Structural evolution of the Tally Ho shear zone (NTS 105D), southern Yukon

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ABSTRACT

The Tally Ho shear zone is located along the western boundary of the Whitehorse Trough in southern Yukon, and separates the Stikine Terrane to the east and the Nisling Assemblage to the west. Complex geologic structures, Jurassic and Cretaceous plutonism and abundant Tertiary volcanism obscure the nature of this boundary and its relation to adjacent terranes. Pyroxenite, gabbro, marble, and highly strained volcaniclastic rocks form a 3-km-wide belt that is in intrusive- and fault-contact with megacrystic granite and granodiorite, respectively. Structural relations in the field indicate that the ultramafic rocks in the Tally Ho shear zone are allochthonous, and have been thrust to their present position and subsequently folded in the Early Jurassic. Younger brittle and semi-brittle faulting occurred along the Llewellyn fault in the Late Cretaceous.

RÉSUMÉ

La zone de cisaillement Tally Ho est située le long de la limite ouest du bassin de Whitehorse, au sud du Yukon, et sépare le terrane de Stikine, à l'est, du terrane de Nisling, à l'ouest. Des structures géologiques complexes, un plutonisme du Jurassique et du Crétacé, et un abondant volcanisme du Tertiaire rendent moins évidente la nature de cette limite et sa relation avec les terranes adjacents. De la péridotite, du gabbro, du marbre et des roches volcanoclastiques très déformées forment une ceinture, atteignant 3 km de largeur au contact intrusif et de faille, respectivement avec du granite mégacristallin et de la granodiorite. Les relations structurales sur le terrain indiquent que les roches ultramafiques dans la zone de cisaillement Tally Ho sont allochtones et ont été charriées jusqu'à leur position actuelle et plissées par la suite, au Jurassique précoce. Il y a eu par la suite formation plus récente de failles cassantes et semi-cassantes le long de la faille de Llewellyn, au Crétacé tardif.

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INTRODUCTION

The Tally Ho shear zone (THSZ) is a 40-km-long zone of highly strained rocks along the western margin of the Whitehorse Trough in southern Yukon, first recognized by Hart and Radloff (1990). The deformed belt of rocks is 3 km wide and separates the Stikine Terrane to the east from Nisling Assemblage rocks of the Yukon-Tanana Terrane to the west (Fig. 1). The Tally Ho shear zone passes through the Wheaton valley area and is accessible via the Annie Lake Road off of the Klondike Highway near Carcross (Fig. 2). Mineral exploration trails provide access to much of the study area (parts of NTS map sheets 105 D/2, 3, 6 and 7).

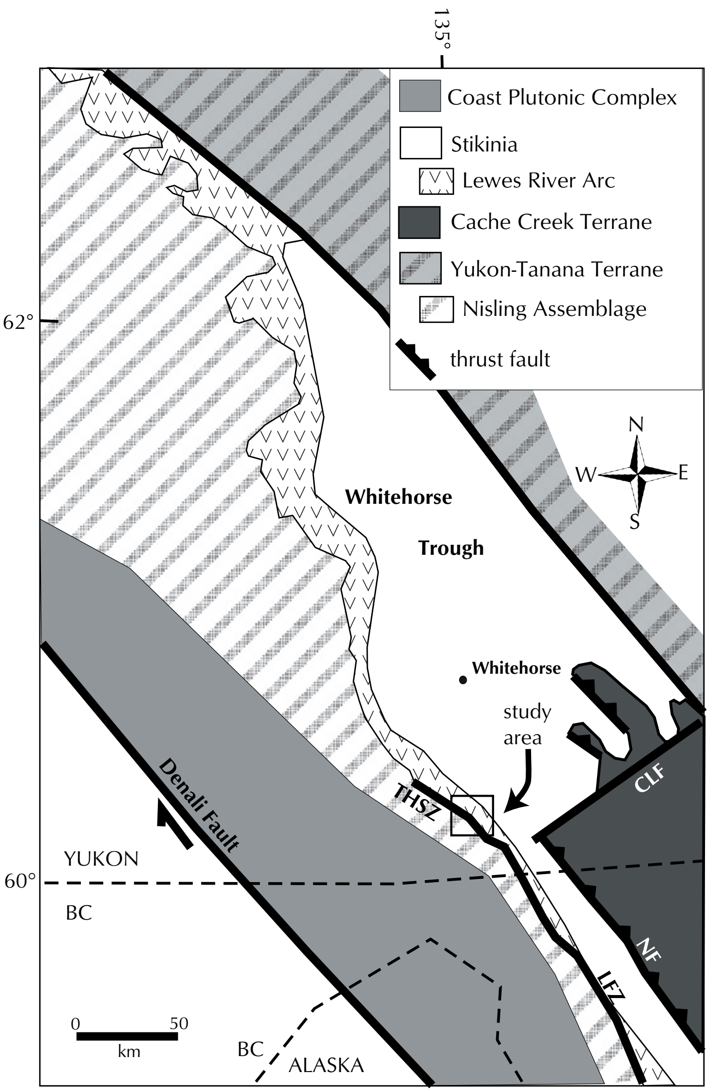

Figure 1. Simplified tectonic boundaries of southern Yukon showing location of the Tally Ho shear zone (THSZ) and Llewellyn fault zone (LFZ) and their relation to the Nisling Assemblage (of Yukon-Tanana Terrane), Stikinia and Cache Creek Terrane. CLF = Crag Lake fault; NF = Nahlin fault. Modified after Wheeler and McFeeley (1991).

The THSZ is well exposed at Tally Ho Mountain where it is characterized by northwest-trending belts of heterogeneously strained volcanic and volcaniclastic rocks, gabbro and pyroxenite, and various massive intrusive bodies (Fig. 3). Hart and Radloff (1990) interpreted the THSZ as having experienced at least two phases of deformation: 1) Late Triassic sinistral ductile shear; and 2) mid-Cretaceous and younger dextral brittle shear. An interesting feature of the shear zone is a small (1700 x 600 m) body of pyroxenite. Wheeler (1961) suggested three possible mechanisms for the origin of the pyroxenite: 1) an intrusion that was folded with the surrounding rocks; 2) an allochthonous sheet that was folded with the surrounding rocks after emplacement; or 3) a syn-kinematic pluton that intruded during mid-Cretaceous folding. This paper presents additional structural relationships in the THSZ to that of Hart and Radloff (1990) and suggests a mechanism for the emplacement of the ultramafic rocks on Tally Ho Mountain.

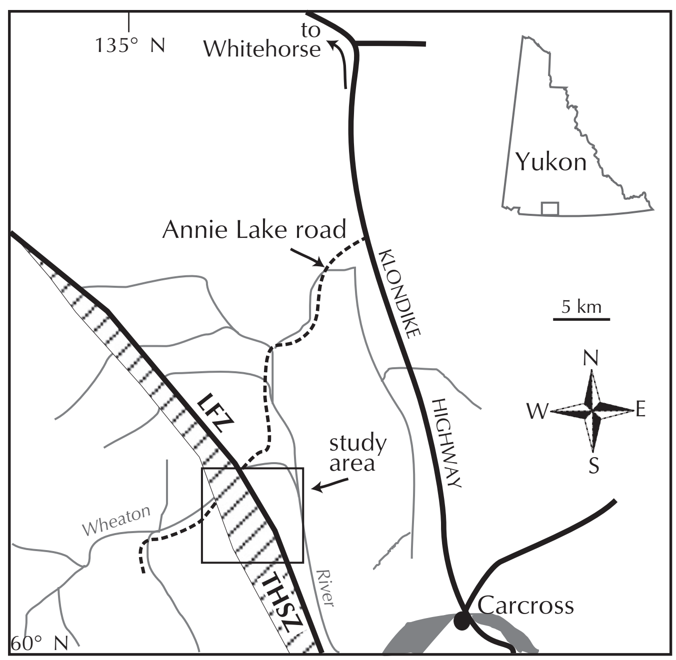

Figure 2. Access to the Tally Ho shear zone (THSZ) and Llewellyn fault zone (LFZ) via the Annie Lake Road.

REGIONAL TECTONIC FRAMEWORK

The THSZ lies within the northern part of the Intermontane Superterrane, an amalgamation of the Stikine, Cache Creek, and Quesnel terranes (Gabrielese et al., 1991; Gordey and Makepeace, 2001). The Whitehorse Trough is part of Stikinia (Fig. 1) and consists, in part, of a Late Triassic to mid-Jurassic onlap assemblage of immature sedimentary rocks derived from middle to Late Triassic volcanic rocks of the Lewes River Group and Joe Mountain volcanics to the east (Hart, 1995). The clastic sedimentary sequence and associated reefal carbonates of the Lewes River Group may host significant oil and gas reserves (Lowey, 2004; English et al., 2005). The Lewes River Group volcanic rocks and the Whitehorse Trough strata underlie much of the THSZ.

Approximately 20 km east of the THSZ, the Cache Creek Terrane is juxtaposed with Stikinia along a number of southwest-vergent thrust faults and normal faults (Fig. 1). The Cache Creek Terrane consists of Lower Carboniferous to Middle Jurassic rocks of oceanic affinity and is interpreted to have been thrust southwestwards over Stikinia by the Middle Jurassic (Monger et al., 1991).

West of Stikinia, the Nisling Assemblage is part of the pericratonic Yukon-Tanana Terrane, and is characterized by Proterozoic to Paleozoic metasedimentary rocks (Johnston et al., 1996). The Stikinia/Yukon-Tanana Terrane boundary in southwest Yukon has been interpreted as the Tally Ho shear zone. Plutons of the Long Lake Suite intruded and pinned together the Yukon-Tanana and Stikine terranes by the Early to Middle Jurassic (Johnston et al., 1996; Hart, 1997). The Lllewellyn fault zone (LFZ), a kilometre-wide north-trending zone of semi-brittle fracturing that affects rocks as young as mid-Cretaceous age, overprints and further complicates the Stikinia/Yukon-Tanana boundary. The style of deformation in the THSZ and LFZ is commonly obscured by younger structures, Jurassic and Cretaceous plutons, and Tertiary volcanic rocks.

MAJOR LITHOLOGICAL UNITS IN THE TALLY HO MOUNTAIN AREA

The THSZ and associated rocks are well exposed on the four mountains that make up the Tally Ho massif: Tally Ho Mountain, Wheaton Mountain, Mt. Stevens and Dickson Hill (Fig. 3). The majority of the study area is composed of heterogeneously strained volcanic and volcaniclastic rocks and several bodies of intrusive rocks.

LEWES RIVER GROUP

Rocks of the Tally Ho shear zone are mainly part of the Upper Triassic Lewes River Group (Wheeler, 1961; Hart and Radloff, 1990). Regionally, the Lewes River Group consists of dominantly volcanic Povoas formation overlain by sedimentary Aksala formation (Hart, 1997). In the study area, the Lewes River Group is composed of a variably strained tuffaceous and volcaniclastic sequence referred to as the Annie Member, consisting of massive augite-phyric basalt, tuff, marble and associated volcaniclastic rocks. The Annie Member occurs on Dickson Hill and is characterized by dark reddish brown- to green-weathering, medium- to fine-grained, massive tuff. Massive augite-phyric dark grey-weathering basalt exists on Tally Ho Mountain and Dickson Hill and is distinguished by black augite phenocrysts up to one centimetre in diametre. The basalt weathers dark greenish grey and is dark grey on fresh surfaces. Chlorite alteration is common.

Marble and variably strained volcanic and volcaniclastic rocks are intercalated on Tally Ho Mountain. The buff-weathering marble is white on fresh surfaces and exhibits a pervasive flaggy fabric. Highly strained volcanic and volcaniclastic rocks are characterized by a mylonitic to gneissic fabric with distinct, black augite porphyroclasts (Fig. 4) up to one centimetre in diameter. The augite-porphyroclastic schist weathers dark greenish grey and is dark grey on fresh surfaces. Away from the high strain zone, small clasts and relict bedding are visible in lesser strained volcaniclastic rocks. Both the highly strained and

Figure 4. *Rotated augite porphyroclasts in augite schist on Dickson Hill indicating top-to-the-east displacement.*

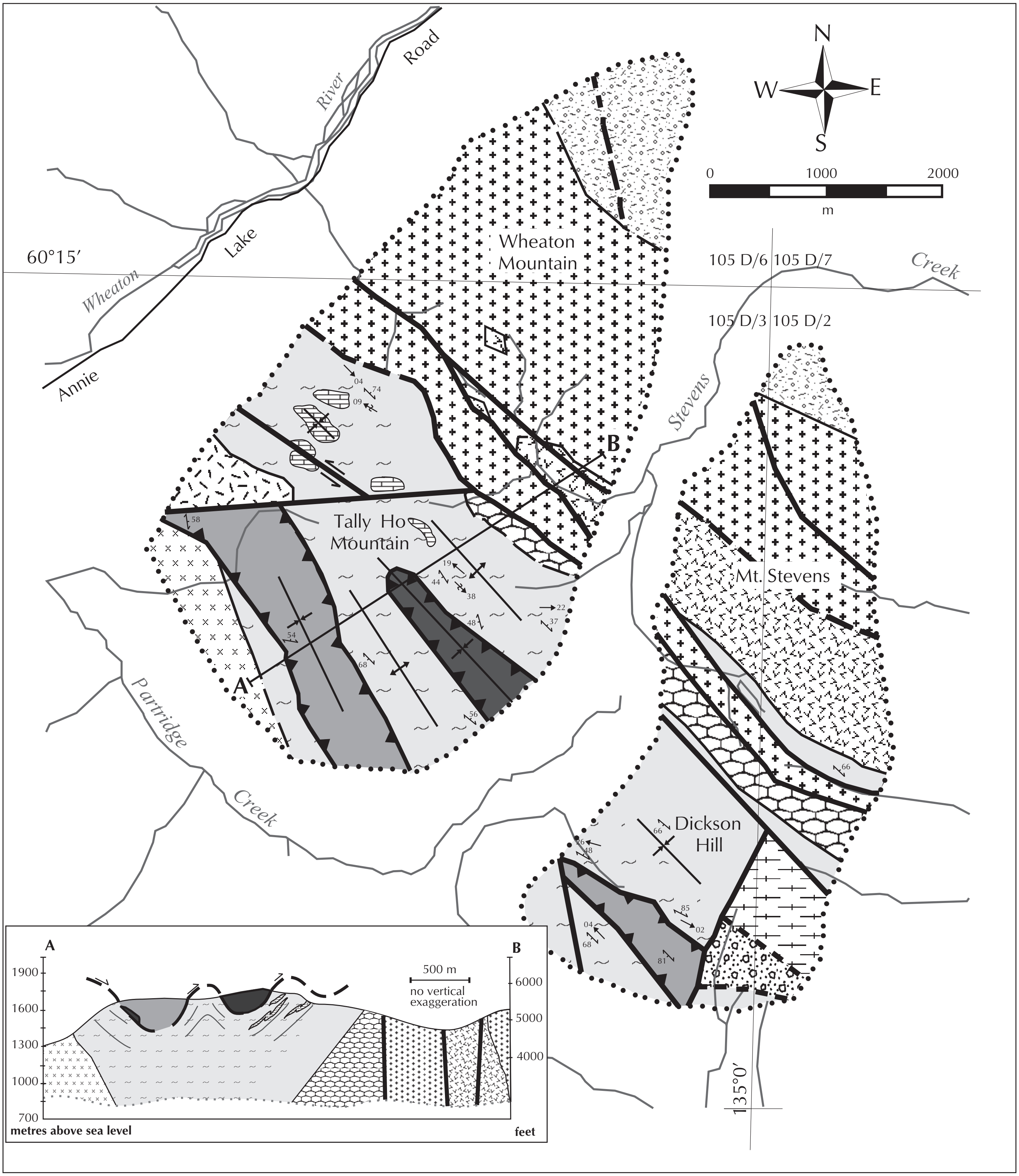

Figure 3. Geological map of the Tally Ho Mountain area; geologic cross-section of Tally Ho Mountain, A-B. Legend on facing page. Modified after Hart (1997).

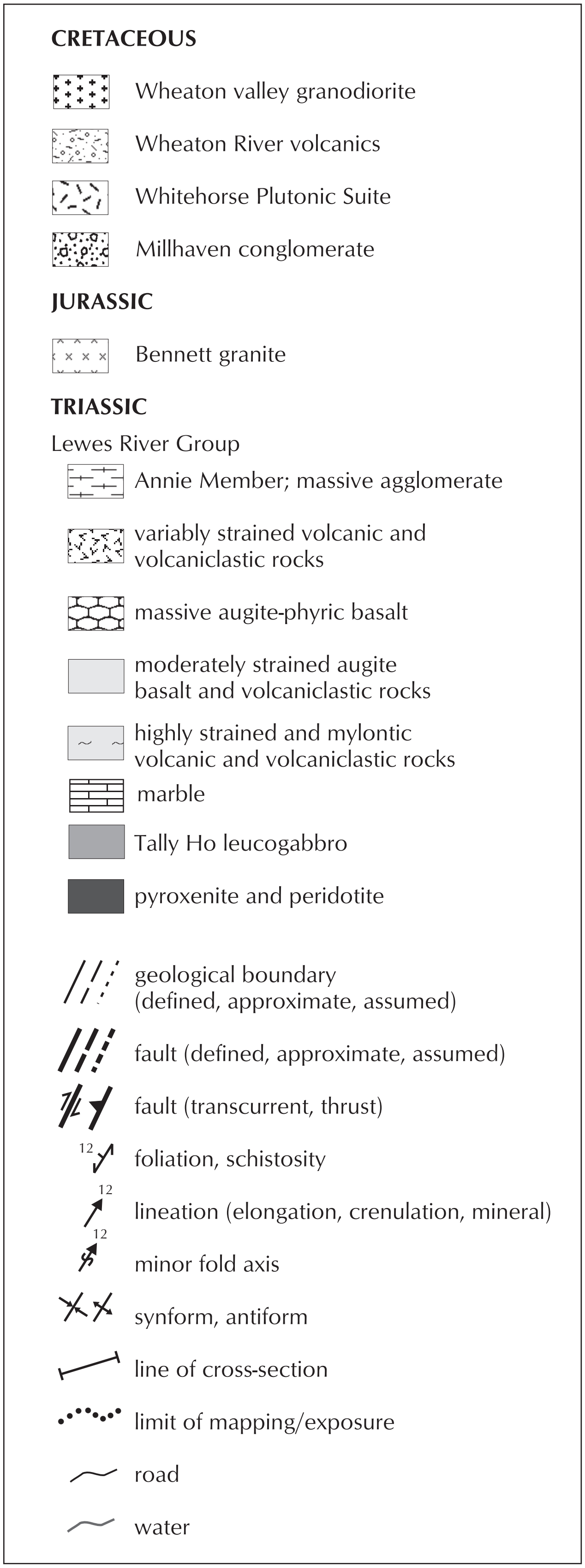

Figure 3. *Legend.*

Figure 5. *Coarse-grained and mottled appearance of the Tally Ho leucogabbro on Tally Ho Mountain.*

less strained rocks weather greenish grey and exhibit chlorite alteration in the THSZ.

Gabbro and pyroxenite occur on Tally Ho Mountain and Dickson Hill and, based on a U-Pb age date of 213.8±0.6 Ma on Tally Ho gabbro (Hart, 1995), likely belong to the Lewes River Group. The Tally Ho leucogabbro (Hart and Radloff, 1990) is a mottled dark green, black and white, medium- to very coarse-grained plagioclase-hornblende gabbro that is weakly to moderately well foliated (Fig. 5). The leucogabbro is weakly to moderately well foliated and has been intruded by the Bennett granite. A massive, variably serpentinized body of pyroxenite and peridotite forms a resistant, blocky ridge line on the top of Tally Ho Mountain. The massive to well foliated ultramafic rock weathers dark greyish brown and is medium- to coarse-grained. Chrysotile and magnetite can be found in veinlets within the pyroxenite. The gabbro and pyroxenite are likely part of the same body as suggested by interlaying of gabbro and pyroxenite on the western flank of Tally Ho Mountain. Although the gabbro and pyroxenite are included within the Lewes River Group, this is speculative and future work will examine the origin of these rocks.

BENNETT GRANITE

The massive coarse-grained and megacrystic Bennett granite occurs in the westernmost part of the map area where it intrudes augite-schist and foliated gabbro (Fig. 6). The light grey-weathering granite is characterized by

Figure 6. *Intrusive contact between the Bennett granite (BG) and foliated Tally Ho leucogabbro (THL) on Tally Ho Mountain.*

Figure 7. *Mafic xenolith cross-cut by small aplite dyke in the mid-Cretaceous Whitehorse Suite on Tally Ho Mountain.*

potassium-feldspar megacrysts up to 2 cm in length, and contains less than 10% mafic minerals. The Bennett batholith is believed to be Early Jurassic in age, based on U-Pb dates of the felsic phase of the intrusion and age dates of other phases comprising this polyphase batholith (Hart, 1995). The Bennett granite in the study area is likely a phase of this batholith. Future U-Pb zircon geochronological analysis of the granite will provide further constraints on the age of crystallization.

MILLHAVEN CONGLOMERATE

A dark reddish brown-weathering, massive, polymictic orthoconglomerate outcrops on Dickson Hill. Clasts of quartz, quartzite, schist, granite, chert and volcanic rock (Hart and Radloff, 1990) are up to 6 cm in diameter and are subangular to subrounded. The formation appears to be in fault-contact with all other units in the study area.

WHEATON RIVER VOLCANICS

The easternmost study area is underlain by pale green to grey massive volcanic and volcaniclastic rocks that are in intrusive-contact with the Wheaton valley granodiorite (Fig. 3). On Wheaton Mountain, the rocks are typically green-grey-weathering and tuffaceous. On Mt. Stevens, the Wheaton River volcanics are represented by dark grey, massive, phenocrystic basalt, andesite and lapilli tuff. A weakly developed planar depositional flow fabric is locally developed in volcanic rocks on Wheaton Mountain.

WHEATON VALLEY GRANODIORITE

Medium- to coarse-grained xenolithic Wheaton valley granodiorite and diorite make up most of Wheaton Mountain and part of Mt. Stevens (Fig. 3). An intrusive- and fault-contact relationship exists with rocks of the Lewes River Group. The granodiorite is medium-grained, equigranular and locally characterized by a magmatic fabric. Variably chloritized hornblende and biotite account for up to 30% of the rock. A U-Pb zircon age of 78 Ma was obtained (Hart, 1995).

WHITEHORSE PLUTONIC SUITE

An undeformed, buff-weathering, medium-grained and equigranular granitic stock of the Cretaceous Whitehorse Plutonic Suite is in fault- and intrusive-contact with strained rocks on Tally Ho Mountain (Fig. 3). This rock is characterized by pink-weathering potassium-feldspar crystals, up to 5% mafic minerals and xenoliths. Associated pink aplitic dykes up to 60 cm wide are offset by small north-trending faults (Fig. 7).

YOUNGER VOLCANISM

Numerous rhyolite, basalt and porphyry intrusions cross-cut the geologic trend of the shear zone throughout the study area. These small intrusions are dominantly undeformed and are believed to be related to the Late Cretaceous to Eocene Mount Skukum Volcanic Complex, Bennett Lake Caldera Complex and the Wheaton River volcanics (Hart and Radloff, 1990).

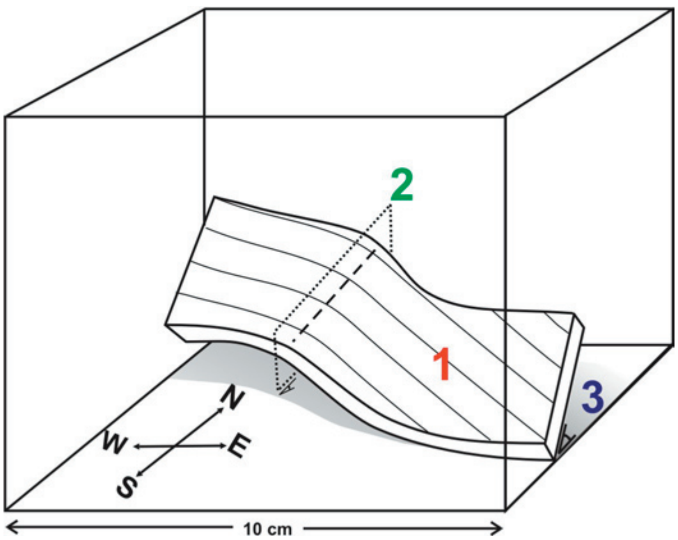

Figure 8. *Schematic diagram showing the relationship between lineations (1), crenulations (2) and foliation (3) in mylonitic rocks on Tally Ho Mountain.*

STRUCTURE

Two structural domains, the THSZ and the LFZ, each characterized by a distinct structural style, are recognized in the study area. The Llewellyn fault is a younger event that overprinted structures of the THSZ, resulting in steep brittle to brittle-ductile deformation in the Late Creteceous or younger. The THSZ is moderately inclined and decreases in strain beneath and to the east of the highly strained volcaniclastic rocks at the summit of Tally Ho Mountain.

TALLY HO SHEAR ZONE

The Tally Ho shear zone is a zone of highly strained, northwest-trending gneissic to mylonitic rocks (Fig. 8). Lineations developed on the foliation surface dominantly plunge shallowly to the southeast, however, many also trend shallowly to the northwest. Variations in foliation measurements on Dickson Hill and Tally Ho Mountain indicate that the shear zone fabric is folded. Crenulations of the schistose and mylonitic fabric verge predominantly east (Fig. 9), likely mimicking the larger fold structure. Fold axes on Tally Ho Mountain plunge shallowly to moderately to the southeast. The majority of observed rotated augite porphyroclasts and extensional shears (Fig. 10) indicate a top-to-the-east sense of shear.

On the eastern flank of Tally Ho Mountain, fabric development and strain in volcanic and volcaniclastic rocks decreases easterly from mylonitic to weakly foliated at structurally deeper levels beneath the shear zone. The decrease in strain is interpreted as being a transition from

Figure 9. *East-vergent crenulations in mylonite on Tally Ho Mountain.*

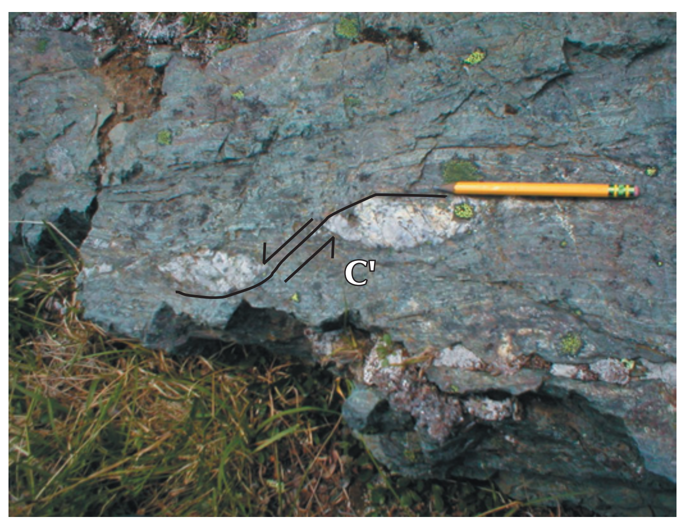

Figure 10. *Extensional C' shears in mylonite on Tally Ho Mountain. The sense of movement indicated by the shears is top-down and to the east. Pencil parallels C fabric.*

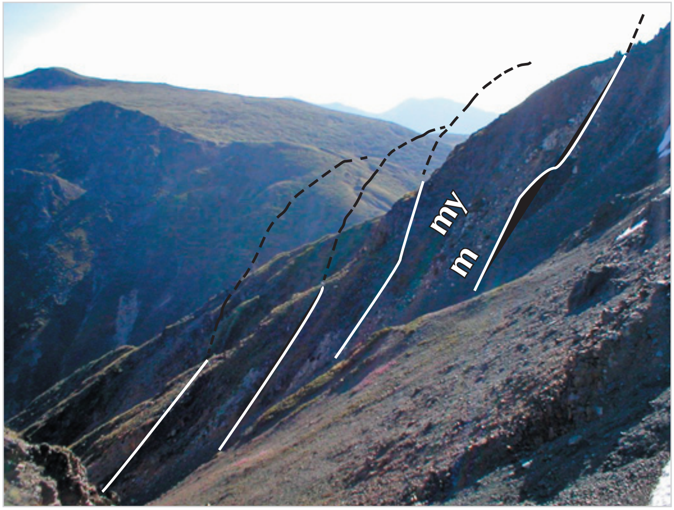

Figure 11. *East-vergent duplex structures repeating marble (m) and mylonite (my) on the north face of Tally Ho Mountain.*

the THSZ to less-strained volcaniclastic and volcanic rocks of the Lewes River Group cropping out beneath the shear zone (cross-section in Fig. 3).

A thrust fault on Tally Ho Mountain juxtaposes the Tally Ho leucogabbro and associated ultramafic rocks, which occur within and above the shear zone, against volcanic and volcaniclastic rocks that lie in and below the shear zone. Pyroxenite and leucogabbro are, in general, less strained than the underlying volcaniclastic rocks. Partitioning of strain into the volcaniclastic rocks may have occurred due to their finer grained, more siliceous nature. No evidence of contact metamorphism was found in the mylonite to indicate an intrusive origin of the pyroxenite. The lack of any evidence of intrusion of the gabbro or pyroxenite, coupled with the observed high-strain rocks along the contact with the volcaniclastic succession (mylonite), indicates that the pyroxenite and leucogabbro were tectonically emplaced above the volcaniclastic rocks along the THSZ. On the north face of Tally Ho Mountain a series of duplex structures stacking mylonite and marble indicates an apparent eastward vergence (Fig. 11). The duplex structures measure 2 m and greater in cross-section and may reflect the sense of movement of the larger thrust fault on Tally Ho Mountain.

Figure 12. *Tension gashes in granodiorite indicating post mid-Cretaceous sinistral brittle deformation on Mt. Wheaton.*

LLLEWELLYN FAULT ZONE

The Llewellyn fault zone (LFZ) is characterized by a number of fault splays that isolate and surround less strained fault bound blocks. Fault splays commonly trend northwest and cut all lithological units in the area, and locally appear to have exploited lithological boundaries. For example, the western contact of the Wheaton valley granodiorite with the Tally Ho shear zone is fractured and faulted, as is the intrusive contact between volcanic rocks and the granodiorite between Tally Ho and Wheaton mountains. Displacement along the fault splays is variable, changing from dextral strike-slip to dip-slip, as indicated by movement indicators in the field such as slickensides and slickenlines. Tension gashes and Reidel shears on

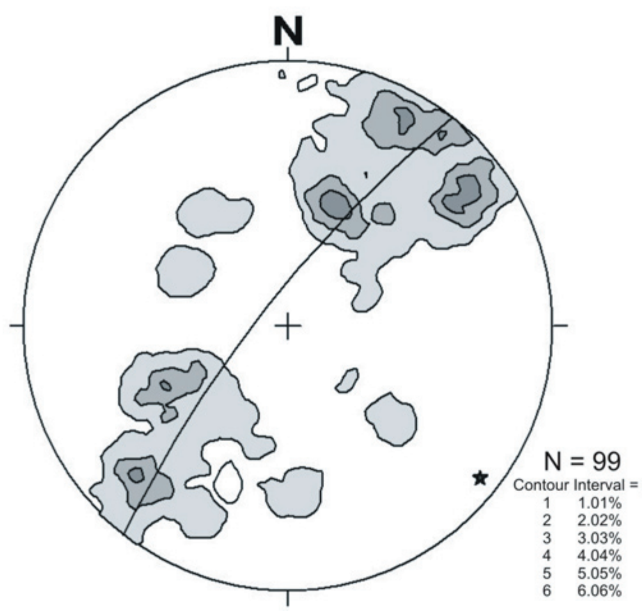

Figure 13. *Contoured stereoplot of poles to foliation measurements in schistose and mylonitic rocks on Tally Ho Mountain and Dickson Hill. Star = pole to girdle.*

Mt. Wheaton and Mt. Stevens imply sinistral strike-slip displacement (Fig. 12). Variable displacement vectors may indicate multiple displacement events along the LFZ.

STEREOPLOT ANALYSIS

An analysis of fabrics, lineations and fault orientation data using lower hemisphere equal-angle stereoplots was carried out using the methods of Woodcock and Naylor (1983), Lin and Williams (1992), and Ramsay and Huber (1987). Poles to foliation from the strained volcaniclastic and volcanic rocks on Tally Ho Mountain and Dickson Hill define a weak girdle pattern, consistent with folding about a shallowly southeast-plunging fold axis (Fig. 13). Lineations in the same area parallel the fold axis (Fig. 14).

DISCUSSION AND INTERPRETATION

Ductile deformation that characterizes the THSZ post-dates deposition of the Upper Triassic Lewes River Group (which is highly strained within the shear zone), and pre-dates crystallization of the Early Jurassic Bennett granite since the granite intrudes Lewes River Group augite porpyroclastic schist and foliated leucogabbro. It is likely that folding of the THSZ occurred before the intrusion of the Bennett granite as the granite appears to cross-cut the folded shear zone. Thus the THSZ is probably an Early Jurassic structure. Discrete shears and brittle faults observable in Cretaceous plutons in the study area constrain the timing of the LFZ to Late Cretaceous or younger. Multiple displacement events along the LFZ may explain the array of movement indicators.

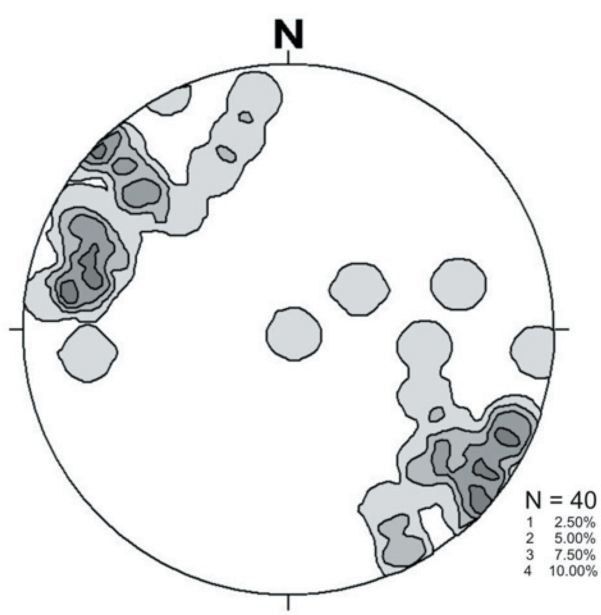

Figure 14. *Contoured stereoplot of lineation measurements from Tally Ho Mountain and Dickson Hill.*

Peridotite and leucogabbro were emplaced over the Lewes River Group volcaniclastic rocks within the THSZ. The thrust fault on Tally Ho Mountain likely carried the pyroxenite and leucogabbro in from the west, based on top-to-the-east vorticity of rotated porphyroclasts, extensional shears and east-trending elongation lineations. Potential sources of the mafic and ultramafic rocks in the THSZ are the Cache Creek Terrane to the east or, more likely, the exhumed roots of the Lewes River arc. Although the Cache Creek Terrane includes a significant volume of ultramafic and mafic rocks, the leucogabbro and pyroxenite are not characteristic of this terrane. Moreover, the timing of Stikinia-Cache Creek interaction post-dates the timing of the THSZ (Mihalnyuk et al., 2004; Ricketts et al., 1992). Alternatively, westerly derived garnet peridotite and ultra-high pressure rocks deposited in the Laberge Group of the Whitehorse Trough (MacKenzie et al., in press) suggests that rapid uplift and erosion of deep-seated rocks occurred during the Early Jurassic, which corresponds to the timing of the THSZ.

SUMMARY

Ultramafic and gabbroic rocks of the Tally Ho shear zone are allochthonous, having been thrust to their present position and folded by the Early Jurassic. Timing of the THSZ is constrained by the age of crystallization of the Early Jurassic Bennett granite, which cross-cuts the shear zone. Late Cretaceous and younger brittle and semi-brittle faulting occurred along the Lllewellyn fault zone.

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