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HUMBER ZONE – DUNNAGE ZONE RELATIONSHIPS AND THE LONG RANGE FAULT, SOUTH OF GRAND LAKE, WESTERN NEWFOUNDLAND: PRELIMINARY RESULTS

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ABSTRACT

Preliminary results of structural investigations of the Long Range Fault, western Newfoundland, indicate that the Silurian movement on the fault is oblique, with west-side-up dip–slip and dextral strike–slip components. Results from the present study suggest that during the Silurian deformation, amphibolite-facies Humber Zone rocks were uplifted ("extruded") between the Long Range Fault and the west-vergent thrusts to the west, with respect to rocks of the Dashwoods Subzone of the Dunnage Zone. The Dashwoods Subzone is characterized by Ordovician deformation and metamorphism, but was only marginally affected by Silurian deformation.

INTRODUCTION

The Baie Verte–Brompton line (BVB), separates the Laurentian continental margin to the west of the BVB from allochtonous terranes of the Dunnage Zone to the east, represented by the Notre Dame and the Dashwoods subzones (Figure 1). The Laurentian continental margin in Newfoundland, also known as the Humber Zone (Williams, 1979), is divided into a western external zone having weakly metamorphosed and deformed rocks, and an eastern internal zone having strongly metamorphosed and deformed rocks (Cawood *et al.*, 1994).

Previously it was considered that the main deformation and metamorphism, in the internal Humber Zone, occurred during the Middle Ordovician Taconic Orogeny, at which time, the Humber Zone was overthrusted by the Notre Dame and Dashwoods subzones, i.e., the accretion of this part of the Dunnage Zone to the Laurentian continental margin (e.g., Hibbard, 1983). However, Cawood *et al*. (1994) showed, using radiometric age dating, that peak metamorphism and deformation in the internal Humber Zone was Early Silurian. In contrast, timing of the main deformation and metamorphism in the Dashwoods Subzone was before Late Ordovician (e.g., Currie and van Berkel, 1989; Dunning *et al.,* 1989; Currie *et al.,* 1992).

The objective of this study is to investigate the discrepancy in timing of the main deformational and metamorphic event in the two tectonic zones (Humber and Dunnage)

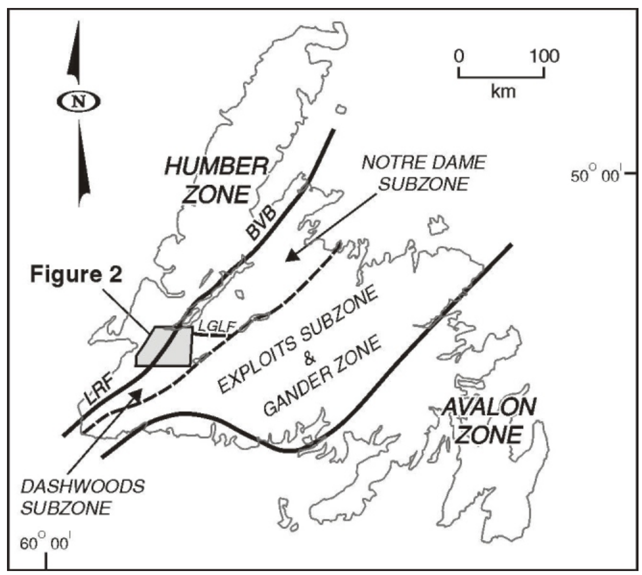

Figure 1. *Location of the study area (area of Figure 2) and tectono-stratigraphic zones of Newfoundland (modified after Whalen* et al., *1997). BVB = Baie Verte - Brompton Line; LGLF = Little Grand Lake Fault; LRF = Long Range Fault.*

across the Baie Verte–Brompton Line by meso- and microscopic structural analyses, and U–Pb and $^{40}Ar/^{39}Ar$ age dating of igneous and metamorphic rocks. In the internal Humber Zone, it is important to establish the relationship between deformation on the Long Range Fault and the

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Salinian west-vergent thrusting as described by e.g., Dunning *et al.* (1990). In this paper, a general summary of the geology of the study area and preliminary results of the field studies in the summer of 2001 are presented.

GEOLOGICAL SETTING OF THE STUDY AREA

The study area covers an area of approximately 40 by 25 km south of the southwestern arm of Grand Lake (Figure 2). In this area, the boundary between the Humber Zone and the Dashwoods Subzone is the Long Rang Fault (LRF; Piasecki *et al.*, 1990), which constitutes part of the Baie Verte–Brompton line that was originally defined north of Grand Lake (Williams and St.-Julien, 1978).

Internal Humber Zone

The internal Humber Zone is bounded by the Grand Lake Fault (GLF) to the west and the LRF to the east (Figure 2). In the study area, this zone consists mainly of Precambrian basement rocks of the Grenville Province (P_{DH}, P_{SM} and P_G; Figure 2). The oldest rocks belong to the Disappointment Hill complex (P_{DH}) and comprises two-pyroxene granulite gneisses in various stages of retrogression, intruded by orthopyroxene-bearing granitoid rocks (Currie and van Berkel, 1992). A sample from P_{DH} has yielded an U–Pb zircon age of 1498 ± 8 Ma (Currie *et al.*, 1992), representing the age of the granulite-facies metamorphism.

South of the Disappointment Hill complex, the Steel Mountain complex (P_{SM}) comprises massive, coarse crystalline anorthosite and anorthositic gabbro, grading to gabbro toward its northern and northeastern margins. The complex appears to intrude the Disappointment Hill complex, but a clear relationship is lacking (Currie and van Berkel, 1992). The Steel Mountain complex extends approximately 40 km toward the south.

North and east of the Disappointment Hill complex are upper-amphibolite facies, hornblende and biotite-bearing (migmatitic) quartzofeldspathic gneisses (Grand Lake gneisses of Owen and Greenough, 1994; P_G, Figure 2). These rocks have not been dated directly, but based on their lithology, texture and contained mafic dykes, they are tentatively correlated with Grenville Province rocks exposed in inliers (e.g., Long Range Massif) in western Newfoundland (Piasecki, 1991; Owen and Greenough, 1994).

These Mesoproterozoic units (P_{DH}, P_{SM} and P_G) of the internal Humber Zone experienced regional deformation and metamorphism most probably during the Grenville Orogeny. Their structural fabrics have a prevalent northwest trend. Throughout the study area these Mesoproterozoic units are cut by north-trending schistose amphibolitic dykes. The dykes cut the gneissose fabric (P_G), but do not appear to cut younger rocks (E_{FL}, E_{HH}) (Piasecki, 1991).

Metasedimentary rocks structurally overlie the basement rocks (e.g., Piasecki, 1991). The quartzite, pelitic schists and calcareous schists have been assigned to the Eocambrian to Ordovician (?) Fleur de Lys Supergroup (E_{FL}) (Knapp *et al.*, 1979; Currie and van Berkel, 1992; Cawood *et al.*, 1994). However, lack of fossils and amphibolite-facies metamorphism impedes an accurate assessment of their age. North and south of Grand Lake, these rocks form a series of imbricate thrust stacks with the quartzofeldspathic gneisses (P_G). This unit also contains a low-grade metamorphosed conglomerate, containing granite cobbles presumably derived from the Hare Hill granite (Currie and van Berkel, 1992).

Leucocratic pink alkaline to peralkaline granites of the Hare Hill complex (E_{HH}) are the youngest rocks known in the internal Humber Zone. They have intruded part of the metasedimentary rocks (E_{FL}) and the granulite gneisses (P_{DH}) (Currie *et al.*, 1992). A leucogranite has been dated at 608 ± 4 Ma (U–Pb on zircon). Hence, most of the Fleur de Lys Supergroup in this area was probably deposited in the late Neoproterozoic.

The youngest regional deformation and peak amphibolite-facies metamorphism in the internal Humber Zone are well constrained to be Early Silurian (Cawood *et al.*, 1994): U–Pb zircon dating on a syntectonic pegmatite yielded an age of 434 +2/-3 Ma; $^{40}Ar/^{39}Ar$ cooling ages on hornblendes from amphibolites and muscovite, from metasediments, range between 430 to 420 Ma; U–Pb ages of monazite and rutile from garnet–kyanite–staurolite schists are 430 ± 2 Ma and 437 ± 6 Ma, respectively.

Figure 2. (opposite page) *Simplified geological map of the study area (compiled from Currie and van Berkel, 1992 and Owen and Greenough, 1994). LGLF = Little Grand Lake Fault; 480 = Burgeo Highway. Grid references of outcrops shown (Grid Zone 21U, Nad-27): "A": 5382220 N, 427892 E; "B": 5373143 N, 421328 E; "C": 5371564 N, 419729 E; "D": 5353703 N, 406565 E; "E": 5334212 N, 387153 E; and "F": 5381974 N, 415179 E; "G": 5368779 N, 418383 E; "H": 5377991 N, 426204 E; "I": 5385734 N, 4116565 E; and "J": 5381579 N, 430883 E.*

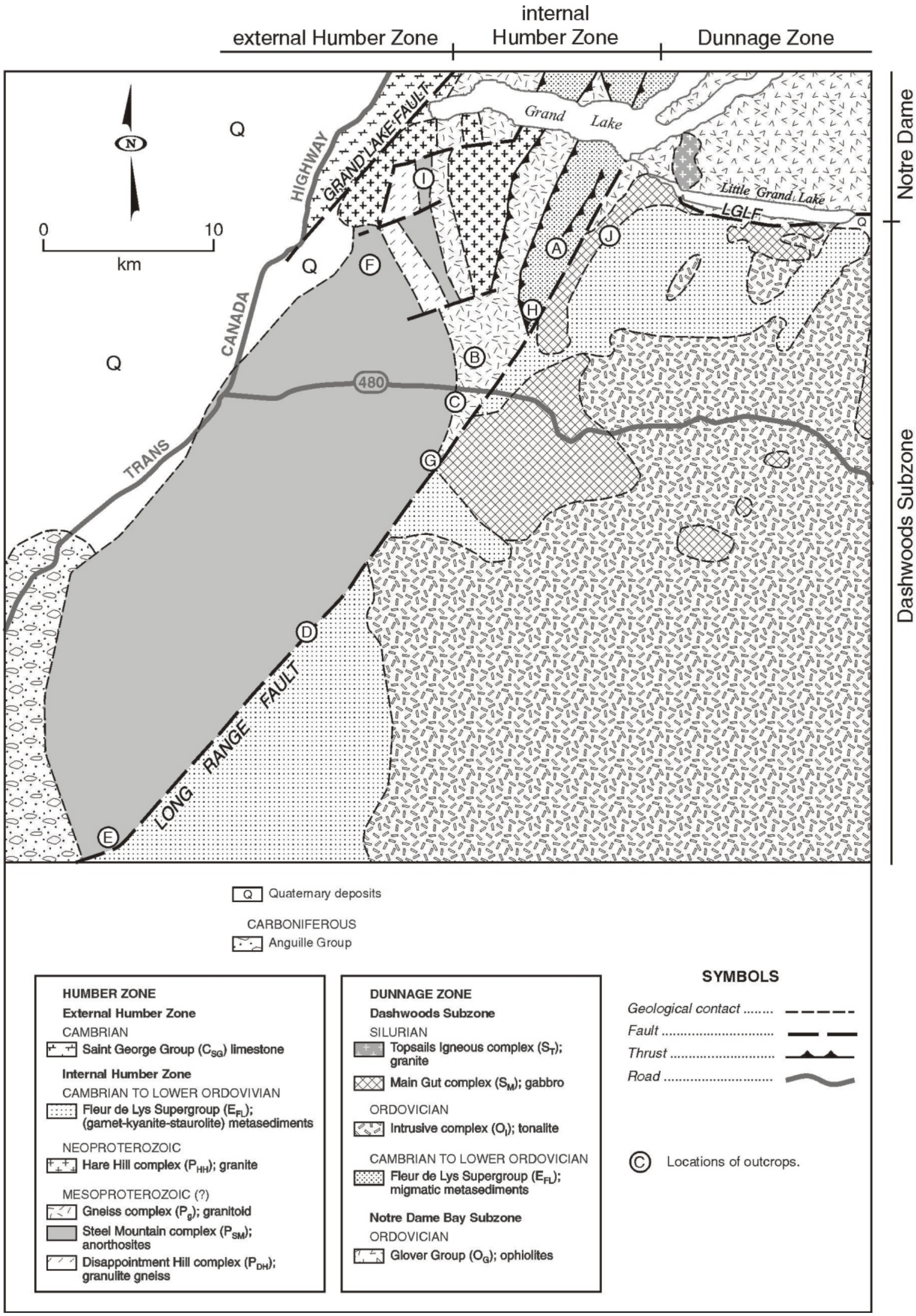

Figure 2. *Caption on previous page.*

Dashwoods Subzone

The Dashwoods Subzone is bounded by the LRF to the west and the Little Grand Lake Fault (LGLF) to the north (Figure 1). The oldest known rocks in the zone are migmatitic metasedimentary rocks, which are correlated with the Fleur de Lys Supergroup (E_{FL}) (Currie and van Berkel, 1992). The unit contains disrupted amphibolite dykes, and is locally transformed into mélange (Hall and van Staal, 1999), making it easily distinguishable from the metasediments of the internal Humber Zone. Sheared and broken metasediments along the trace of the LRF contain ultramafic and mafic remnants of ophiolitic rocks (Fox and van Berkel, 1988; Piasecki, 1995).

Throughout the Dashwoods Subzone multiple, coarse-crystalline tonalite to granodiorite plutons (O_I, O_{IG}) intrude amphibolite- to granulite-facies quartzofeldspatic gneisses. K–Ar and U–Pb zircon ages of the intrusions and the gneisses yielded Early to Middle Ordovician ages (488 to 455 Ma) (Stevens *et al.*, 1982; Dunning *et al.*, 1989; Dubé *et al.*, 1996), suggesting syntectonic emplacement of the plutons. This interpretation is supported by the observation that tectonic fabrics are best developed in the oldest intrusive rocks.

A suite of intrusions, ranging from gabbro to diorite (S_M), occurs in the area south of Little Grand Lake. Dunning *et al.* (1990) reported an Early Silurian U–Pb zircon age of 431 ± 2 Ma for one of the plutons (Main Gut gabbro), representing the age of emplacement. These Silurian intrusions cut bodies of strongly foliated Ordovician tonalite and generally do not display any regional, tectonic fabrics. It is only along the Subzone boundaries that locally penetrative fabrics have developed. This key observation, in addition to the Ordovician K–Ar cooling ages of the high-grade metamorphic rocks and the presence of unmetamorphosed Upper Ordovician to Silurian conglomerates and red beds indicate that the (youngest) main regional deformation and metamorphism in the Dashwoods Subzone took place during the Middle Ordovician (Currie and van Berkel, 1989, 1992; Dunning *et al.*, 1990; Dubé *et al.*, 1996) and that no regional metamorphic phase of any significance affected the Dashwoods Subzone subsequently.

STRUCTURE

Long Range Fault (LRF)

The north–northeast-striking LRF is a steeply dipping structure (70 to 80° E), having a complex history of ductile and brittle movements. The LRF is morphologically expressed as a steep slope of several decametres (Plate 1). However, this morphological expression is not visible north of the Burgeo Highway (Route 480), where the relief around the LRF is rather low and exposure is poor.

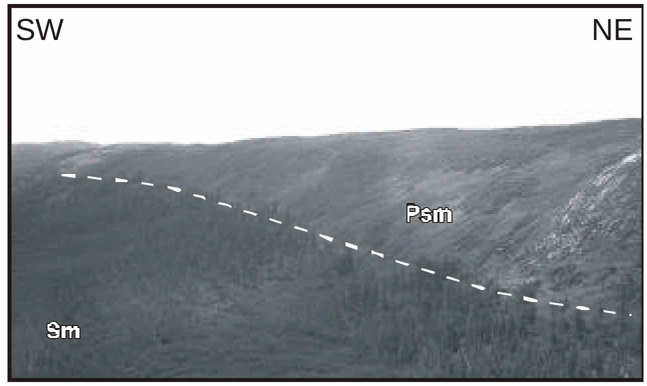

Plate 1. *Morphology of the Long Range Fault (dashed line) along the eastern edge of the Steel Mountain complex. The internal Humber Zone clearly stands high with respect to the Dashwoods Subzone. Psm = Steel Mountain complex, Proterozoic anorthosite representing the internal Humber Zone; Sm = Main Gut gabbro, Silurian mafic intrusives in the Dashwoods Subzone. Difference in elevation is approximately 80 m.*

The LRF along the Steel Mountain complex is characterized by a zone up to 800 m wide of anorthositic and gabbroic gneisses, and in the easternmost, a zone 50 m wide of straight gneisses (Plate 2). Generally, the strike of the foliation along the LRF is north–northeast, but deviates locally. On the southern edge of the Steel Mountain complex the strike of the foliation deviates to east–northeast (Figures 2 and 3e) and along the Burgeo Highway the strike of the foliation deviates toward the north(northwest) (Figure 3c), the reason(s) for these deviations are not yet known. The gneisses contain shallowly plunging mineral and stretching lineations, predominantly plunging toward the south(west) (Figures 3b, e and Plate 3), but locally toward the north (Fig-

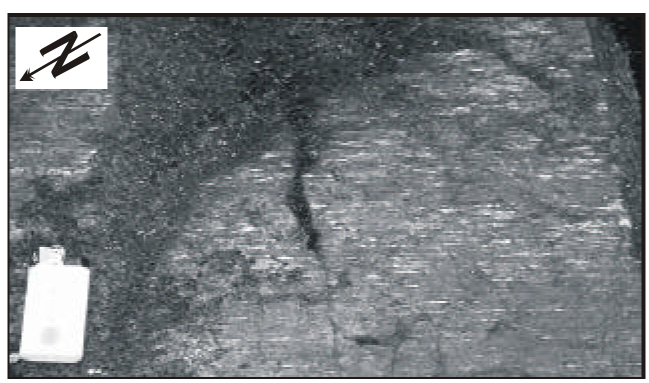

Plate 2. *Straight gneiss from the Long Range Fault. Photo taken at site G (see Figure 2).*

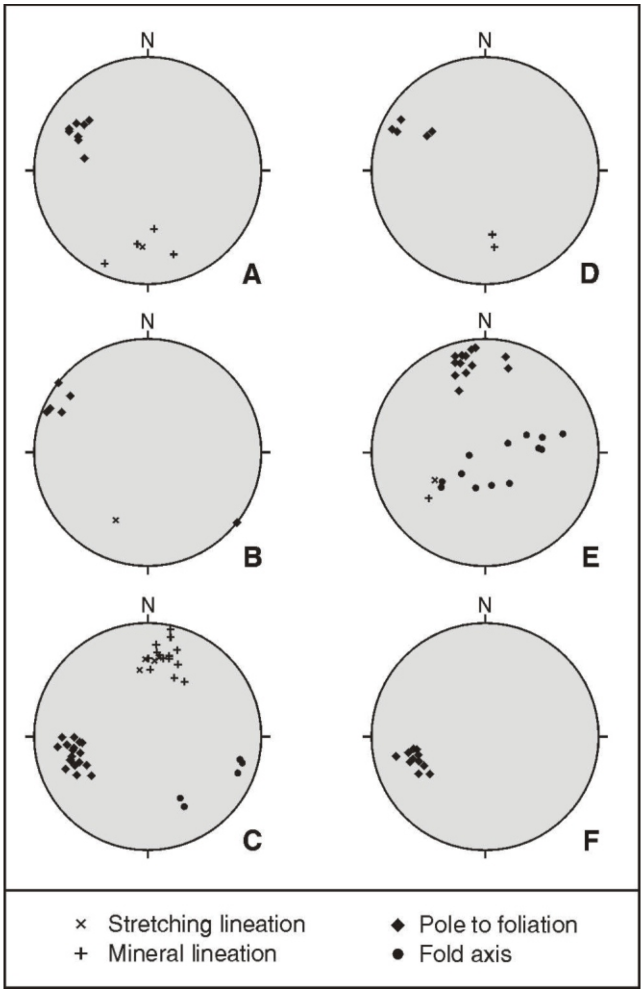

Figure 3. *Equal area lower hemisphere projections of foliations and lineations from 5 localities along the LRF (A, B, C, D and E) and from one location in the internal Humber Zone (F).*

ure 3c). Shear-sense indicators such as shear bands, drag folds and asymmetric boudins, combined with the orientation of lineations, indicate an oblique movement with a west-side-up dip–slip component and a dextral strike–slip component (sinistral in outcrop C; Figures 2 and 3). At outcrop E (Figure 2) several pegmatitic granite dykes intrude the strongly foliated straight gneisses. The pegmatite dykes are folded or boudinaged depending on their orientation, but are not internally foliated (Plate 4). They are interpreted to have intruded during the later stages of the main deformation. Steeply dipping dykes clockwise from the foliation are folded and those counterclockwise from the foliation are boudinaged, indicating dextral sense of shear. Two such dykes have been sampled for U–Pb dating in order to better constrain the time of deformation. North of Grand Lake, syn-deformational pegmatitic pods within segments of the imbricated internal Humber Zone have yielded a Silurian age (434 +2/-3 Ma; Cawood et al., 1994).

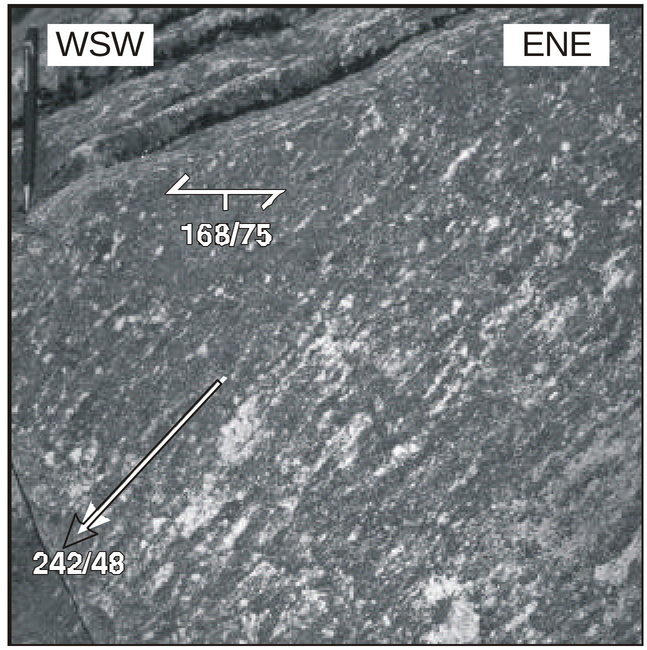

Plate 3. *Southwest-plunging stretching lineation at site E (*see *Figure 2). Associated kinematic indicators show a northwest-side-up movement.*

At the eastern edge of the LRF is a narrow zone of chlorite-rich mylonite and phyllonite. The mylonite zone is parallel to the LRF (i.e., north-northeast to south-southwest). Mineral lineations in the mylonite plunge shallowly to the south (Figure 3d). Shear bands indicate east–southeast side-down, a shear sense similar to that in the straight gneisses. It is possible that the mylonites are lower grade equivalents of the straight gneisses that formed deeper in the crust and were brought up during movement along the LRF, either during the same deformation that formed the mylonite or during a later deformation that formed the cataclasite zone described below.

The cataclasite zone occurs between the straight gneisses and the mylonites described above. It is 250 to 700 m wide. It overprints and essentially obliterates pre-existing fabrics. This zone can be traced from near outcrop D in Figure 2 to Grand Lake. The cataclasites are generally of granitic composition with K-feldspar porphyroclasts. Many striated surfaces have been observed and measured, but a clear direction of movement in the cataclasite could not be established.

South of Grand Lake, metapelites and metapsammites of the Fleur de Lys Supergroup are found in thrust slices interleaved with quartz-rich granitoid mylonites. At several outcrops along the trace of the LRF it was observed that early fabric defined by the medium-grade metamorphic assemblage kyanite, staurolite and garnet is crenulated and

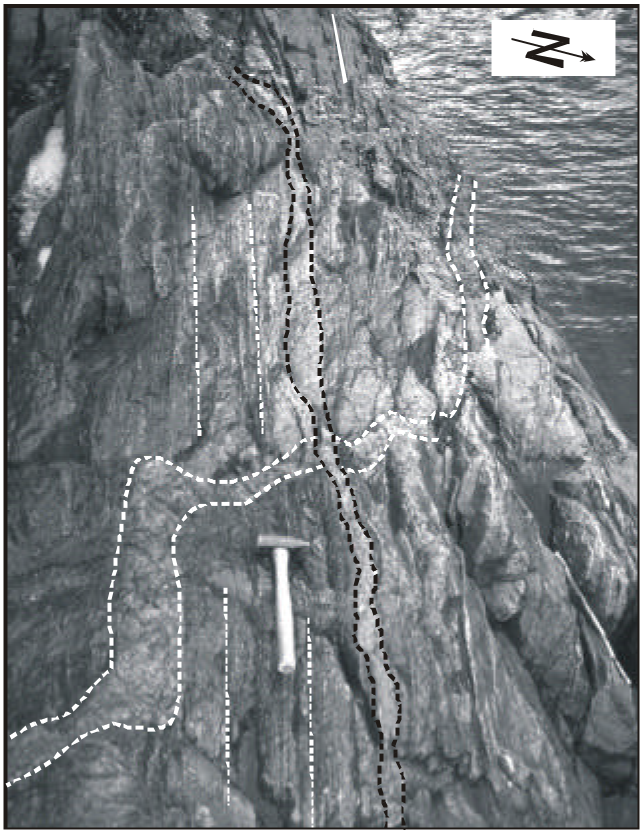

Plate 4. *Pegmatitic dykes, intruding strong foliated gneisses. Dykes clockwise from the foliation are folded (white-dashed pattern), and those counterclockwise from the foliation are boudinaged (black-dashed pattern). Such geometry indicates dextral sense of shear. Photograph taken at site E (*see *Figure 2).*

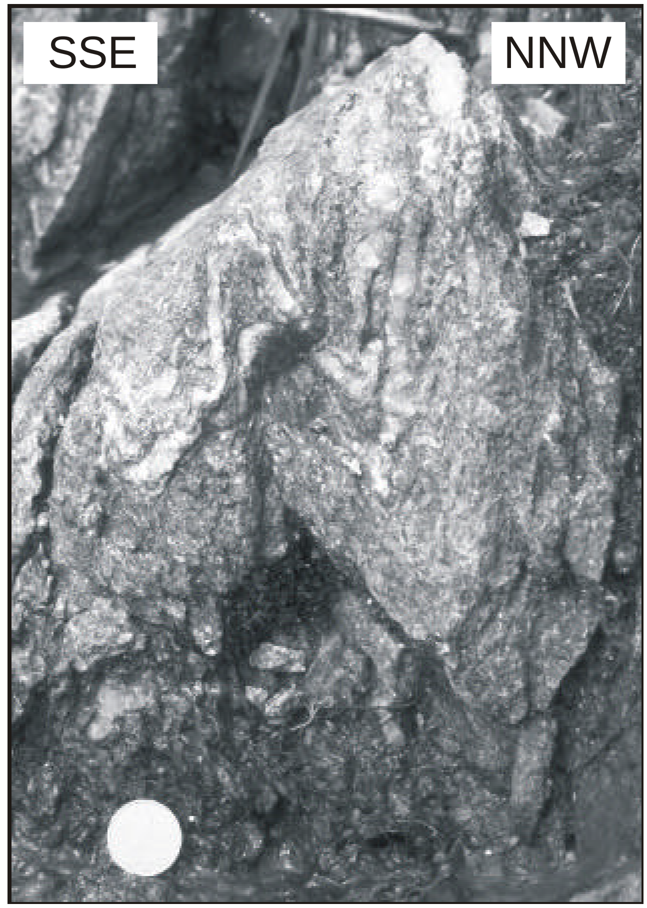

Plate 5. *Folded garnet-kyanite-staurolite schists of the Fleur de Lys Supergroup. Photo taken at site H (*see *Figure 2). Individual minerals are not clearly visible at this scale.*

folded (Plate 5). The axial planes generally strike east-west and dip steeply to vertically. Fold axes plunge shallowly toward the west. Foliation in the quartz mylonite strikes north–northwest and dips steeply to the east. Stretching lineations plunge shallowly to the south. Shear sense indicators, such as boudinaged quartz-veins in the metasediments, indicate an oblique sinistral, south-over-north movement (Figure 3a), which is in accordance with the folding. Emplacement of the thrust slices has been attributed to the Salinian orogeny (e.g., Cawood *et al.*, 1994). The relationship between the south-over-north movement as observed here and the west-side-up movement described above along the eastern edge of the Steel Mountain complex is not yet understood, but it appears that the latter predates the south-over-north movement. However, both movements appear to be during the Salinian orogeny. A possible explanation for this discrepancy is provided by Owen and Greenough, (1994) who indicate that younger ductile shear zones deflect some mylonite zones related to the westward displacement of the thrust complex.

Internal Humber Zone

The intensity of metamorphism and deformation weakens toward the west in the internal Humber Zone. This can be seen best along the Burgeo Highway (Route 480). From the LRF toward the intersection with the Trans Canada Highway (Figure 2) a section of anorthositic gneisses to locally gneissic anorthosite–gabbro to undisturbed massive anorthosite (gabbro) is exposed. Amphibolitic intrusions within the anorthosite are found all along the Burgeo Highway and they become schistose near the LRF, where the foliation is parallel to those in the anorthosite gneiss, suggesting that the time of intrusion was before the main deformation along the LRF. Within the anorthositic gneisses, several late remobilizate pods have developed containing hornblende crystals, up to 4 cm in length. There is no foliation in these pods but the mineralogical composition is similar to the anorthositic gneisses suggesting that the remobilizates have formed near the end of the main deformation phase. A sample has been collected for Ar–Ar dating of the hornblende.

In the area north of the Burgeo Highway, the exposed rocks contain two foliations, designated as S_1 and S_2. They are best developed in the Hare Hill granite (E_{HH}), but also occur in the Disappointment Hill complex (P_{DH}) and the quartzofeldspatic gneiss unit (P_G). The S_1 foliation has mainly developed as elongated quartz and feldspar mineral aggregates. The more prominent foliation (S_2), defined by biotite and hornblende, strikes predominantly north–northeast and dips primarily 55 to 90° E. Associated mineral and stretching lineations are subhorizontal to oblique, but are locally steep to down-dip. The lineations plunge toward the north, east and south. Shear-sense indicators related to S_2 show a prevalent west–northwest-block-up movement (Figures 3f and Plate 6), but the opposite movement has also been observed.

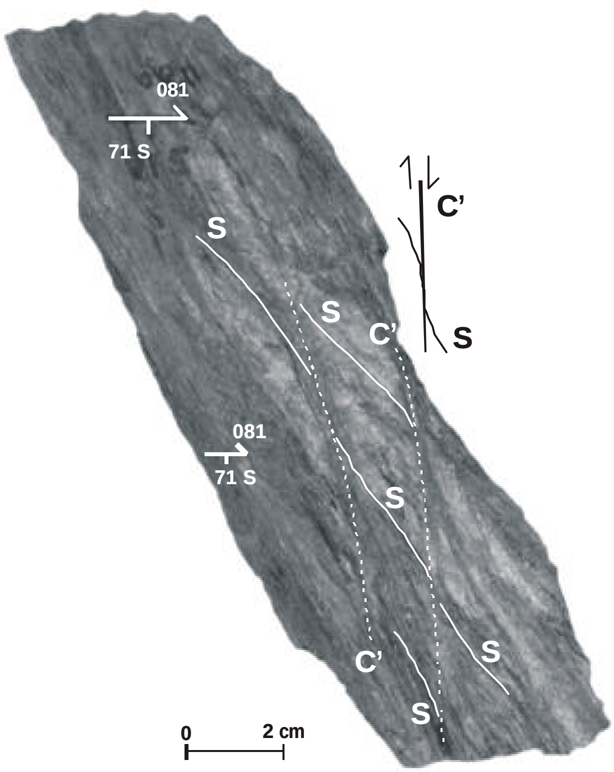

Plate 6. *Mylonite in the internal Humber Zone near the Grand Lake Fault showing west-side-up movement. The plane of the photograph is perpendicular to the shear fabric, and approximately parallel to the mineral lineation. Photograph taken at site I (*see *Figure 2).*

Care is needed in interpreting the age of deformation (and metamorphism) of rocks in the internal Humber Zone because most of these rocks (P_{DH}, P_{SM} and P_G; Figure 2) also underwent metamorphism and deformation in the Precambrian.

Dashwoods Subzone

Within the Dashwoods Subzone, Silurian rocks of the Main Gut complex (S_M) are bound by the LRF and the LGLF (Figure 2). These mafic intrusive rocks, e.g., those along the Burgeo Highway, do not show a regionally penetrative fabric. They cut an earlier, inferred Ordovician, foliation. Locally, they are affected by both ductile and brittle deformation, e.g., in the area south of Little Grand Lake (Plate 7). These local structures are constrained to be

Plate 7. *Photograph of a brittle fault zone in a Silurian gabbro (S_M). Slickensides in the fault zone showed a (minor reverse) sinistral movement. Photograph taken at site J (*see *Figure 2).*

younger than 431 Ma, the intrusive age of the Main Gut gabbro (Dunning *et al.*, 1990). The observation that Silurian deformation in the Dashwoods Subzone is not penetrative at the regional scale, is consistent with the occurrence of undeformed Upper Ordovician to Silurian conglomerates and red beds in the Dashwoods Subzone (Dubé *et al.*, 1996).

DISCUSSION

Preliminary interpretation of the field data suggests that during the Salinian orogeny (Silurian), amphibolite-facies metamorphic rocks of the internal Humber Zone were obliquely uplifted along the LRF (Figure 4). On the basis of kinematic indicators observed in the field, this deformation is interpreted to include a significant component of dextral transcurrent displacement. The intensity of deformation and metamorphic grade decrease toward the west, suggesting greater uplift proximal to the LRF. Waldron *et al.*, (1998) described west-vergent, ductile out-of-sequence thrusts that formed during early Salinian deformation (pre-peak metamorphism) within the internal and part of the external Humber Zone. Assuming that the out-of-sequence thrusts and the LRF were contemporaneous and kinematically related, the combined geometry and kinematics indicate that the rocks of the internal Humber Zone (between the external thrust belt and the LRF) extruded during the deformation (Figure 4), a situation similar to that described in Oman (Chemenda *et al.*, 1996) and the Himalayan Orogen (e.g., Burchfiel *et al.*, 1992). Such extrusion must have occurred in a short time span because there is no overprint of lower grade metamorphic assemblages. Cawood *et al.* (1994) pointed out that peak metamorphism in the internal Humber Zone was followed by rapid exhumation. The Dashwoods Subzone on the other hand acted as a relatively stable, rigid hanging wall in which little deformation occurred. Only the rocks along the LRF in the hanging wall are mylonitized under greenschist-facies conditions and subsequently cataclastically deformed. Based on similarity in kinematics, the mylonites and greenschist-facies rocks along the LRF are proposed to have been formed contemporaneously with the straight gneisses and amphibolite-facies rocks of the internal Humber Zone. A K-feldspar-rich granite within this cataclasite zone does not resemble any other intrusion in the area. Possible interpretations are that this granite is fault-zone restricted and was generated as a result of movements along the fault-zone or that fault-zone related fluids have altered the original composition.

At this point, the relationship between the west-side-up movement all along the LRF in the internal Humber Zone and the south-over-north movement observed in the thrust complex is not clearly understood yet. In addition, the assumption made earlier that the west-vergent thrusting in the internal Humber Zone and the deformation on the LRF

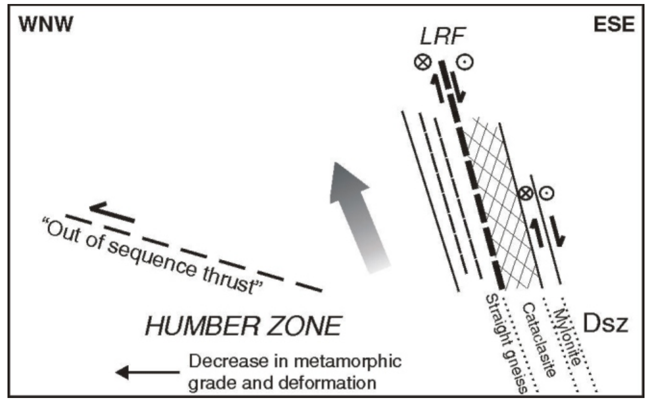

Figure 4. *Sketch profile through the (internal) Humber Zone. Rocks from the internal Humber Zone are brought up from depth with a dextral transcurrent movement component along the LRF, whereas the Dashwoods Subzone remains relatively in place. The contact between the zones is characterized by a cataclastic zone. Arrow indicates direction of extrusion.*

were contemporaneous and kinematically related needs to be tested. Furthermore, there are problems that the subhorizontal lineations (along the LRF??) indicate primarily strike–slip motion and only minor dip–slip movement that need to be resolved. Additional field and laboratory work (including U–Pb and Ar–Ar geochronological work) is planned to resolve these problems.

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