Age and Geologic History of the Ecstall Greenstone Belt, Northwest British Columbia

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INTRODUCTION

The Ecstall Greenstone Belt is 80 kilometres long and 3 to 20 kilometres wide, and lies midway between the northern port cities of Prince Rupert and Kitimat (Figure 1). A century of prospecting has located 37 sulphide mineral occurrences at surface, including 3 VMS deposits with combined reserves of 10 million tonnes (Alldrick, this volume). In response to continued interest and encouragement from the exploration industry, Ecstall has been the focus of many geological research programs, including four geochronological studies of intrusive, volcanic and sedimentary units (Gareau, 1991a; Childe, 1997; Gareau and Woodsworth, 2000; this report). This paper compiles all the results from these four studies and incorporates the dates into a geologic history for the belt.

GEOLOGIC SETTING

The Ecstall Greenstone Belt is a small segment of the Central Gneiss Complex, a 2000-kilometre-long anastomosing network of metamorphosed Proterozoic to Paleozoic volcanic, sedimentary and minor plutonic rocks (Wheeler and McFeely, 1991; Read *et al*., 1991). The Central Gneiss Complex is enclosed by Late Silurian to Eocene granitoid rocks of the Coast Plutonic Complex (Woodsworth *et al*., 1992). Together, these two complexes comprise the Coast Crystalline Belt.

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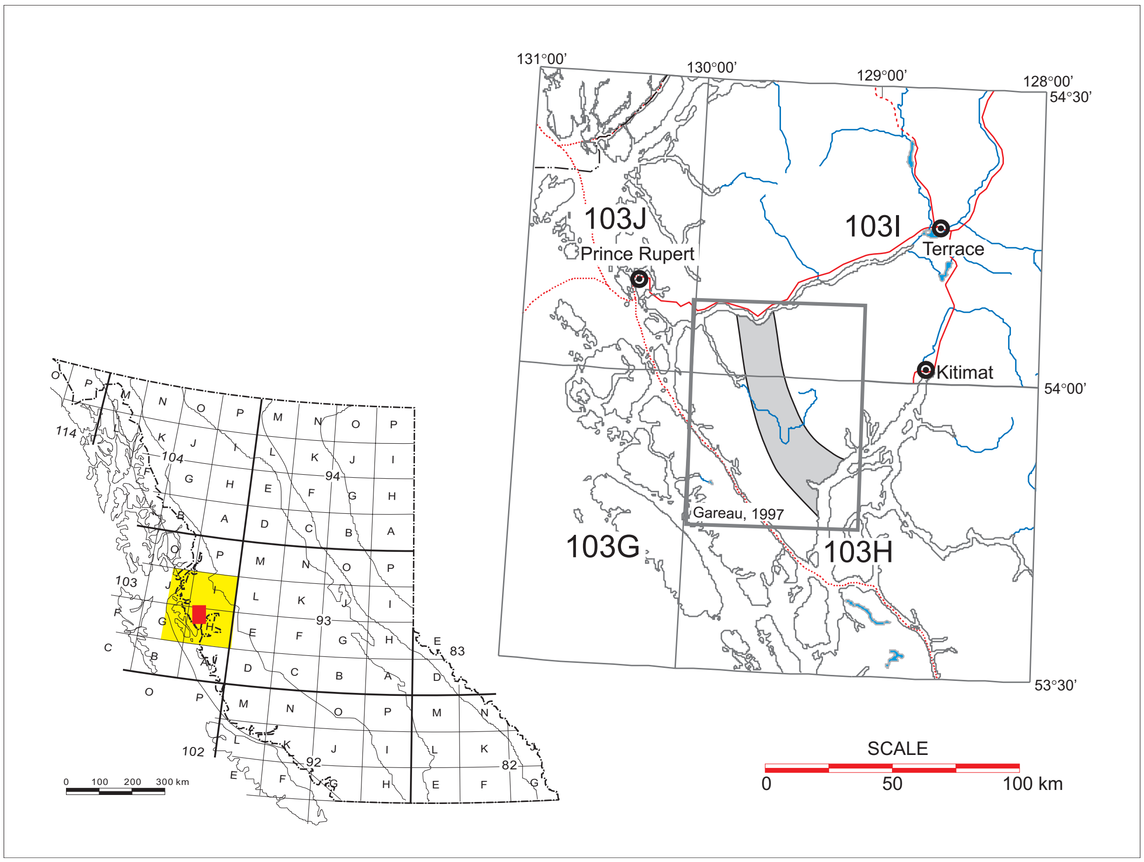
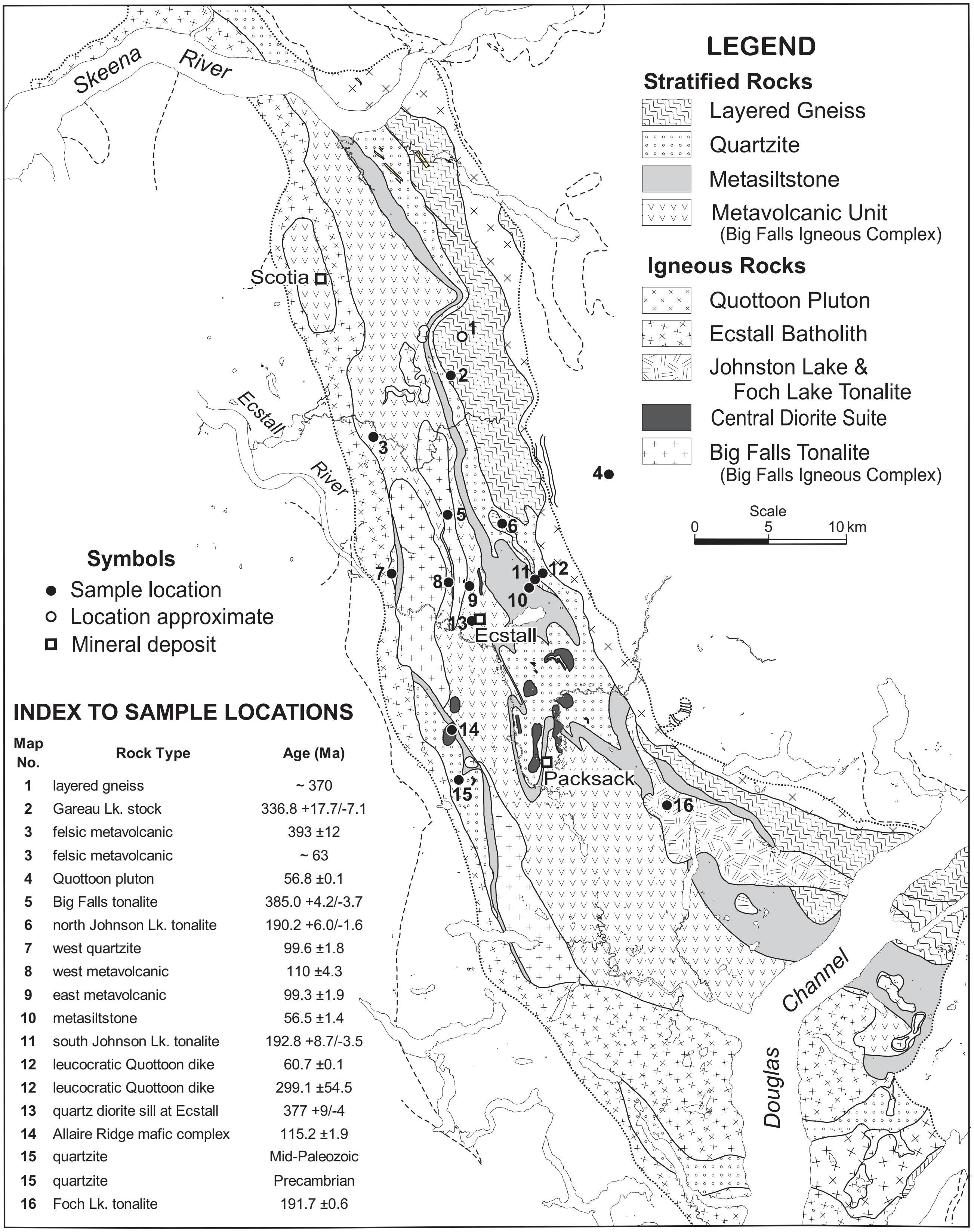


Figure 1. Location of the Ecstall belt in British Columbia. Box shows area of Gareau (1997) geology map.



Map No.	Rock Type	Age (Ma)
1	layered gneiss	~ 370
2	Gareau Lk. stock	336.8 +17.7/-7.1
3	felsic metavolcanic	393 ±12
3	felsic metavolcanic	~ 63
4	Quottoon pluton	56.8 ±0.1
5	Big Falls tonalite	385.0 +4.2/-3.7
6	north Johnson Lk. tonalite	190.2 +6.0/-1.6
7	west quartzite	99.6 ±1.8
8	west metavolcanic	110 ±4.3
9	east metavolcanic	99.3 ±1.9
10	metasiltstone	56.5 ±1.4
11	south Johnson Lk. tonalite	192.8 +8.7/-3.5
12	leucocratic Quottoon dike	60.7 ±0.1
12	leucocratic Quottoon dike	299.1 ±54.5
13	quartz diorite sill at Ecstall	377 +9/-4
14	Allaire Ridge mafic complex	115.2 ±1.9
15	quartzite	Mid-Paleozoic
15	quartzite	Precambrian
16	Foch Lk. tonalite	191.7 ±0.6

Figure 2. Simplified geology of the Ecstall belt (modified from Gareau, 1997) and geochronology sample sites (*see* Tables 1 and 2).

The Ecstall belt is a north-northwest trending, medium to high-grade metamorphic belt bounded by the elongate mid-Cretaceous Ecstall pluton on the west and the Paleocene Quottoon pluton on the east (Figure 2). Gareau (1991a) divided stratified rocks of the belt into four principal units: metavolcanic rocks, metasedimentary rocks, quartzite and layered gneiss. The metavolcanic unit consists of mafic to intermediate composition metavolcanic rocks, interlayered with lesser felsic metavolcanic and metasedimentary rocks. Within the belt, metavolcanic rocks have a gradational contact with the two large mid-Devonian plutons of the Big Falls tonalite (Figure 2). Gareau (1991a) suggests that the gradational zone between identifiable plutonic and volcanic rocks may mark a transition from cogenetic high-level intrusive to extrusive rocks, implying that the main volcanic sequence in the belt is also of mid-Devonian age. In addition to Paleozoic intrusions, two elongate plutonic bodies of Early Jurassic age, the Johnson Lake and the Foch Lake tonalites, intrude the eastern part of the belt (Figure 2).

GEOCHRONOLOGY STUDIES

Gareau (1991a, p.160-199) completed age determinations on a comprehensive suite of intrusive rocks from the Ecstall belt. Seven samples were dated using the U-Pb method to obtain ages of the protoliths of metamorphic rocks, to date magmatic episodes related to periods of tectonic activity, and to determine the ages of the two bounding plutons to the Ecstall belt. The latter would help to constrain the timing of regional metamorphism and deformation that affected Ecstall belt rocks. A suite of five hornblende K-Ar samples were collected to document the timing of cooling below the hornblende K-Ar closure temperature after the last regional metamorphic event, to evaluate the thermal effect of the bounding plutons, and to provide a minimum age for a mafic-ultramafic intrusive suite that could not be dated by U-Pb methods.

Childe (1997, p.222-238) dated a quartz diorite sill that crops out immediately west of the Ecstall volcanogenic massive sulphide deposit, to determine a minimum age for the syngenetic VMS mineralization.

Gareau and Woodsworth (2000, p.27-28) report preliminary results of U-Pb detrital zircon work on a sample of the extensive quartzite unit exposed along both margins of the Ecstall belt and a U-Pb date on zircon from the layered gneiss unit in the northeastern part of the belt.

This report presents two new U-Pb dates obtained from one rock sample; a protolith age for a felsic metavolcanic rock and an age for a metamorphic zircon separate from the same rock.

ANALYTICAL RESULTS

Analyses of 16 samples collected during these four geochronological studies have yielded 19 dates. These results are listed in geographical order (Table 1 and Figure 2) and in chronological order (Table 2). U-Pb analytical data are presented in Table 3 and Figure 3 shows the stan-

TABLE 1
INDEX TO SAMPLES LISTED NORTH TO SOUTH (*SEE* FIGURE 2).
(NOTE THAT 19 SEPARATE DATES HAVE BEEN DETERMINED FROM 16 SAMPLES)

Map N0.	Sample Number	Rock Type	Method	Mineral	Age (Ma)	Comment	Reference
1	G89-132-2	Layered Gneiss	U-Pb	zircon	**~ 370**	age of igneous protolith	G & W, 2000
2	G88-140-2	Gareau Lake stock	U-Pb	zircon	**336.8 +17.7 / -7.1**	age of quartz diorite stock	Gareau, 1991a
3	A99-5-6	felsic metavolcanic	U-Pb	zircon	**393 +/- 12**	age of felsic protolith	this report
3	A99-5-6	felsic metavolcanic	U-Pb	zircon	**~ 63**	metamorphic zircon	this report
4	G87-246-1	Quottoon pluton	U-Pb	zircon	**56.8 +/- 0.1**	age of tonalite pluton	Gareau, 1991a
5	G87-172-2	Big Falls tonalite	U-Pb	zircon	**385.0 +4.2 / -3.7**	age of tonalite protolith	Gareau, 1991a
6	G87-218-2	north Johnson Lake tonalite	U-Pb	zircon	**190.2 +6.0 / -1.6**	age of tonalite protolith	Gareau, 1991a
7	G88-67-2	west quartzite	K-Ar	hornblende	**99.6 +/- 1.8**	hornblende cooling age	Gareau, 1991a
8	G88-80-2	west metavolcanic	K-Ar	hornblende	**110 +/- 4.3**	hornblende cooling age	Gareau, 1991a
9	G88-73-2	east metavolcanic	K-Ar	hornblende	**99.3 +/- 1.9**	hornblende cooling age	Gareau, 1991a
10	G88-84-2	metasiltstone	K-Ar	hornblende	**56.5 +/- 1.4**	hornblende cooling age	Gareau, 1991a
11	G87-139-5	south Johnson Lake tonalite	U-Pb	zircon	**192.8 +8.7 / -3.5**	age of tonalite protolith	Gareau, 1991a
12	G87-140-2	leucocratic Quottoon dike	U-Pb	zircon	**60.7 +/- 0.1**	age of Quottoon dike	Gareau, 1991a
12	G87-140-2	leucocratic Quottoon dike	U-Pb	zircon	**299.1 +/- 54.5**	inherited zircon	Gareau, 1991a
13	EL-GC-01	quartz diorite sill at Ecstall VMS	U-Pb	zircon	**377 +9 / -4**	age of quartz diorite sill	Childe, 1997
14	G88-147-1	Allaire Ridge mafic complex	K-Ar	hornblende	**115.2 +/- 1.9**	hornblende cooling age	Gareau, 1991a
15	G89-98-6	quartzite	U-Pb	zircon	**Mid-Paleozoic**	detrital zircon	G & W, 2000
15	G89-98-6	quartzite	U-Pb	zircon	**Precambrian**	detrital zircon	G & W, 2000
16	G88-108-2	Foch Lake tonalite	U-Pb	zircon	**191.7 +/- 0.6**	age of tonalite protolith	Gareau, 1991a

TABLE 2
DATES FROM THE ECSTALL BELT IN CHRONOLOGICAL ORDER
(NOTE THAT 19 SEPARATE DATES HAVE BEEN DETERMINED FROM 16 SAMPLES)

Map No.	Rock Type	Age (Ma)	Comment
10	metasiltstone	56.5 ±1.4	hornblende cooling age
4	Quottoon pluton	56.8 ±0.1	age of tonalite pluton
12	leucocratic Quottoon dike	60.7 ±0.1	age of Quottoon dike
3	felsic metavolcanic	~ 63	metamorphic zircon
9	east metavolcanic	99.3 ±1.9	hornblende cooling age
7	west quartzite	99.6 ±1.8	hornblende cooling age
8	west metavolcanic	110 ±4.3	hornblende cooling age
14	Allaire Ridge mafic complex	115.2 ±1.9	hornblende cooling age
6	north Johnson Lk. tonalite	190.2 +6.0/-1.6	age of tonalite protolith
16	Foch Lk. tonalite	191.7 ±0.6	age of tonalite protolith
11	south Johnson Lk. tonalite	192.8 +8.7/-3.5	age of tonalite protolith
12	leucocratic Quottoon dike	299.1 ±54.5	inherited zircon
2	Gareau Lk. stock	336.8 +17.7/-7.1	age of quartz diorite stock
1	layered gneiss	~ 370	age of igneous protolith
15	quartzite	Mid-Paleozoic	detrital zircon
13	quartz diorite sill at Ecstall	377 +9/-4	age of quartz diorite sill
5	Big Falls tonalite	385.0 +4.2/-3.7	age of tonalite protolith
3	felsic metavolcanic	393 ±12	age of felsic protolith
15	quartzite	Precambrian	detrital zircon

dard Pb/U concordia plots. Results are discussed below in geochronological order, with reference to the schematic stratigraphy (Figure 4) and geologic history of the belt (Figure 5).

GEOLOGY AND GEOCHRONOLOGY

Regional stratigraphy was extensively discussed by Gareau (1991a,b,c and 1997). Stratigraphic tops, however, remain unclear (*e.g.* Figure 2 in Gareau, 1991a). Stratigraphic indicators identified by exploration geologists, such as pillow lavas (Hassard *et al.*, 1987, p.10), graded beds and accretionary lapilli (Schmidt, 1996, p.8) were too deformed to be interpreted reliably. The sense of stratigraphic `tops' used in this report is based on the conspicuous absence of the extensive Big Falls tonalite within the widespread metasedimentary units that are locally adjacent to the tonalite plutons (*e.g.* Gareau, 1997), and on the presence of abundant "granitoid" (tonalite) clasts within conglomeratic members of the metasiltstone unit (Gareau, 1991a; Figure 7b in Gareau and Woodsworth, 2000).

The oldest dates from Ecstall belt rocks are Precambrian and mid-Paleozoic ages obtained from detrital zircons in a sample of quartzite (metasandstone) collected along the southwestern edge of the Ecstall belt (sample location 15 on Figure 2 and Tables 1 and 2) (Gareau and Woodsworth, 2000). These detrital zircon ages suggest that the maximum possible age for deposition of this sandstone is mid-Paleozoic; however, the actual depositional age may be younger. As shown in Figures 4 and 5, these sedimentary rocks are now interpreted to have been deposited following the accumulation of the metavolcanic sequence.

At the base of the stratigraphic sequence is the metavolcanic unit which consists of mafic to intermediate to felsic metavolcanic rocks and derived metasedimentary rocks. The unit has been isoclinally folded (Gareau, 1991a, p.46), consequently apparent stratigraphic thicknesses, which range from 1 to 10 kilometres, are at least double their original value. A welded, felsic pyroclastic rock (sample number A99-5-6; location 3 on Figure 2 and Tables 1 and 2) was collected in the north-central part of the metavolcanic sequence, from a rockcut on a logging road along the south bank of Big Falls Creek. Felsic metavolcanic rocks from this same stratigraphic interval host the F-13 sulphide prospect on the north bank of Big Falls Creek, 220 metres to the north-northwest (Alldrick, this volume). Two populations of zircon were recovered from this sample: clear, colourless, gem-quality subrounded to stubby prismatic grains, interpreted as metamorphic in origin; and pale yellow, well-faceted, elongate prismatic grains, interpreted as igneous in origin. The results of four analysed fractions define a linear array on a concordia plot (Figure 3a). Clear rounded grains yield relatively young ages and euhedral elongate prismatic grains give older ages. A regression line through the data yields an upper intercept of 393 ± 12 Ma, interpreted as the best esti-

TABLE 3
U-Pb ANALYTICAL DATA FOR ROCKS FROM THE ECSTALL BELT

Fraction[1]	Wt	U[2]	Pb[*3]	$^{206}Pb^{4}$/^{204}Pb	Pb[5]	$^{208}Pb^{6}$	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]		
	mg	ppm	ppm		pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
A99-5-6 felsic metavolcanic rock												
B m,4,p	0.030	443	12	3764	6.1	11.2	0.0275 (0.13)	0.1992 (0.19)	0.0525 (0.10)	175.0 (0.4)	184.5 (0.6)	307 (4.6)
C m,5,p,e	0.010	339	13	1511	5.3	10.1	0.0376 (0.13)	0.2781 (0.26)	0.0536 (0.18)	238.1 (0.6)	249.1 (1.1)	354 (8.3)
D m,4,sr	0.015	217	2.1	393	5.3	9.2	0.0099 (0.27)	0.0647 (1.5)	0.04761 (1.4)	63.3 (0.3)	63.7 (1.9)	80 (67/69)
E f,9,sr	0.015	315	5.5	774	6.8	9.3	0.0175 (0.18)	0.1213 (0.49)	0.05026 (0.42)	111.9 (0.4)	116.3 (1.1)	207 (20)
EL-GC-01 quartz diorite sill at Ecstall VMS property												
A c,40,p	0.315	393	22	20943	21	6.5	0.058 (0.25)	0.4331 (0.29)	0.05413 (0.10)	363.6 (1.8)	365.4 (1.8)	377 (4.4)
B c,35,p	0.236	474	26	27192	14	6.9	0.0559 (0.15)	0.4165 (0.21)	0.05406 (0.09)	350.5 (1.0)	353.5 (1.3)	374 (4.1)
C m,50,p	0.275	438	25	40696	11	6.7	0.0579 (0.63)	0.4315 (0.64)	0.05409 (0.10)	362.6 (4.4)	364.2 (3.9)	375 (4.4)
D f,90,p	0.072	511	29	18076	7.3	7.2	0.0573 (0.13)	0.4272 (0.20)	0.05408 (0.09)	359.1 (0.9)	361.2 (1.2)	374 (4.2)
E c,50,p	0.042	579	33	9146	10	6.5	0.0586 (0.11)	0.4371 (0.19)	0.05411 (0.10)	367.0 (0.8)	368.2 (1.2)	376 (4.3)
F c,30,p	0.091	430	24	5766	24	6.8	0.0566 (0.13)	0.4215 (0.21)	0.0540 (0.12)	354.7 (0.9)	357.1 (1.3)	373 (5.4)
G c,12,p	0.045	493	28	7931	10	6.6	0.0577 (0.21)	0.4304 (0.27)	0.05407 (0.11)	361.8 (1.5)	363.4 (1.6)	374 (4.7)
H m,40,p	0.054	484	27	8154	12	6.7	0.0576 (0.11)	0.4298 (0.20)	0.05409 (0.10)	361.2 (0.8)	363.0 (1.2)	375 (4.6)

Analytical techniques listed in Friedman et al., 2001 (in press).

[1] Zircon fractions air abraded except EL-GC-01, B. Grain size, intermediate dimension: cc=>250µm, c=<250µm and >134µm, m=<134µm and >104µm, f=<104µm and >74µm, ff <74µm; Grain size code followed by number of grains analysed. Grain character codes: b= broken, e=elongate, p=prismatic, sr=subrounded. Zircons nonmagnetic on Franz magnetic separator at field strength of 1.8A and sideslopes of 1°-2°. Front slope of 20°.

[2] U blank correction of 1pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.004/amu).

[3]Radiogenic Pb

[4]Measured ratio corrected for spike and Pb fractionation of 0.0035 to 0.0042/amu ± 20% (Daly collector), which was determined by repeated analysis of NBS Pb 981 standard throughout the course of this study.

[5]Total common Pb in analysis based on blank isotopic composition.

[6]Radiogenic Pb

[7]Corrected for blank Pb (2-10 pg), U (1 pg) and common Pb concentrations based on Stacey Kramers model Pb at the age or the $^{207}Pb/^{206}Pb$ age of the rock.

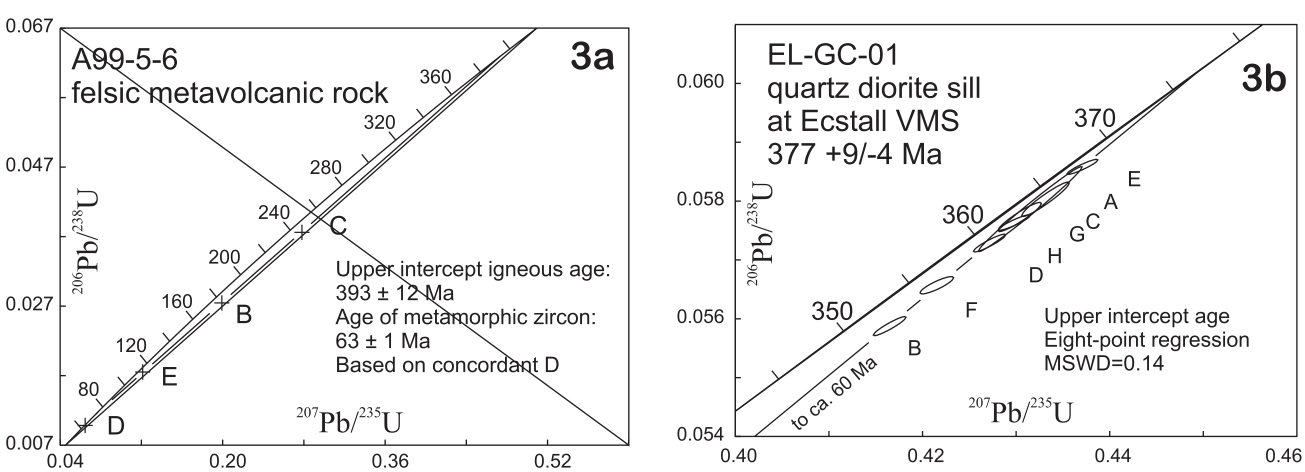


Figure 3. Concordia plots showing U-Pb zircon results for samples from the Ecstall belt: 3a. Sample A99-5-6, felsic metavolcanic rock; 3b. Sample EL-GC-01, quartz diorite sill from the Ecstall VMS property. Error ellipses are plotted at the 2σ level of uncertainty. Data on plot 5a are represented as crosses that do not reflect precision; see Table 3 for analytical precision. See text for detailed interpretations.

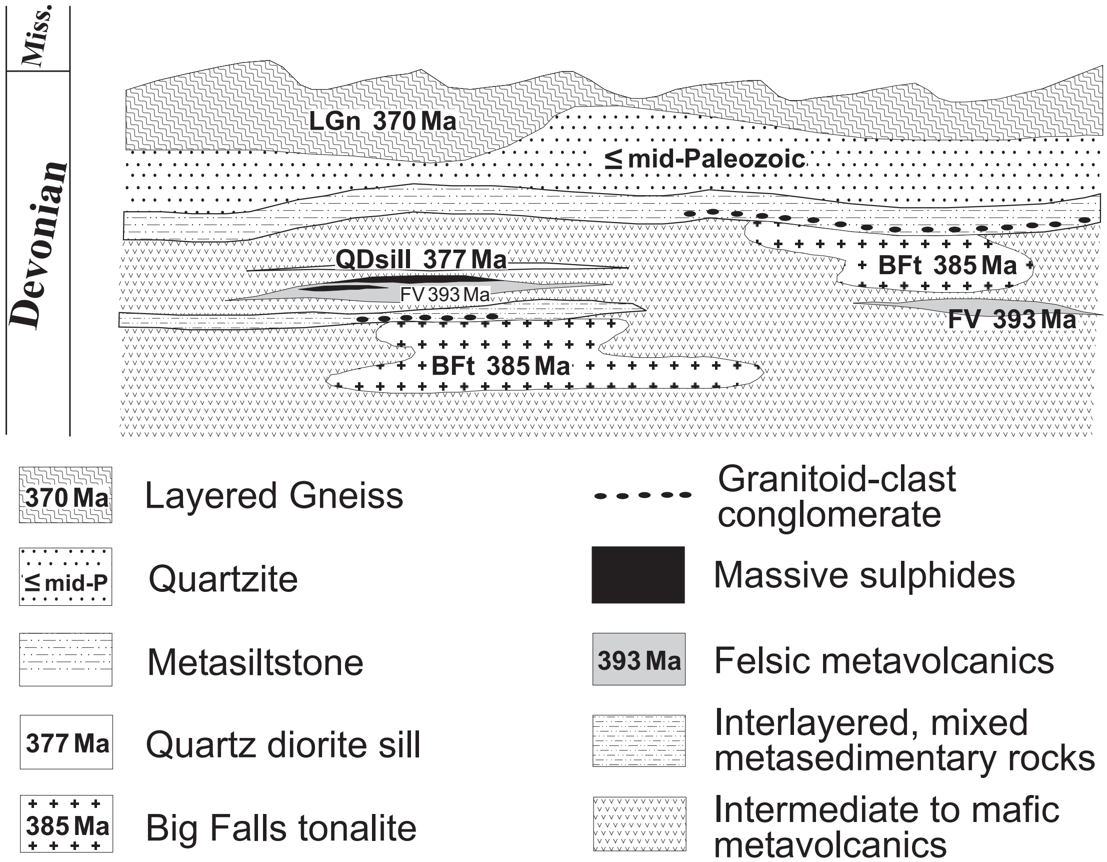


Figure 4. Schematic stratigraphy of the Ecstall belt.

mate for the igneous age of the sample. This U-Pb zircon age of 393 Ma confirms the mid-Devonian age attributed to the Ecstall belt volcanic sequence by Gareau (1991a,b). This sample also yielded fraction D (Figure 3a) which produced a concordant age of ~63 Ma that is interpreted as a good estimate for the crystallization age of metamorphic zircon in this rock.

Gareau (1997) mapped two large bodies of foliated intrusive rock, collectively named the Big Falls tonalite (location 5 on Figure 2 and Tables 1 and 2). These are enclosed mainly by the metavolcanic sequence of the Ecstall metamorphic belt, and locally by the overlying metasiltstone unit. A sample from the eastern lens of this rock produced a U-Pb zircon age of 385 ± 4 Ma, leading Gareau (1991a,b) to conclude that the tonalite bodies are coeval, subvolcanic intrusions that fed the overlying volcanic pile. Recent global research into the geologic setting of VMS deposits has stressed the importance of subvolcanic plutons of tonalite/trondhjemite composition as the heat source which generates VMS deposits at the overlying paleosurface (Galley, 1996; Large *et al.*, 1996).

Childe (1997) analysed a sample of foliated quartz diorite sill (location 13 on Figure 2 and Tables 1 and 2) that crops out just to the west of the North Lens of the Ecstall massive sulphide deposit (Alldrick, this volume; Schmidt, 1995). U-Pb analytical results for eight zircon fractions from sample EL-GC-01 define a linear array on a concordia plot (Figure 3b). A regression line through these data yield an upper intercept of 377 +9/-4 Ma, interpreted as the best estimate for the igneous age of the quartz diorite intrusion. This 377 Ma U-Pb zircon age provides a Late Devonian minimum age for the nearby, syngenetic sulphide deposit and its enclosing metavolcanic host rocks (Childe, 1997). The regression line also indicates a lower intercept age of 60 +107/-109 Ma, which likely records the age of Pb loss.

The U-Pb zircon age of 377 +9 / -4 Ma obtained from the quartz diorite sill at the Ecstall deposit is statistically similar to the 393 ± 12 Ma age for the metavolcanic rocks reported above. The age of this sill is also within error of the 385 +4.2 / -3.7 Ma age for the Big Falls tonalite. Taken together, these three U-Pb zircon results (locations 13, 3 and 5 on Figure 2) reveal a Middle Devonian intrusive-extrusive complex consisting of a suite of subvolcanic, synvolcanic stocks and sills; coeval, comagmatic volcanic rocks; and associated sedimentary rocks. This Middle Devonian volcanic rock succession hosts all three of the massive sulphide deposits and most of the smaller sulphide prospects of the Ecstall belt. These comagmatic rocks and their locally derived, intercalated sedimentary rocks are informally referred to as the Big Falls Igneous Complex to denote the rocks most important for the for-

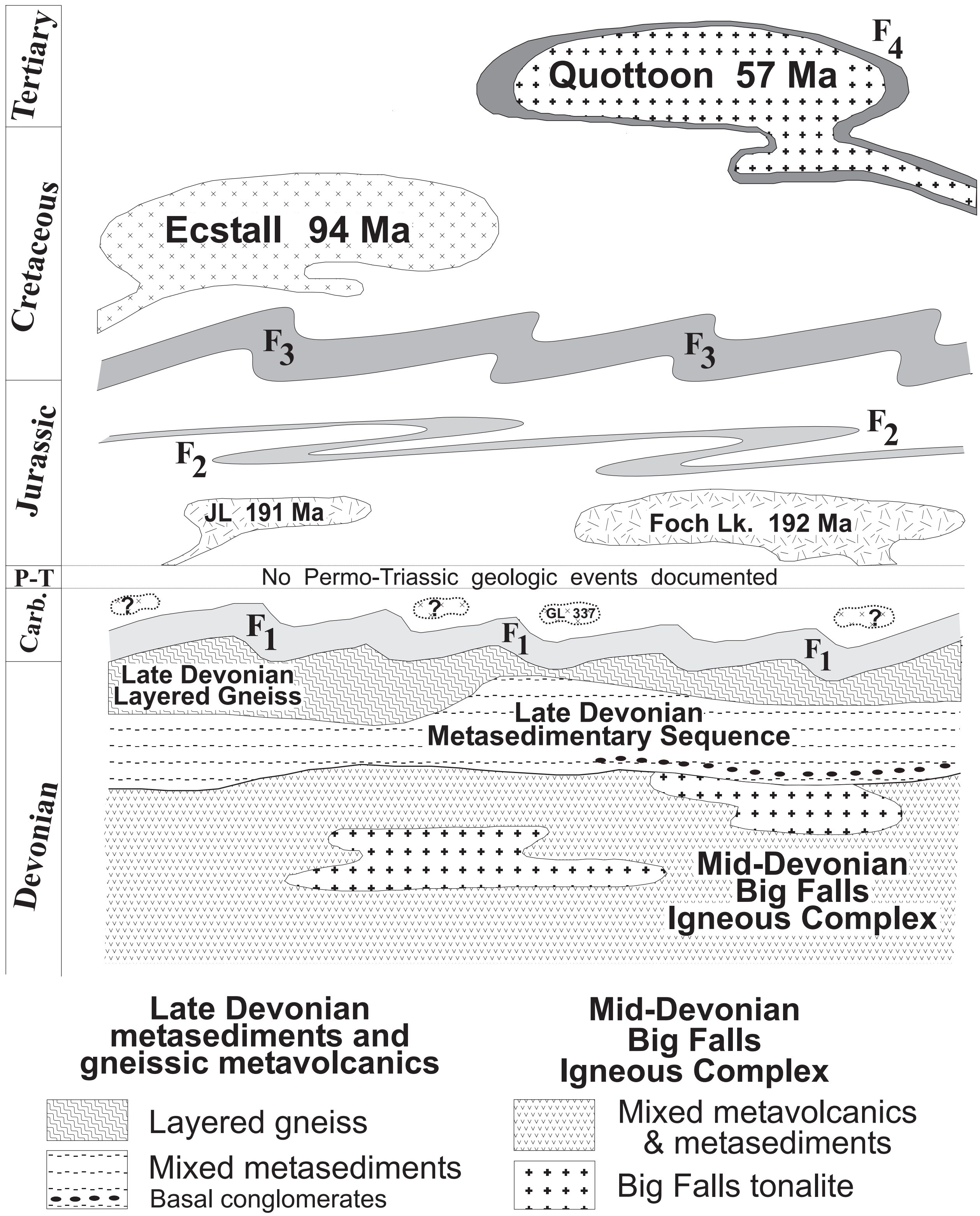


Figure 5. Schematic geologic history of the Ecstall belt. F-1, F-2, F-3 and F-4 are successive episodes of deformation. JL = Johnson Lake stock; GL = Gareau Lake stock (adapted from Gareau, 1991a,b,c and 1997).

mation and preservation of volcanogenic massive sulphide deposits within the belt.

The volcanic succession is overlain regionally by a unit of medium to dark grey to black metasiltstone that is locally pyritic. This is the "metasedimentary unit" of Gareau (1991a) and the "metaclastic unit" of Gareau and Woodsworth (2000). The hornblende-biotite-quartz-feldspar-epidote rock has a mafic mineral content ranging from 20% to 70% (Gareau, 1991a). Rare intervals that contain fine disseminated magnetite grains have been noted. Thickness of this unit ranges from 100 metres near the Packsack deposit to greater than 5 kilometres along Douglas Channel; much of this increase is due to structural thickening near the axis of a regional scale fold in the Douglas Channel-Hawkesbury Island area. Gareau (1991a) describes contacts between the metasiltstone unit and the metavolcanics ranging from gradational to sharp. This unit is significant in the regional stratigraphic construction because no dikes, sills or stocks correlated with the adjacent Big Falls Igneous Complex have been identified within the metasiltstone unit, although younger intrusive rocks are common. In contrast, the unit does incorporate repeated, extensive lenses of granitoid clast conglomerate (Gareau, 1991a). Clasts average 10 centimetres in diameter and typically make up 10% of the rock. Gareau (1991a) reports an exposure of conglomerate on the ridgecrest north of Johnston Lake that is 300 metres thick. Mafic mineral content of the granitoid clasts ranges from 20% to 70%, and K-feldspar is absent, indicating a compositional range from tonalite to quartz diorite. A K-Ar determination on hornblende from this metasiltstone unit yielded an age of 56.5 ±1.4 Ma. This young age was attributed to resetting by the nearby Late Paleocene Quottoon pluton (Gareau, 1991a). Gareau's geological map (1997) shows one extra zircon sample site within this unit, at latitude 52º 47' and longitude 129º 22'; this is a duplicated and mislocated plot of the Foch Lake orthogneiss sample.

The dark grey to black metasiltstone unit is overlain regionally by an extensive unit of quartzite (metasandstone). This white to light grey, well-laminated rock resembles thin-bedded sandstone, but the thin micaceous partings, rhythmically spaced at 5 to 10 centimetre intervals, are interpreted to result from metamorphic differentiation and do not reflect primary compositional variation. Minor associated lithologies include dark grey to black metapelite, black phyllite, dark grey metasiltstone and rare marble. Thickness of this unit ranges from 600 metres near Gareau Lake to more than 7 kilometres near the upper Ecstall River where the unit has been structurally thickened. Gareau (1991a) describes the contact between this unit and the metasiltstone unit as gradational over a 20 to 100 metre interval. Along the eastern margin of the Ecstall belt, this unit is in contact with a black and white layered gneiss. Gareau (1991a) describes the contact between these units as sharp to gradational over an interval of 500 metres. Like the subjacent metasiltsone unit, this quartzite unit is an important component in the regional stratigraphic construction because no dikes, sills or stocks correlated with the Big Falls Igneous Complex have been identified within it. A sample of this rock was collected to the south of the Allaire Ridge mafic intrusive complex, west-southwest of the Packsack deposit, for extraction of detrital zircons (location 15 on Figure 2 and Tables 1 and 2). Two zircon grains gave Precambrian and mid-Paleozoic U-Pb dates (Gareau and Woodsworth, 2000). The mid-Paleozoic date represents a maximum age for this extensive metasedimentary unit, and is consistent with the stratigraphic interpretation that this sedimentary unit overlies the Middle Devonian Big Falls Igneous Complex.

Along the eastern edge of the Ecstall belt, the quartzite unit is in contact with an extensive unit of black and white layered gneiss which is interpreted as a metavolcanic rock (Gareau, 1991a). The metamorphic grade here, upper amphibolite to granulite facies, is higher than the rest of the belt (Gareau, 1991a). The protolith to this gneiss might be a repeated fold limb of the metavolcanic sequence of the Big Falls Igneous Complex, or a different, younger, mafic volcanic rock. The unit is more homogeneous and more mafic than the Big Falls Igneous Complex (S. Gareau, personal communication, 2000). The regionally extensive metasiltstone rock unit has not been recognized anywhere along the contact between the quartzite and the layered gneiss units (Gareau, 1997), which suggests that the layered gneiss may be a different, younger volcanic unit, rather than a repetition of Big Falls Igneous Complex stratigraphy. Gareau and Woodsworth (2000) report a preliminary U-Pb zircon age of ~370 Ma (location 1 on Figure 2 and Tables 1 and 2) for a sample of this rock collected northeast of the Gareau Lake stock. All these lines of evidence support the interpretation that the mafic volcanic protolith for this rock is a younger volcanic package which stratigraphically overlies the quartzite unit.

The layered gneiss is the youngest (uppermost) stratigraphic unit preserved in the Ecstall metamorphic belt. The remaining 13 dates from the belt are from younger plutons that cross-cut the stratigraphy, from metamorphic zircons, or from zircon and hornblende that have undergone partial or complete thermal resetting during metamorphism.

Gareau (1991a, p.173-175) describes a small (<100 metres diameter) weakly foliated quartz diorite stock that intrudes the layered gneiss unit on a ridgecrest 2 kilometres southeast of Gareau Lake (location 2 on Figure 2 and Tables 1 and 2). The rock is composed of 75% plagioclase, 10% quartz, 5% biotite and 3% hornblende with accessory titanite, apatite, zircon and opaque minerals. The U-Pb zircon age for this rock is 336.8 + 17.7 / -7.1 Ma (Gareau, 1991a) although the data reasonably allow for an interpreted crystallization age as young as 320 Ma. This date is consistent with intrusion into the older layered gneiss unit and indicates a mid-Mississippian magmatic episode of quartz diorite composition.

Gareau (1991a, p.21-22) describes a series of Jurassic or Cretaceous mafic and ultramafic stocks intruded through the central Ecstall belt. These rocks crop out in three main areas: two stocks on Allaire Ridge, 10 kilometres south-southwest of Johnston Lake; several small stocks scattered all along on Prospect Ridge, immediately west and uphill of the Packsack VMS deposit; and a small body mapped on the peak of Red Gulch Mountain, 2.7 kilometres north-northeast of the north end of the Ecstall VMS deposit. These mafic rocks are dominantly diorites, but range in composition from quartz diorite through diorite and gabbro to hornblendite. Gareau sampled coarse-grained hornblendite from the Allaire Ridge intrusions for a K-Ar analysis on hornblende (location 14 on Figure 2 and Tables 1 and 2) and interpreted the 115 Ma K-Ar age as a reset date due to early to mid-Cretaceous regional metamorphism. The age of intrusion of all these rocks is unknown, although they must be younger than the quartzite host rock with a probable Late Devonian depositional age and older than the Early Cretaceous metamorphism. It is possible that these scattered clusters of weakly foliated mafic to ultramafic stocks are all comagmatic with the foliated Gareau Lake diorite stock, described above, in which case they would have a mid-Mississippian age of ~337 Ma (Figure 5).

Gareau's (1991a) U-Pb zircon analysis of a young (unfoliated) pegmatite dike gives an emplacement age of 61 Ma, but also contains a component of inherited zircon with a U-Pb age of 299.1 ± 54.5 Ma (location 12 on Figure 2 and Tables 1 and 2). This is interpreted as the average age of the inherited zircon in the grains analysed and indicates that the dike has incorporated some zircons from the enclosing Paleozoic host rocks (Gareau, 1991a).

An important discovery in Gareau's study was the identification of two large, elongate Early Jurassic intrusions emplaced along the eastern margin of the Ecstall belt. These plutons are both weakly to strongly foliated tonalite; one is medium-grained and equigranular and the other is plagioclase megacrystic. The northern, equigranular, Johnston Lake tonalite (location 6 and 11 on Figure 2 and Tables 1 and 2) yielded U-Pb zircon ages of 192.8 + 8.7 / -3.5 Ma and 190.2 + 6.0 / - 1.6 Ma from samples collected at the northern and southern ends of the pluton, respectively. The southern, coarsely porphyritic, Foch Lake tonalite (location 16 on Figure 2 and Tables 1 and 2) yielded a U-Pb zircon age of 191.7 ± 0.6 Ma. These plutons are coeval with igneous rocks within the Stikine terrane, and suggest Early Jurassic proximity of the Ecstall belt (Gareau and Woodsworth, 2000).

Gareau (1991a) collected a series of four samples across the central part of the Ecstall belt for K-Ar age determinations on hornblende (locations 7, 8, 9, 10 on Figure 2 and Tables 1 and 2). The results from west to east were 99.6 ± 1.8 Ma, 110 ± 4.3 Ma, 99.3 ± 1.9 Ma and 56.5 ± 1.4 Ma, Gareau (1991a). This pattern is attributed to resetting of the ages of the central samples by an Early Cretaceous metamorphic event, and to still younger thermal resetting of the westernmost and easternmost samples by the Ecstall (93.5 Ma) and Quottoon (56.8 Ma) plutons respectively. Together with the 115 Ma hornblendite K-Ar age (location 14 on Figure 2), these results support the interpretation that a major metamorphic event terminated in early to mid-Cretaceous time, Gareau (1991a).

Another metamorphic event affected Ecstall Belt rocks during the Paleocene, recorded by metamorphic zircon ages. Sample A99-5-6 (location 3 on Figure 2 and Tables 1 and 2) yielded fraction D (Figure 3a) which gave a concordant age of ~63 Ma that is interpreted as a good estimate for the crystallization age of metamorphic zircon in this rock. One other sample (location 10 on Figure 2 and Tables 1 and 2) shows the effect of Paleocene metamorphism. These ages coincide well with the two U-Pb zircon ages of 56.8 ± 0.1 Ma and 60.7 ± 0.1 Ma that Gareau (1991a) obtained from a sample from the centre of the Quottoon pluton and from a sample of a fresh pegmatite dike collected one kilometre west of the western edge of the Quottoon stock (locations 4 and 12 on Figure 2 and Tables 1 and 2).

GEOLOGIC HISTORY

The 19 dates reviewed in this report provide key constraints for deciphering the geologic history of this highly deformed, repeatedly metamorphosed region (Figure 5).

Mid-Devonian magmatism and volcanism generated the tonalitic stocks, dikes and sills, and a differentiated subaqueous volcanic succession with intercalated sedimentary rocks, collectively termed Big Falls Igneous Complex. Volcanism was followed in Late Devonian time by deposition of a thick sequence of fine-grained sediments with conglomeratic members, followed by an even thicker succession of well-sorted sandstone with minor siltstone members. These regionally extensive sedimentary blankets were overlain in latest Devonian time by another mafic volcanic sequence, now preserved as layered gneiss.

Alldrick and Gallagher (2000) concluded that regional deformation of the Ecstall belt rocks took place in early Mississippian time, following the deposition of the ~370 Ma protolith to the Layered Gneiss unit, but before intrusion of the 337 Ma, weakly foliated Gareau Lake stock.

The mid-Mississippian Gareau Lake diorite, a small stock cutting the Late Devonian Layered Gneiss unit, may be part of an extensive suite of scattered clusters of small, weakly foliated diorite stocks that are preserved throughout the central Ecstall belt.

Gareau and Woodsworth (2000) conclude that the first period of deformation and metamorphism still preserved in Ecstall Belt rocks occurred in the late Paleozoic (Pennsylvanian to Permian), after deposition of the early Mississippian layered gneiss and the intrusion of the mid-Mississippian Gareau Lake stock, but before the intrusion of the Early Jurassic Johnson Lake and Foch Lake plutons. Deformation and recrystallisation were significant and measurable, but Gareau and Woodsworth (op. cit.) consider that this was not the major metamorphic event in the history of the belt.

Two large, colinear, Early Jurassic tonalite plutons, the Johnston Lake and Foch Lake stocks, were intruded along the eastern margin of the belt, and indicate a possible connection with the Stikine Terrane by the Early Jurassic (Gareau and Woodsworth, 2000).

Two major, sequential, mid-Mesozoic (late Early Jurassic to late Early Cretaceous) metamorphic events left their imprint on the rocks of the Ecstall belt (Figure 6 in Alldrick and Gallagher, 2000; and Figure 4 in Gareau and Woodsworth, 2000).

Clusters of dates at mid-Cretaceous and Paleocene times record two metamorphic events associated with intrusion of the two bounding plutons of the Ecstall belt - the mid-Cretaceous Ecstall stock on the west and the Paleocene Quottoon stock on the east. Paleocene deformation only affected rocks along the eastern margin of the Ecstall belt, where they are in contact with the 57 Ma Quottoon pluton (Gareau, 1991a,b; Gareau and Woodsworth, 2000).

CONCLUSIONS

Compilation of results from four successive geochronological studies has helped to clarify the complex stratigraphic, intrusive, metamorphic and metallogenic histories of the Ecstall district. Ongoing research will focus on improving our understanding of the internal stratigraphy of the Big Falls Igneous Complex, the ages of the main metasedimentary rock units, the ages of granitoid clasts from conglomeratic units, the age(s) of the clusters of mafic intrusive stocks and the relative sequence and timing of the major metamorphic events.

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