in the heart of the rugged Coast Mountains the district has admirable access and proximity to infrastructure.

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