Structural Evaluation of the Tom Deposit, Selwyn Basin, Yukon

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Introduction

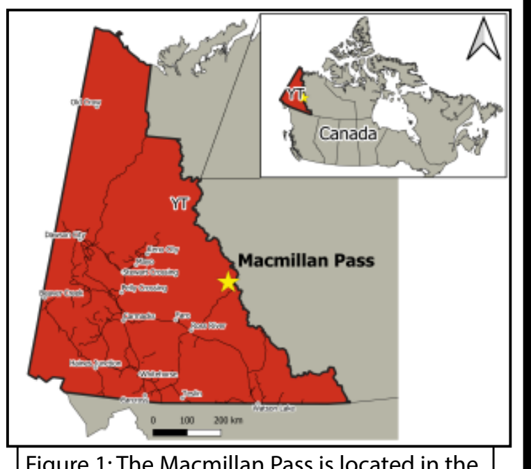


Figure 1: The Macmillan Pass is located in the Yukon near the Northwest Territories border and the community of Ross River.

Stratiform Pb-Zn orebodies that make up shale-hosted massive sulfide (SHMS) deposits account for 40% of Zn and 60% of Pb reserves globally (Tikkanen, 1986). SHMS deposits form at shallow depths and low temperatures in reduced sedimentary basins from upwelling hydrothermal fluids that circulate through the sedimentary sequence scavenging metals during extension. The structural geology of basin genesis along synsedimentary fault conduits is crucial to understanding the formation of Pb-Zn-Ag shale-hosted stratiform sulfide deposits. Fluid circulation is dependent on faults to provide vertical permeability across otherwise impermeable sedimentary layering. Defining the fault architecture of a basin is a critical step in reconstructing basin geometry and identifying prospective areas for SHMS mineralization.

The Selwyn Basin, Yukon, comprises a sequence of clastic sedimentary rocks that host several large SHMS deposits, including the Tom and Jason deposits of the Macmillan Pass area (Fig. 1; (Abbott and Turner, 1991). These deposits are hosted in Devonian strata that have been extensively folded by mid-Cretaceous crustal shortening.

This project intends to build on and improve upon previous local mapping if the Macmillan Pass area and advance the structural understanding of the effect of Cordilleran deformation on SHMS mineralization in the Selwyn Basin.

Evaluating the structural controls of the Macmillan Pass area and identification of fault geometry and kinematic histories further defines the structural geometry, spatial variation in strain accommodation, overprinting relationships and current state of SHMS mineralization seen at the Tom Deposit (Fig 2).

Background

The supercontinent Rodinia underwent protracted extension and rifting in the Late Neoproterozoic to Early Cambrian resulting in the formation of a passive margin on the northwestern margin of the new Laurtentia continent (Nelson et al., 2013). During this time, the Neoproterozoic to Lower Devonian Paleozoic Selwyn basin formed as a large marine depocenter along the northern Laurentian passive margin in what is now central-eastern Yukon. The Selwyn basin was bound on its eastern margin by the similarly aged Mackenzie carbonate platform that developed on the Laurentian continental shelf.

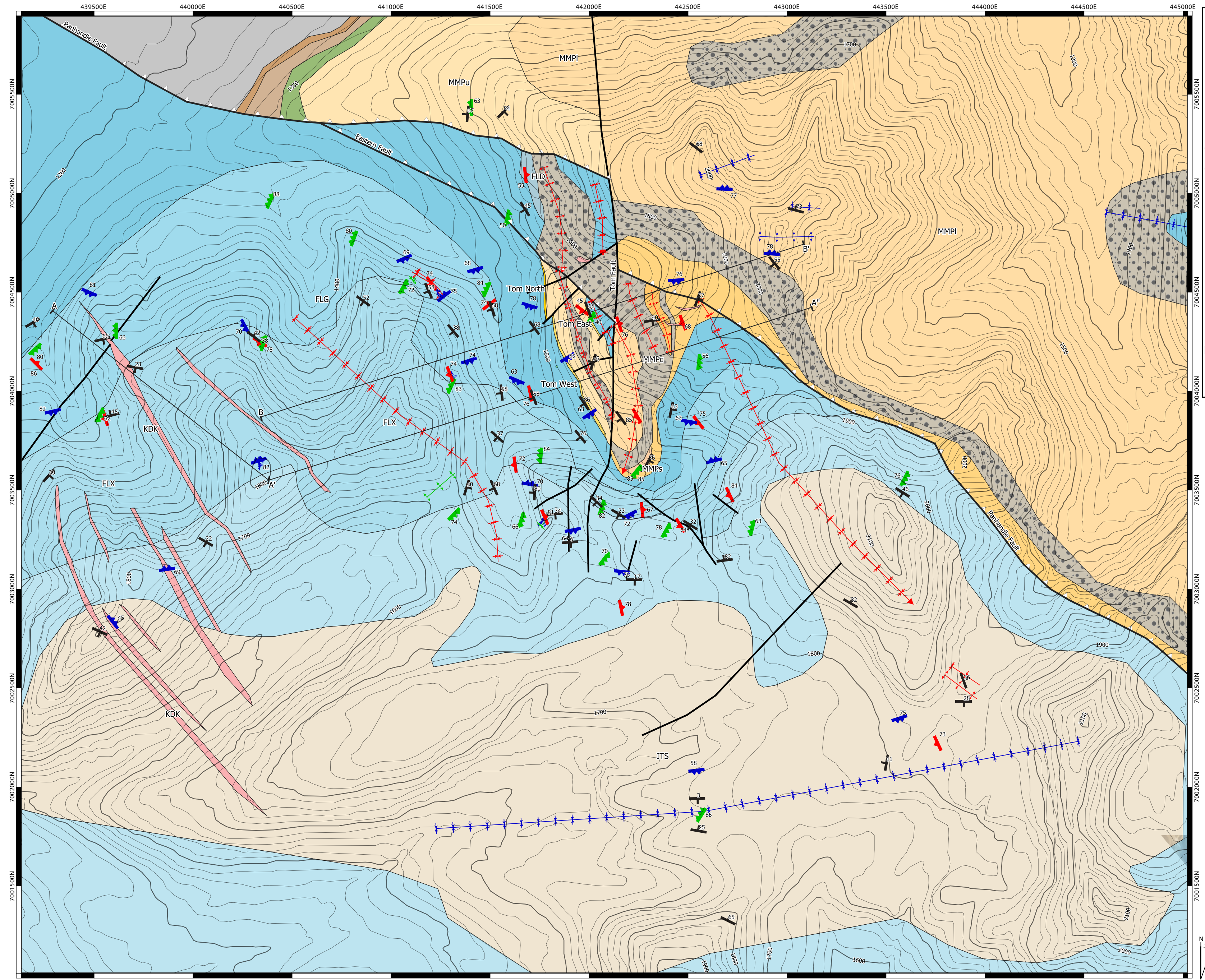
From the Late Devonian, the Laurentian passive margin transitioned into convergent margin with eastward directed subduction (Nelson et al., 2013). Subduction was accompanied by back-arc extension and the formation of back-arc basins into which Devonian to Carboniferous sediments were deposited over Selwyn Basin strata. The Macmillan Pass SHMS deposits are hosted in one such Mid-Devonian to Mississippian extensional basin. Back-arc related sedimentation in the Selwyn basin ended prior to final accretion of the peri-Laurentian and Insular terranes to ancestral North America in the Middle Jurassic (Nelson et al., 2013).

Continued subduction and plate convergence through the Jurassic and Cretaceous resulted in the Cordilleran orogeny. Within the Selwyn basin this orogeny is expressed as a foreland fold and thrust belt that is up to 130 km wide. The Macmillan Pass SHMS deposits occur at eastern edge of this belt, west of a transition into a temporally equivalent fold and thrust belt in Mackenzie platform strata.

Abbott (2013) divided the Macmillan Pass area into three structural domains, the North, Central, and South Domains. The domians differ in terms of the Middle Devonian to Mississippian stratigraphy and the style of and intensity of cordilleran deformation (Abbott and Turner, 1991; Abbott 2013).

The Central Block is bounded by reactivated faults and host to the mineralized SHMS deposits Tom and Jason within the Earn Group (Fig. 2). Detail studies of the Earn Group in this area (Carne 1979, 1982; Abbott and Turner 1991; and Abbot 1982, 1991;) provide an opportunity to improve structural understanding and geological interpretations of the Tom Deposit.

Geological Map of the Tom Despoit, Macmillan Pass, Yukon



LEGEND

Mapping Symbols
- Bedding
- S1
- S2
- S3

Structures
- Normal Fault
- Reverse Fault
- F1 Synform
- F1 Antiform
- F1 Antiform, overturned limb
- F2 Synform
- F2 Antiform
- F3 Synform
- F3 Antiform
- Plunge Direction
- Cross Section A-A'

Contours
- 100m

Geology
- KDK - Intrusive
- ITS - Itsi Formation
- FLE - Fuller Lake Eggshell
- FLX - Fuller Lake Cherty
- FLG - Fuller Lake Gritty
- FLC - Fuller Lake Carbonaceous
- FLD - Fuller Lake Diamicite
- SHMS - Shale Hosted Massive Sulfide
- MMP - MacMillan Pass Undifferentiated
- MMPu - MacMillan Pass Upper Pinstripe
- MMPc - MacMillan Pass Conglomerate
- MMPs - MacMillan Pass Coarse Sandstone
- MMPl - MacMillan Pass Lower Pinstripe
- MVV - MacMillan Pass Volcanics
- SAF - Sapper Formation
- STF - Steel Formation
- DLK - Duo Lake Formation

Stratigraphic Relationships

Cretaceous

KDK INTRUSIVE: Resistant, blocky, grey weathering, porphyritic to equigranular biotite quartz monzonite and biotite granite.

Upper Devonian

ITS ITSI FORMATION: Resistant, brown weathering, thick-bedded, parallel laminated and ripple cross-laminated micaceous sandstone, siltstone and shale.

FLE FULLER LAKE Eggshell: Black carbonaceous mudstone, typically laminated with minor silt, typically radiolarian. Characterised by rounded and flattened barite concretions

FLX FULLER LAKE Cherty: Black carbonaceous mudstone, very siliceous with silt-sized grains of radiolaria. Laminated intervals with minor silt.

FLG FULLER LAKE Gritty: Black carbonaceous mudstone, laminated intervals with minor silt, some mudstone beds appear 'gritty' with silt-sized grains that are mainly radiolarian.

FLC FULLER LAKE Carbonaceous: Black carbonaceous mudstone, lamination may be visible or may appear massive, typically pyritic.

FLD FULLER LAKE Diamictite: Polymictic well rounded mudstone matrix supported diamictite. Typically associated with fault movement.

SHMS SHALE HOSTED MASSIVE SULFIDES: Massive, semi-massive and interbeds of sphalerite, galena, barite, pyrite and carbonaceous mudstone. Unit is heavily deformed among bedding layers with highly contorted laminations.

Middle to Upper Devonian

MMPu MACMILLAN PASS Upper Pinstripe: Medium grey silt banded mudstone. Characterised by carbonate-bearing sandy bands with pervasive ankerite alteration.

MMPc MACMILLAN PASS Conglomerate: Resistant grey weathering, massive chert-pebble conglomerate with siliceous matrix and minor coarse sandstone and mudstone interbeds

MMPs MACMILLAN PASS Coarse Sandstone: Coarse grained chert lithic arenite, silt and mud interbeds. Pulses seen above and below Conglomerate unit.

MMPl MACMILLAN PASS Lower Pinstripe: Medium grey silt banded mudstone. Characterised by carbonate-bearing sandy bands with pervasive ankerite alteration.

Middle Devonian

MMV MACMILLAN PASS Volcanics: Orange weathering, carbonate-rich mafic flows and volcaniclastic rocks with minor related sedimentary rocks. Subsequent blocky, resistant, dark grey weathering, coarse-grained gabbro sills and dikes.

Upper Silurian to Middle Devonian

SAF SAPPER Formation: Very recessive, buff to tan weathering, silty limestone with minor calcareous black shale. Minor lenses of massive grey limestone seen locally.

Middle to Upper Silurian

STF STEEL Formation: Orange to green weathering, dark grey bioturbations disturb bedding, wispy laminated, green shale and mudstone. Thick beds of orange weathering pyritic dolostone are intermittent

Lower Ordovician to Middle Silurian

DLK DUO LAKE Formation: Silver-grey weathering, medium-bedded, siliceous mudstone and chert. Abundant graptolites seen in mudstone layers.

Fuller Lake member
Portrait Lake Formation
Macmillan Pass members
Earn Group
Road River Group

Figure 2: Geological mapping of the Tom deposit. A number of faults are seen, with the most significant being the Eastern Fault, Panhandle Fault and the late Tom Fault.

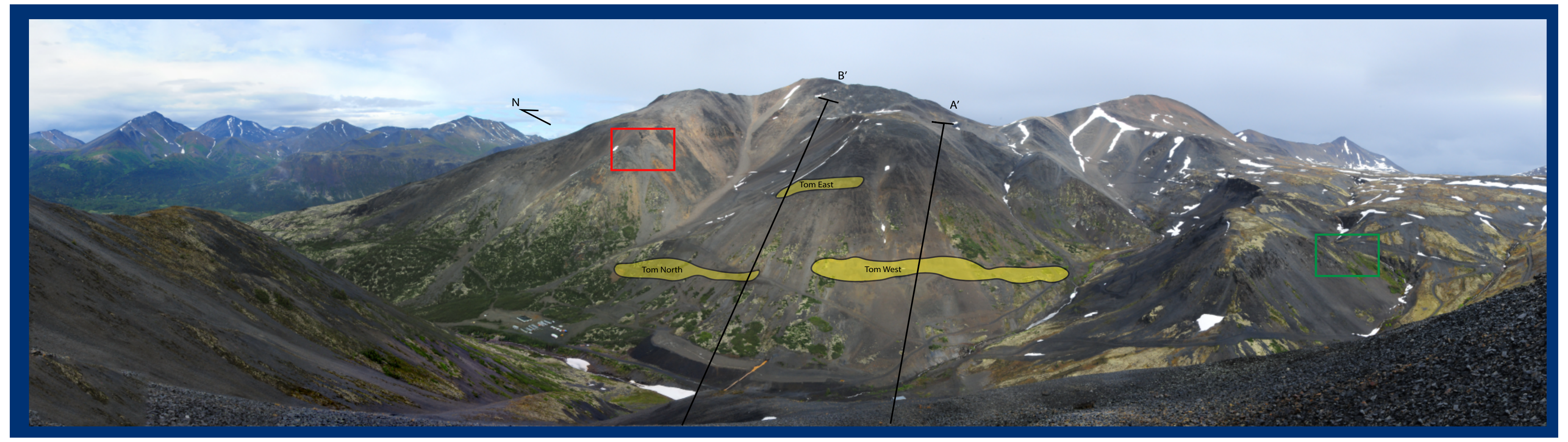


Figure 3: Photo looking East at the Tom West, Tom East and Tom North deposits. Cross-section lines A-A'-A" and B-B' are shown. The green and red boxes relate to figure 7 and figure 9, respectively. (Tom North projected to the surface)

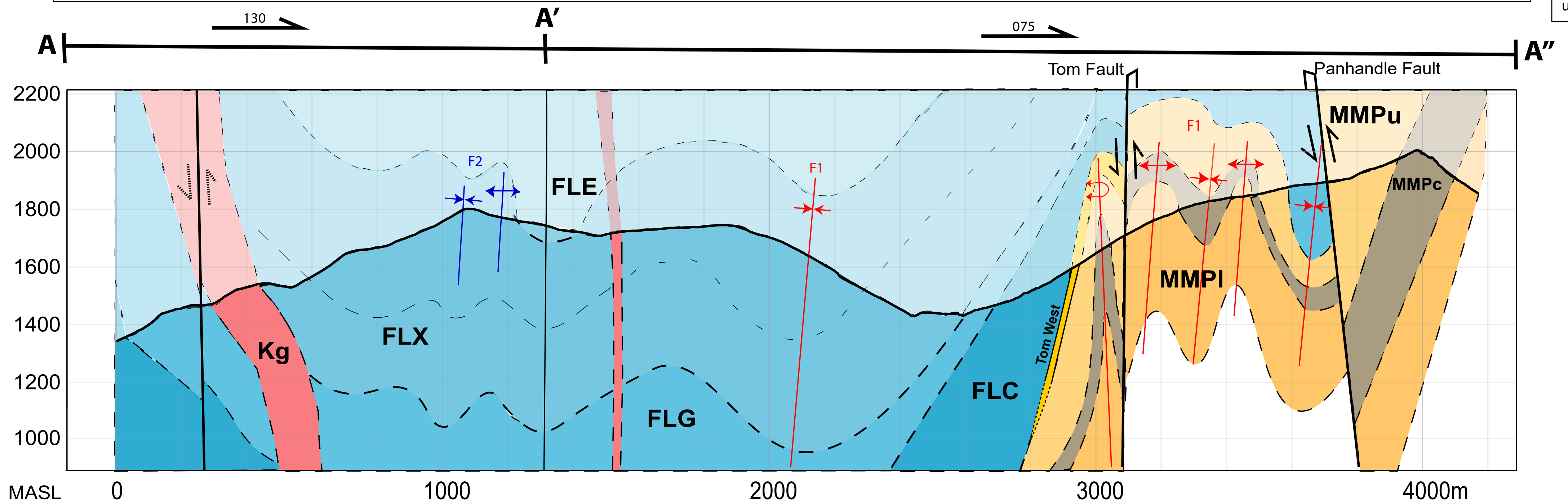


Figure 4: Cross-section A-A'-A". Weaker deformation is noted West of the deposit, where F2 dominates before structural complexities increase as maximum stages of F1 deformation are present at the Tom deposit. The near-vertical North trending Tom Fault intersect both Tom West and Tom East.

Stereographic Projections

Structural data gathered within the mapping area shows three phases of deformation, with F1 being the most dominant locally.

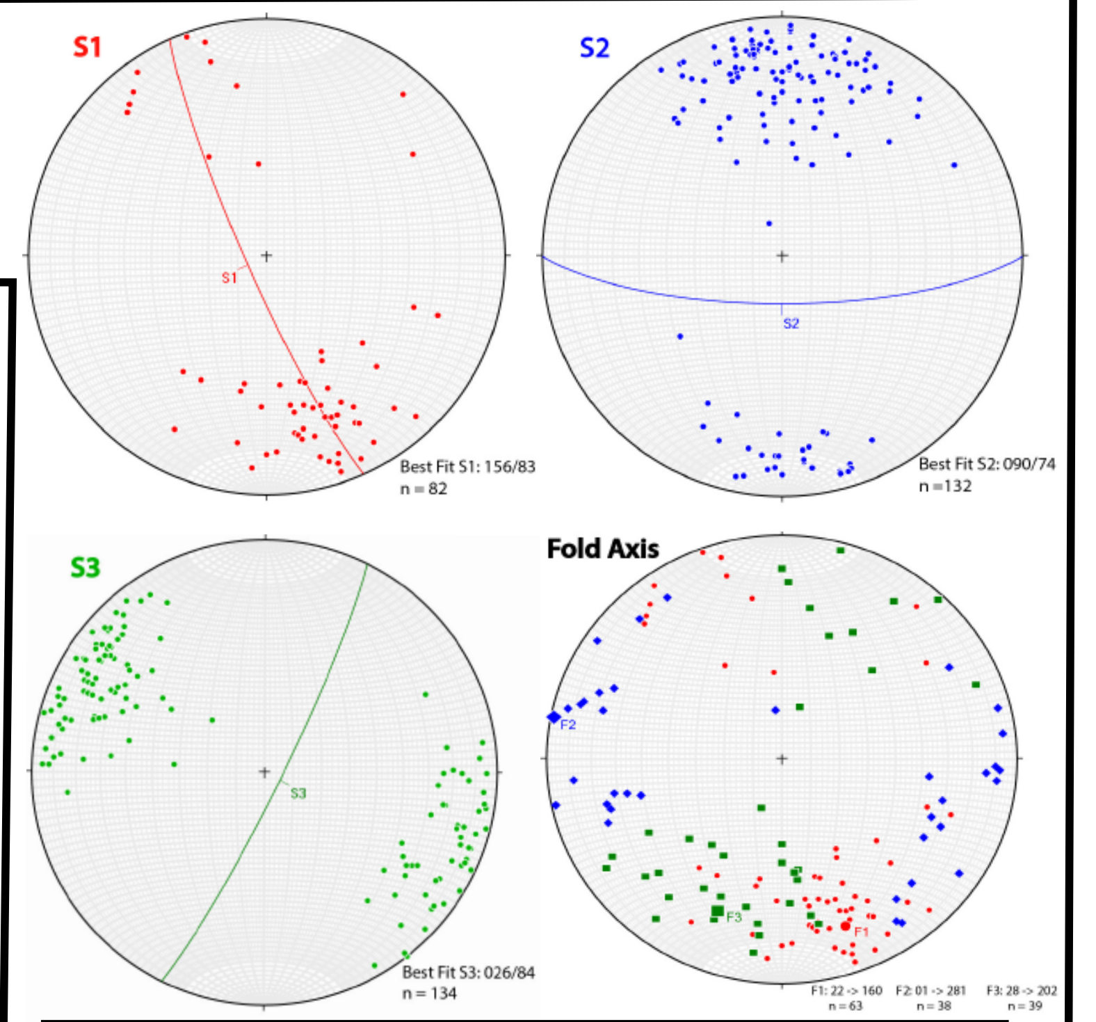


Figure 5: Stereographic projections with best fit foliatons and fold axis shown.

Folds range from very tight, steep folds that plunge south, to open, doubly plunging folds often resulting in metre scale dome-and-basin structures (Fig. 7). S1 is weakly present in areas, and completely absent in others, being difficult to distinguish.
F2 is seen to overprint F1, and is typically seen as upright tight to open folds.
F2 warp folds are seen within Tom West and Tom East (Fig. 7).
The final deformation event, F3, results in weak, open buckle folds with a steep North-South near-vertical fabric associated.

Results

Structural mapping has delineated three major deformation events.

The first major deformation event, D1, is defined by tight, upright folds but is also seen as large open folds. D1 is defined by the crest of the Tom anticlinorium where Tom East and Tom West are found on opposite limbs of a parasitic antiform West of the crest. Inconsistently seen within mapping units, the dominant orientation of S1 fabrics is 156/83. F1 Fold axis dominantly plunging to the south 22 -> 160; it varies to form doubly-plunging structures. The first deformation event is restricted to the Central Block, and furthermore, it is only seen East of the Macmillan River in close proximity to the Tom deposit defining a fourth domain.

The second deformation event, D2, is pervasively developed across the study area. S2 fabrics have an average orientation of 090/74. F2 folds are upright with shallow to moderately inclined plunge. The average F1 fold axis is 01 -> 281. Undulating buckle folds of the Tom deposits are a result of this D2 event.

The last deformation event, D3, is the final and weakest event. It is dominated by a planar, steeply dipping S3 fabric measuring 026/84. F3 folds are weakly developed open buckle folds with wavelengths of one metre oriented 28 -> 202.

Three major fault structures have been identified in the area of the deposit; the Eastern fault, Panhandle fault, and the Tom fault. The Eastern and Panhandle faults are near-vertical reverse faults dipping to the northeast. The Eastern fault is significant as it is thought to truncate and displace the northernmost extent of Tom East. The Tom fault is an extensive, vertical, north-trending structure thought to be a post-Cordilleran folding with little local movement.

Strain accommodation varies owing to heterogeneity between rock units. Competency contrasts are severe, with highly heterogenous interbeds of siliceous radiolarian rich mudstones, chert, carbonaceous mudstones and barite. Less competent rocks, such as massive sulphide mineralization and barite lenses, preferentailly accommodate strain resulting in severe internal deformation.

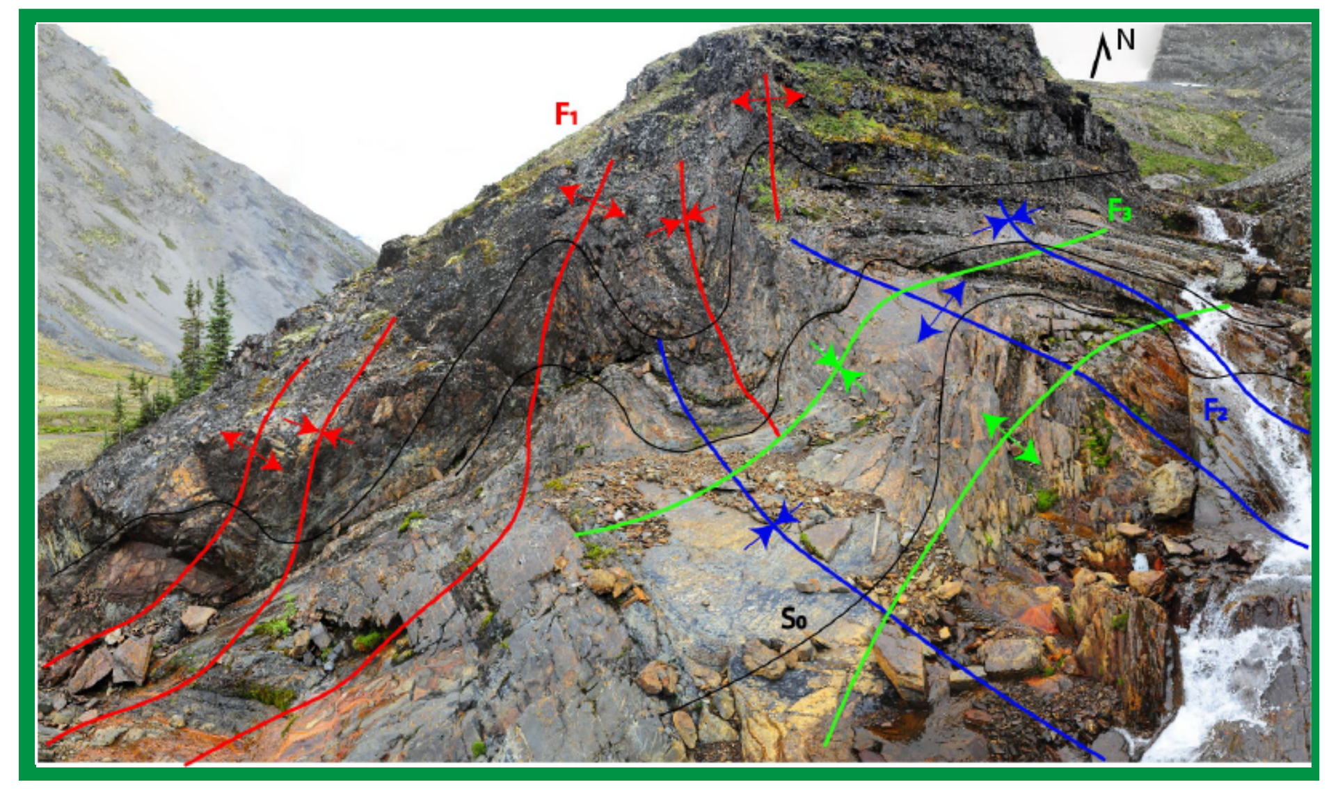


Figure 6: A complex area of polyphase deformation. F1 folds are tight and upright, overprinted by open, upright F2 folds and a weak F3 buckling before returning to monoclinal layering to the North.

Discussion

East of the Macmillan River and local to the Tom deposit, an early stage of deformation is recognized. The timing of this deformation event (D1) is poorly constrained. Previous regional mapping west of the Macmillan river indicate that thrust faulting in the north block cut F2 folding prior to the emplacement of Cretaceous dykes, placing a minimum age for D2 deformation as Cretaceous (Willms ,et al, 2020).

The relative timing of movement between the Eastern and Tom Faults is poorly constrained. If the Eastern Fault was first active, it is likely that northern most extent of Tom East has been truncated, uplifted and eroded. Conversely, if the Tom Fault was first active, the continuation of Tom East may be displaced down to the north, in the subsurface where similar stratigraphy and folding occur (Fig 8).

The Panhandle Fault has red pervasive hematite staining of fault gouge and nearby rock units resultant from groundwater circulation. The fault is exposed at surface over several kilometres. The fault offsets the 1km thick package of the Fuller Lake member to a resultant 300m section to the southeast termed the 'panhandle.'

The Tom Fault is a near-vertical normal fault and trends almost due north for tens of kilometres. It offsets both the Tom East and Tom West to the south of their extents. Stratigraphic displacements across the fault indicate total displacement less than a kilometre. Contrary to previous interpretations, we suggest the Tom Fault is a Cretacous structure unrelated to the mineralization at the Tom deposit.

The timing of the Eastern Fault and Panhandle Fault is poorly constrained. Further investigation is required as the orientation of these faults is similar to regional Devonian structures, diamictite is proximal to the Eastern Fault, and fluid movement is spatially associated with the Panhandle Fault. Is it possible that these faults were feeder structures for mineralization?

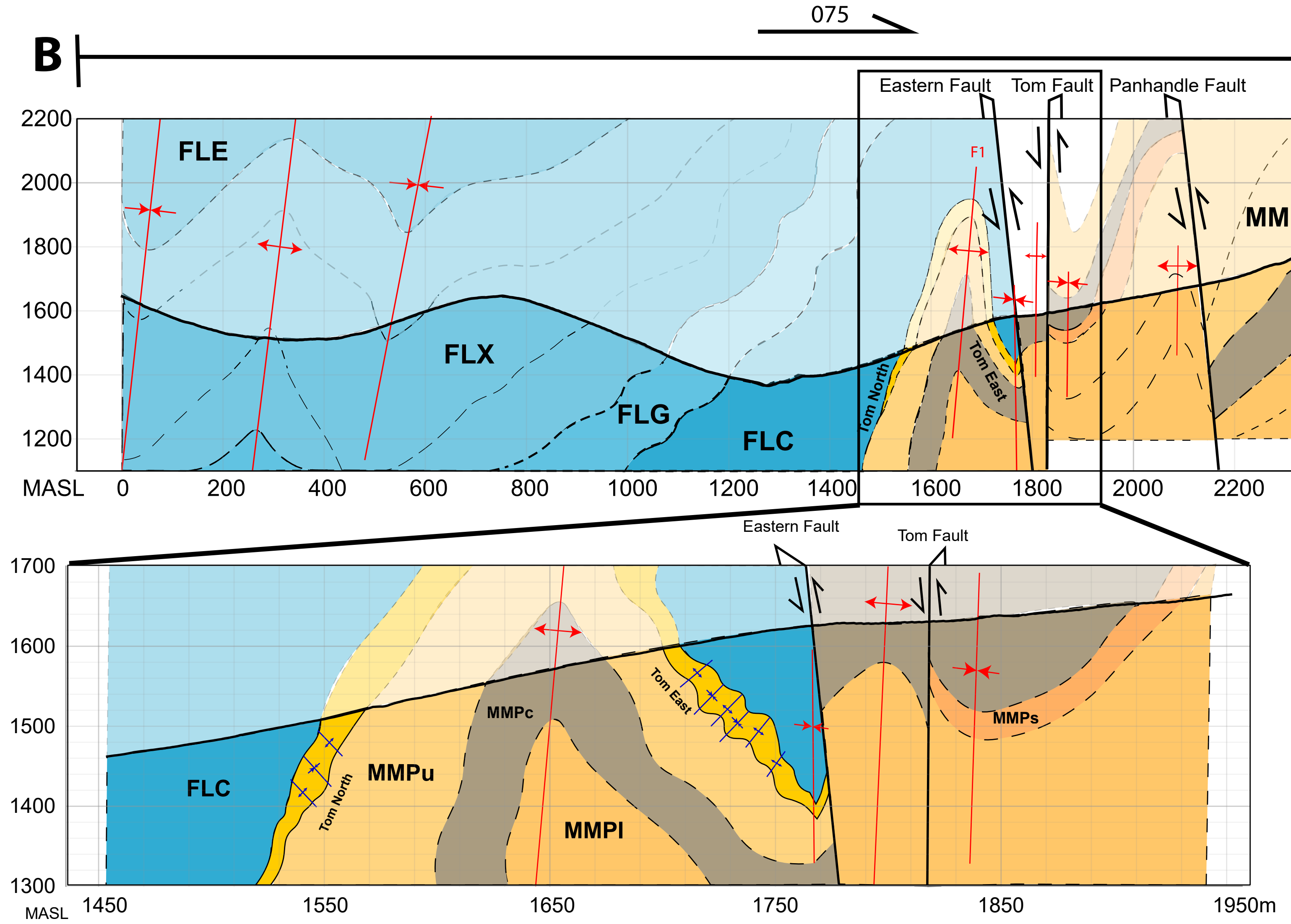


Figure 7: Cross-section B-B'. Complex F1 folding shows Tom West and Tom East within a parasitic antiform to the larger Tom Anticline. Inset: F1 and F2 deformation heavily deform the incompetent ore deposit before the Eastern Fault intersects Tom East, and the Tom Fault intersects the South of Tom East and Tom West.

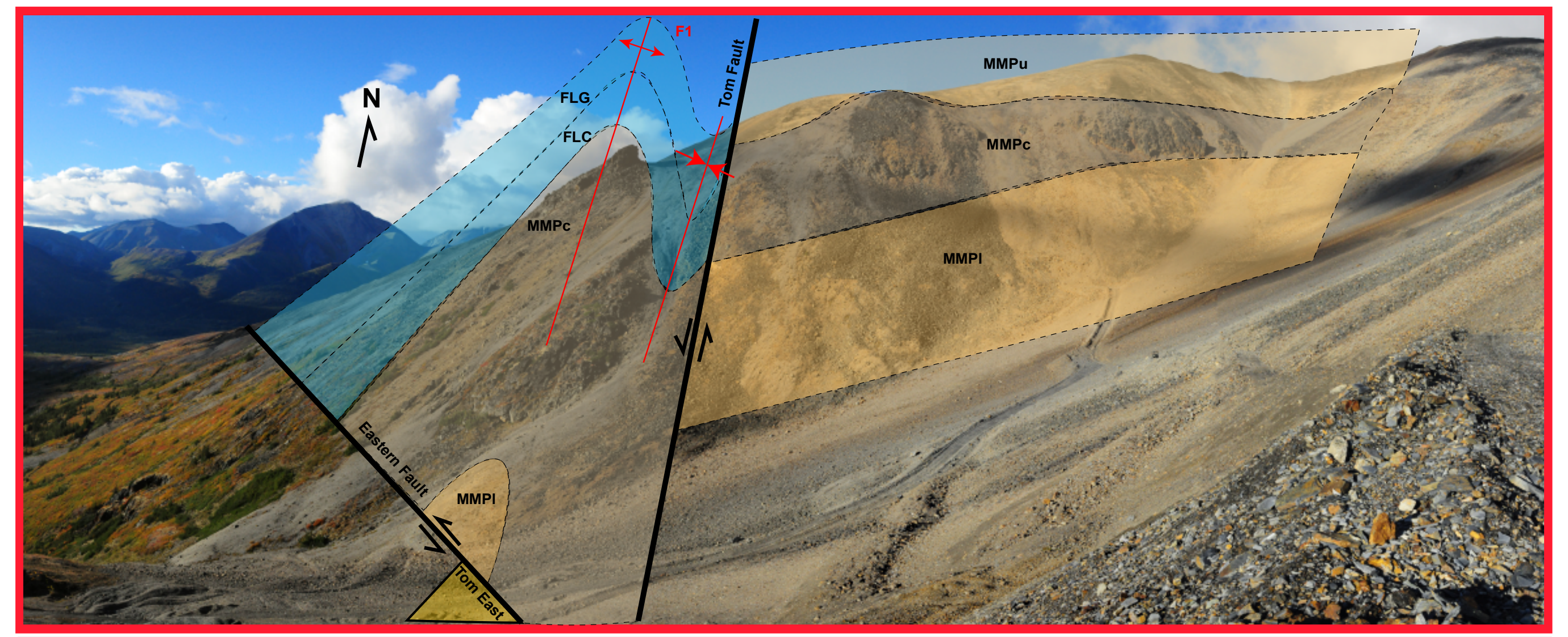


Figure 8: Surface exposure of units 400m North of B-B' inset. Note the homoclinal folding to the East of the Tom Fault. Timing of fault movement between the Eastern Fault and the Tom Fault may either displace Tom East into the sky or further to the North at depth. Antiform synform pair plunge South.

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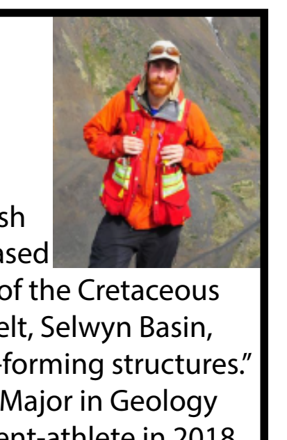
About the Author



Quinton Willms is a current MSc. Candidate in Geological Sciences at the University of British Columbia working on his field-based thesis "Structural reconstruction of the Cretaceous Macmillan Pass fold and thrust belt, Selwyn Basin, Yukon: Identifying Devonian ore-forming structures." Quinton graduated with his BSc. Major in Geology from UBC as a varsity rugby student-athlete in 2018. During his undergraduate degree, he was able to work consecutive seasons in the Yukon on various ore deposit types, and has continued doing so for the last five years.
In undertaking his thesis at UBC, and as the 2019 UBC-SEG student chapter Vice President, he continues to work directly with industry and academic members.

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