YGS Miscellaneous Report MR-21

This Miscellaneous Report supplements YGS Open File 2020-42

Keno Hill Mining Camp

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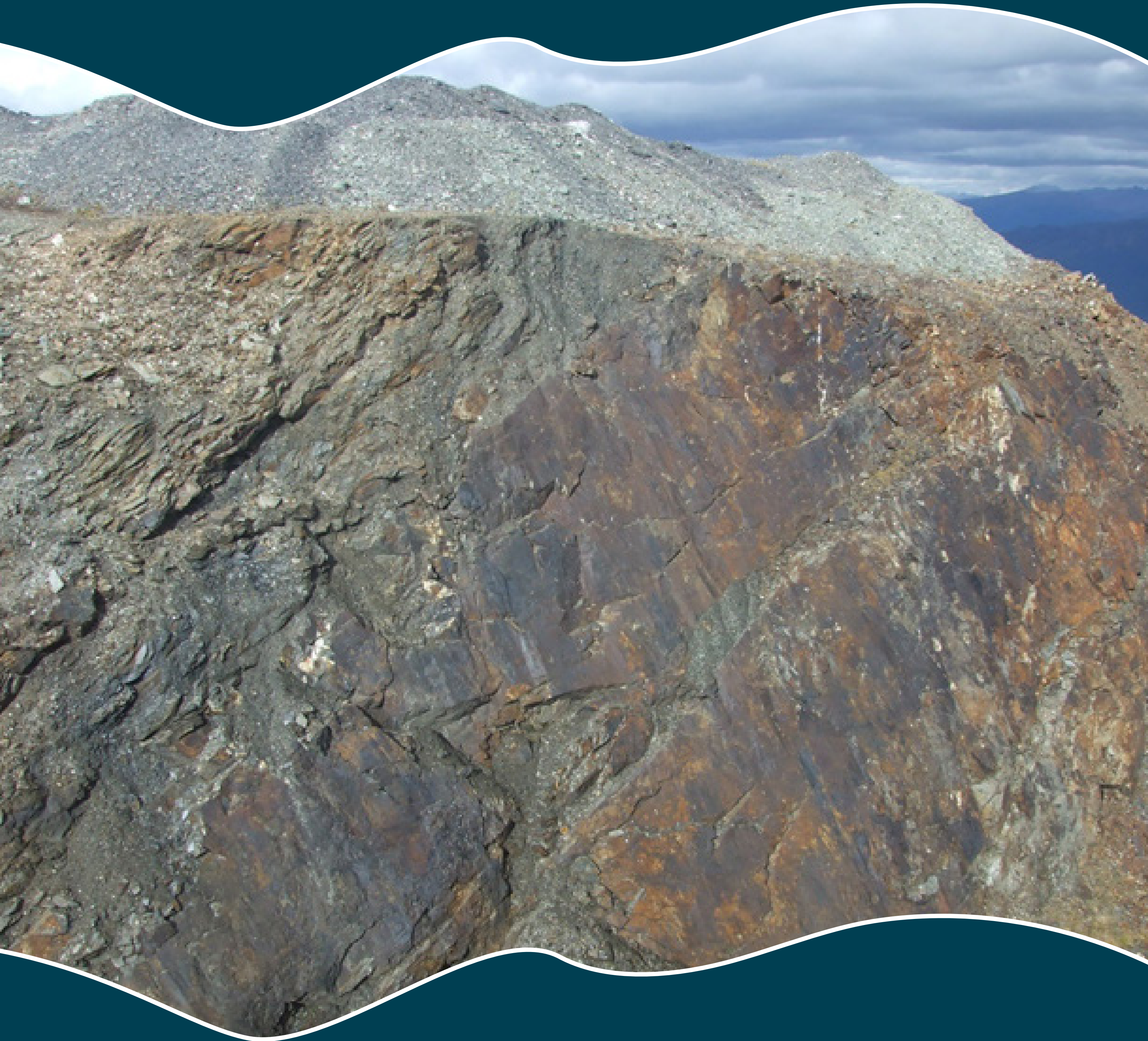

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Cover: On the top of Keno Hill looking west to the manganese stained footwall of No. 9 Vein showing rough corrugations plunging steeply to the right formed during vein fault formation. The top left-hand corner of the footwall consists of chlorite-sericite schist of the Earn Group overlying the inverted stratigraphic base of Basal Quartzite Member composing the rest of the footwall.

Foreword

This Miscellaneous Report includes the presentation that was prepared to accompany the release of YGS Open File 2020-42, Geology of the Keno Hill district by Peter Read, Al McOnie and Seymour Iles, and presented at the 2020 Virtual Yukon Geoscience Forum in November 2020. Because the original presentation was fraught with technical difficulties during the virtual event, the authors have subsequently prepared this version along with detailed notes in order to support the release of their new map for the Keno Hill district. The notes provided in this companion report will greatly facilitate the exploration of the many details included on the maps and cross sections in Open File 2020-42.

Reference

Read, P.B., McOnie, A. and Iles, S., 2020. Geology of the Keno Hill district, Yukon. Yukon Geological Survey, Open File 2020-42, 2 sheets: 1:25 000 and 1:2 500 scale. https://data.geology.gov.yk.ca/Reference/95881#InfoTab.

INTRODUCTION

We stand on the shoulders of those who came before us. In the Keno Hill Mining Camp, these include:

- Ken McTaggart (1960), Geological Survey of Canada, Bulletin 65 who recognized the intensity of deformation and developed the first stratigraphy of the Keno Hill Quartzite and enveloping rocks.
- Robert Boyle (1965), Geological Survey of Canada, Bulletin 111 who wrote the "Bible" on the vein structure, mineralogy and ore formation in the mining camp.
- Don Murphy and Charlie Roots *et al.* (1997), Yukon Geological Survey, Bulletin 6 who developed the regional structural and stratigraphic setting of the mining camp and expanded the Keno Hill Quartzite to include some of the overlying schist.
- Many United Keno Hill Mining geologists, some of whom are mentioned in Bob Cathro (2006) Geoscience Canada, volume 33, number 3, are the source of innumerable, previously unpublished details in the map presented in YGS Open File 2020-42.

The following presentation is divided into

Stratigraphy and Intrusions
Structure
1. Folding
2. Faulting
The Creation of Space for Vein Formation

STRATIGRAPHY

The evolution of the basic stratigraphy of the mining camp is represented in Table 1.

Table 1. *Basic stratigraphy of the Keno Hill camp.*

Boyle's Nomenclature	**Murphy's Nomenclature**	**This Map**
Upper Schist	Yusezyu Formation	Yusezyu Formation
	Robert Service thrust	*Robert Service thrust*
	Keno Hill Quartzite	Sourdough Hill Member
Central Quartzite		Basal Quartzite Member
Lower Schist	Earn Group	Earn Group

- Boyle’s stratigraphy did not recognize the presence of the Robert Service thrust.
- With Murphy and Roots *et al.*’s recognition of the thrust within the Upper Schist, the part of the schist between the thrust and the Central Quartzite was added into the Keno Hill Quartzite.
- Because the boundaries of the quartzite are easily picked, correspond to Boyle’s Central Quartzite, and the quartzite is the unit of economic importance it has been separated out as the Basal Quartzite Member.
- The overlying schist-rich portion added by Murphy and Roots *et al*. to the Keno Hill Quartzite is named the Sourdough Hill Member.

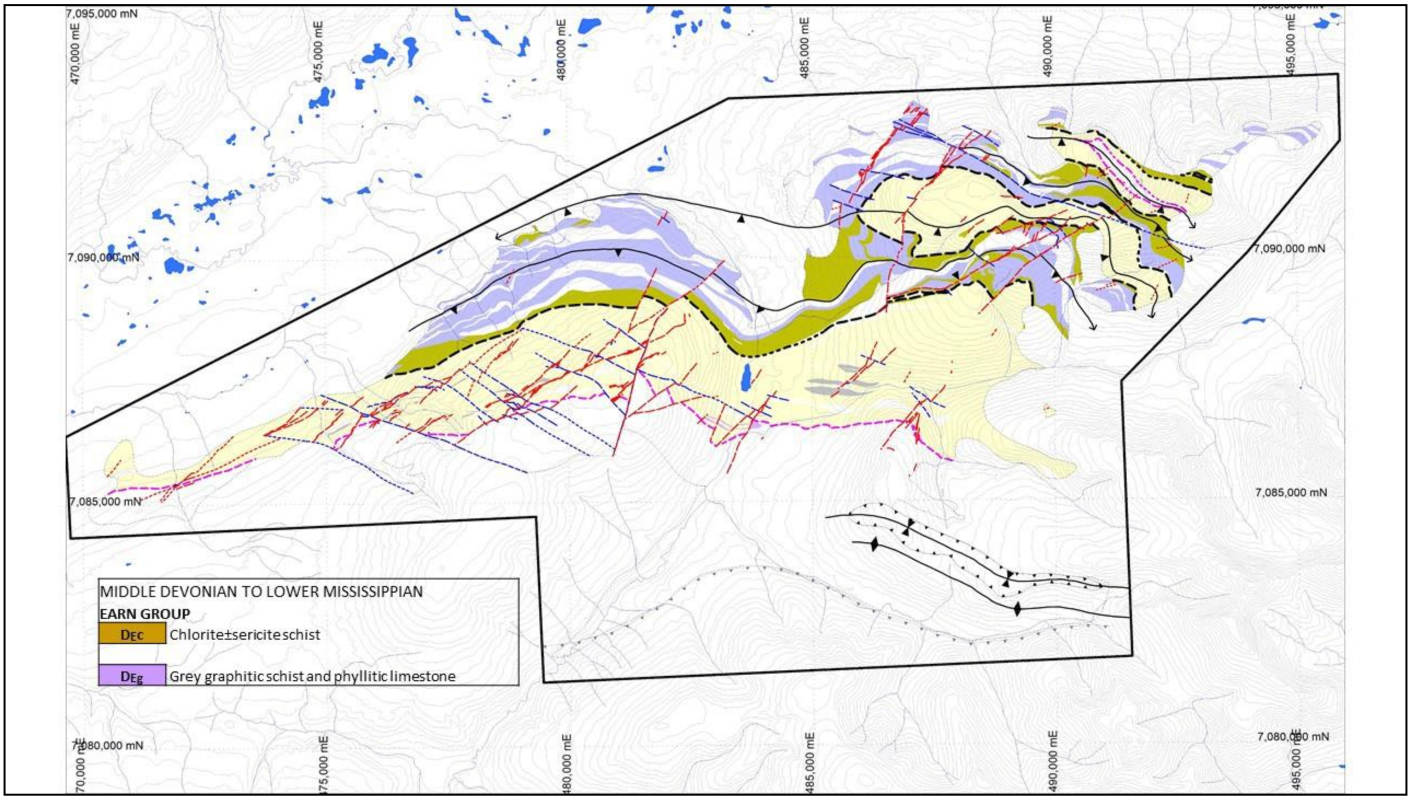
Table 2. *The present legend of the map and stratigraphy for the Keno Hill Mining Camp.*

EARLY LATE CRETACEOUS	
TOMBSTONE SUITE	
LKTlp	Biotite-bearing lamprophyre "sills" *(ca. 89 Ma)*
LKTa	Aplite and quartz porphyry "sills" *(93.5 Ma)*
	Regional deformation and metamorphism *(ca. 110-100 Ma)*
LATE TRIASSIC	
GALENA SUITE	
Ŧgn	Greenstone sills *(ca. 232 Ma)*
MISSISSIPPIAN - PERMIAN?	
Keno Hill Quartzite	
Sourdough Hill Member	
Msc	Green and grey-green schist
Msls	Light to medium grey phyllitic limestone
Msgr	Pale green to grey, clear quartz grain grit
Msgu	Medium to dark grey graphitic schist
Msq	UPPER QUARTZITE: Light to dark grey, platy quartzite with dark grey graphitic schist
Mss	SERICITE SCHIST MARKER: Sercite±chlorite schist; rare clear quartz grain grit
Msg	GRAPHITIC SCHIST MARKER: Medium to dark schist and siliceous schist
Basal Quartzite Member	
MKq	BASAL QUARTZITE: Blocky buff to grey quartzite, locally calcareous, includes graphitic schist and greenstone sills
MKg	Graphitic schist
MKs	Sericite±chlorite schist
MIDDLE DEVONIAN TO LOWER MISSISSIPPIAN	
EARN GROUP	
DEc	Chlorite±sericite schist
DEg	Grey graphitic schist and phyllitic limestone
Robert Service thrust	
NEOPROTEROZOIC - LOWER CAMBRIAN	
HYLAND GROUP	
Yusezyu Formation	
ЄY	Pale green muscovite-chlorite schist, clear and blue gritty schist and silver-grey quartz-rich schist

A description of the stratigraphy will follow the groupings of units given by the dotted lines in the Legend

- Earn Group
- Basal Quartzite Member – the economically important unit
- Sourdough Hill Member
- Intrusions
- Neoproterozoic to Lower Cambrian Yusezyu Formation

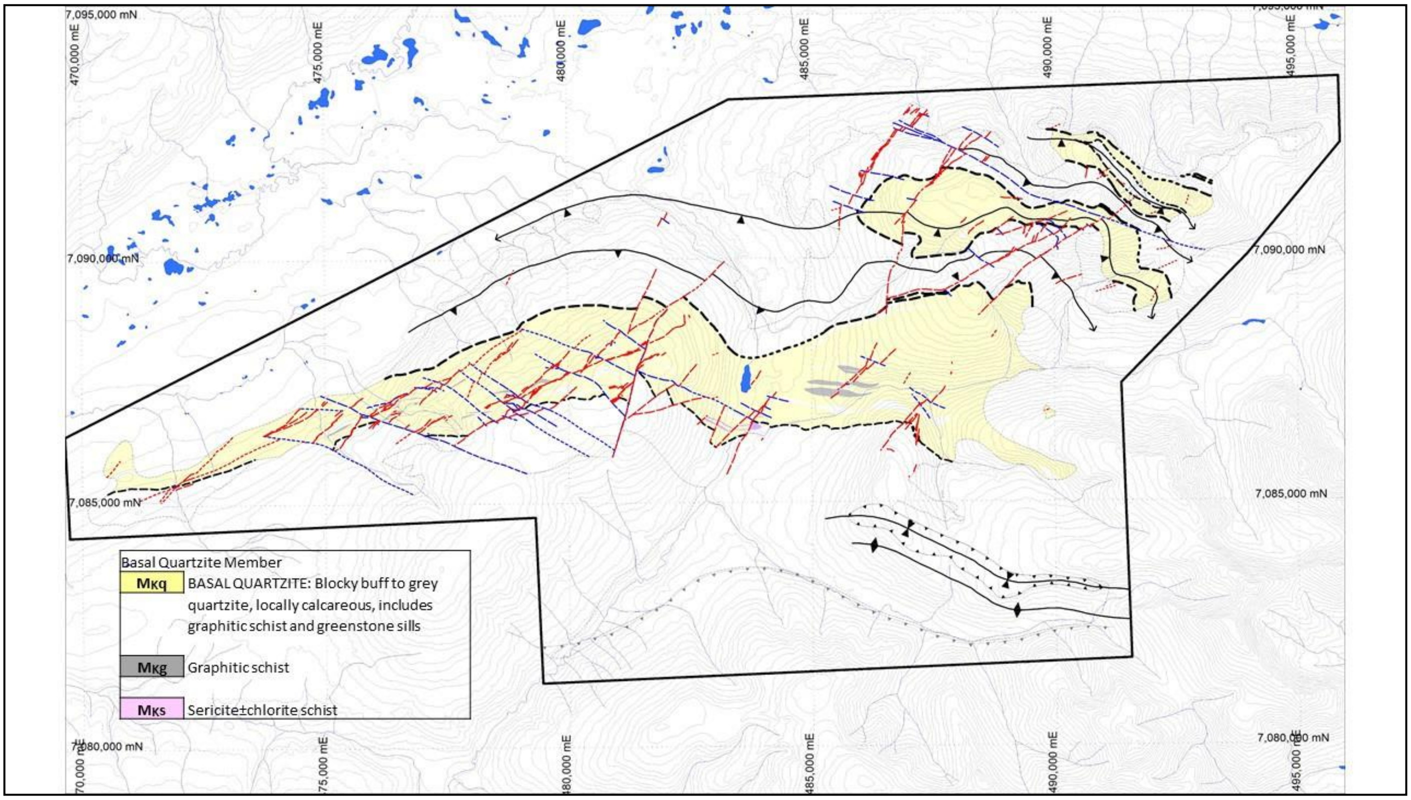
(a) EARN GROUP (Map 1)



Map 1. *Earn Group geology.*

- The Earn Group consists of grey graphitic schist (**DEg**) accompanied by minor grey phyllitic crystalline limestone and thinly laminated (in terms of millimetres) grey quartzite.
- This is topped by a silvery green to green chlorite±sericite schist (**DEc**) with an original felsic volcanic protolith.
- This group forms the core of anticlines throughout the map area.
- In particular, I want to emphasize the nature of the boundary between the Earn Group and overlying Keno Hill Quartzite. Notice how unit **DEc** thins and thickens against the overlying quartzite. This could be the result of an unconformity or because of the intense deformation involving the incompetent Earn Group and overlying competent quartzite of the Keno Hill Quartzite it may result from differential movement between the two units.

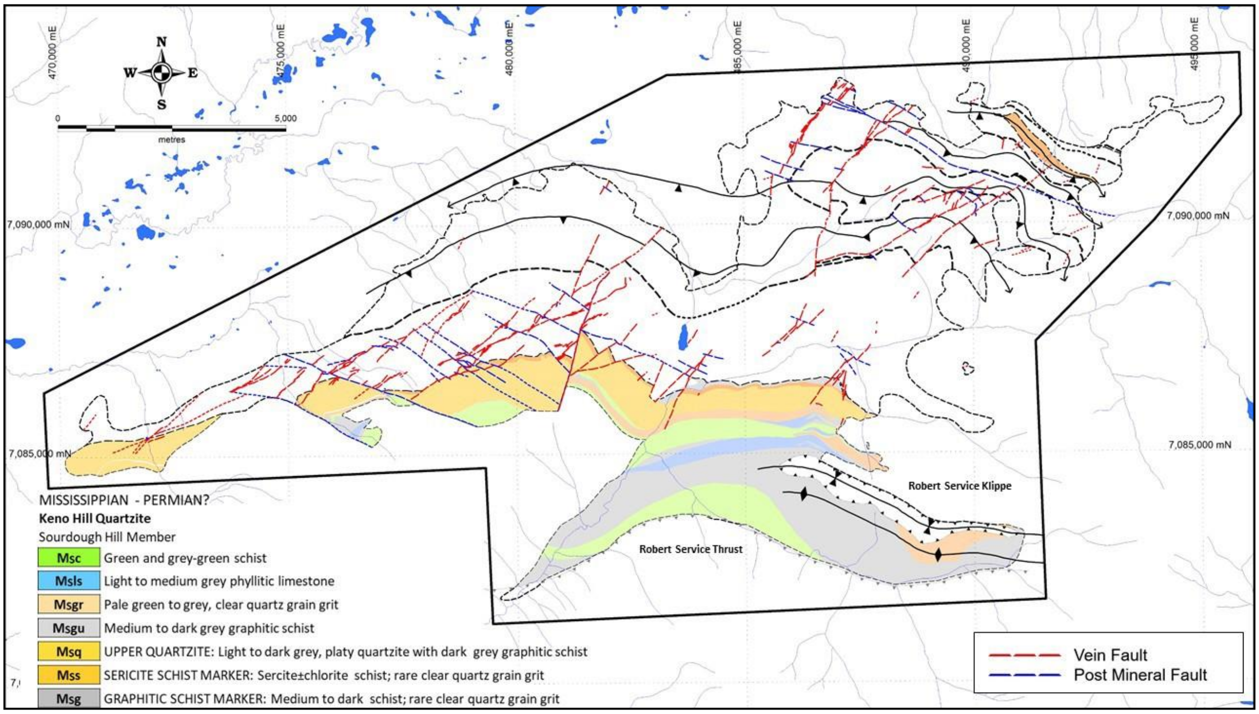
(b) Keno Hill Quartzite – Basal Quartzite Member (Map 2)



Map 2. *Keno Hill Quartzite – Basal Quartzite Member geology.*

- The Basal Quartzite (**Mκq**) is up to 1100 m thick and characterized by blocky quartzite, which is locally calcareous.
- The member includes graphitic schist (**Mκg**) and silvery sericite±chlorite (**Mκs**) layers, which locally exceed 20 m in thickness. Where we have overburden drilling, they are shown on the map, otherwise they are included within (**Mκq**).
- This is the host rock for more than 90% of the mineralized veins and as we shall learn later the presence of these incompetent schist layers is very important in vein formation because they cause vein fault refraction.
- This member forms the core of all the first phase synclines with the largest the Galena Hill Syncline underlying much of Galena Hill (southern yellow belt).

(c) Keno Hill Quartzite – Sourdough Hill Member (Map 3)

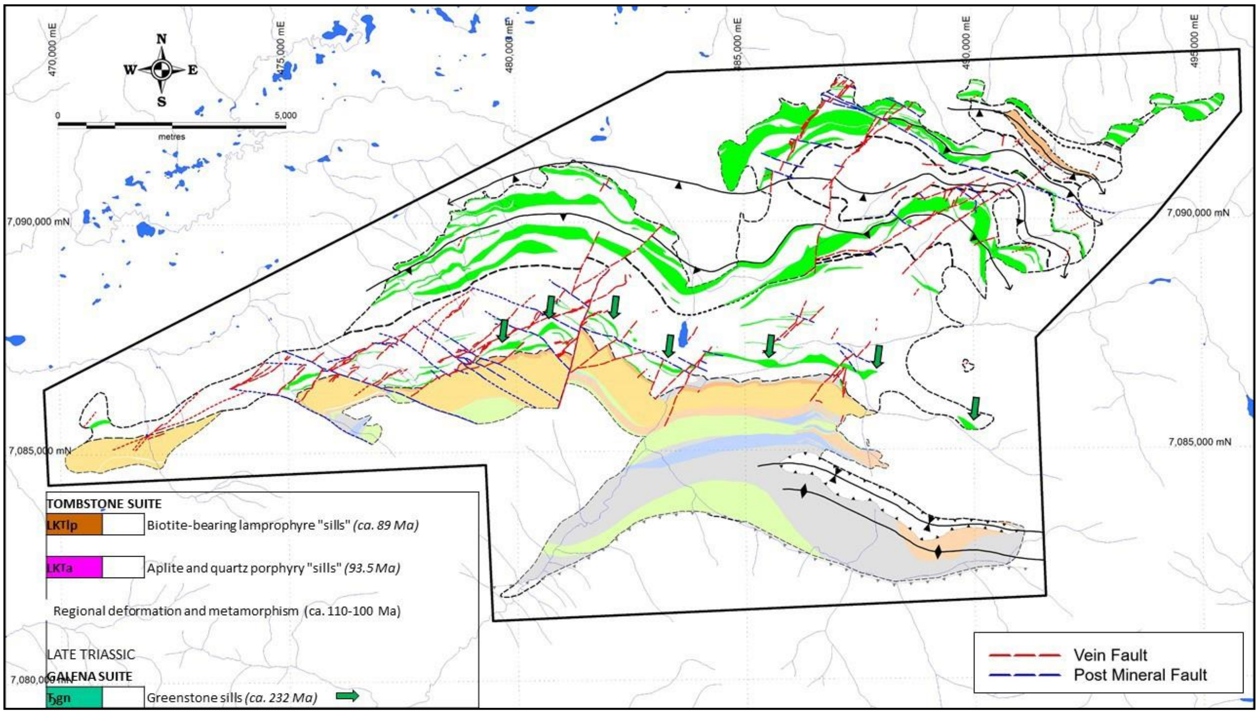


Map 3. *Keno Hill Quartzite – Sourdough Hill Member geology.*

- Two schist units, each up to 60 m in thickness, separate the Basal Quartzite (**Mκq**) from the overlying Upper Quartzite (**Msq**).
- The sequence of Sericite Marker Schist (**Mss**) overlying the Graphitic Marker Schist (**Msg**) works well at Bellekeno on Sourdough Hill but farther west the two rock types are interleaved possibly tectonically.
- The Upper Quartzite (**Msq**) is distinguished from the Basal Quartzite (**Mκq**) by the presence of common thin dark grey schist layers resulting in grey quartzite plates on weathering rather than the common blocks of light grey to buff, weathered Basal Quartzite (**Mκq**).
- Graphitic schist (**Msgu**) sequences are common above the Upper Quartzite as are layers of grey locally phyllitic crystalline limestone (**Msls**). The presence of graphitic schist is an important distinction from its absence in the Yusezyu Formation
- Clear quartz grain meta-grit, gritty schist and rare quartz pebble conglomerate (**Msgr**) form a few sequences above the Upper Quartzite. Unfortunately, clear quartz grain gritty schist is also widespread in the Yusezyu Formation.
- The Sourdough Hill Member forms the core of the northward overturned Galena Hill syncline exposed on Sourdough and Galena hills

(d) Intrusions

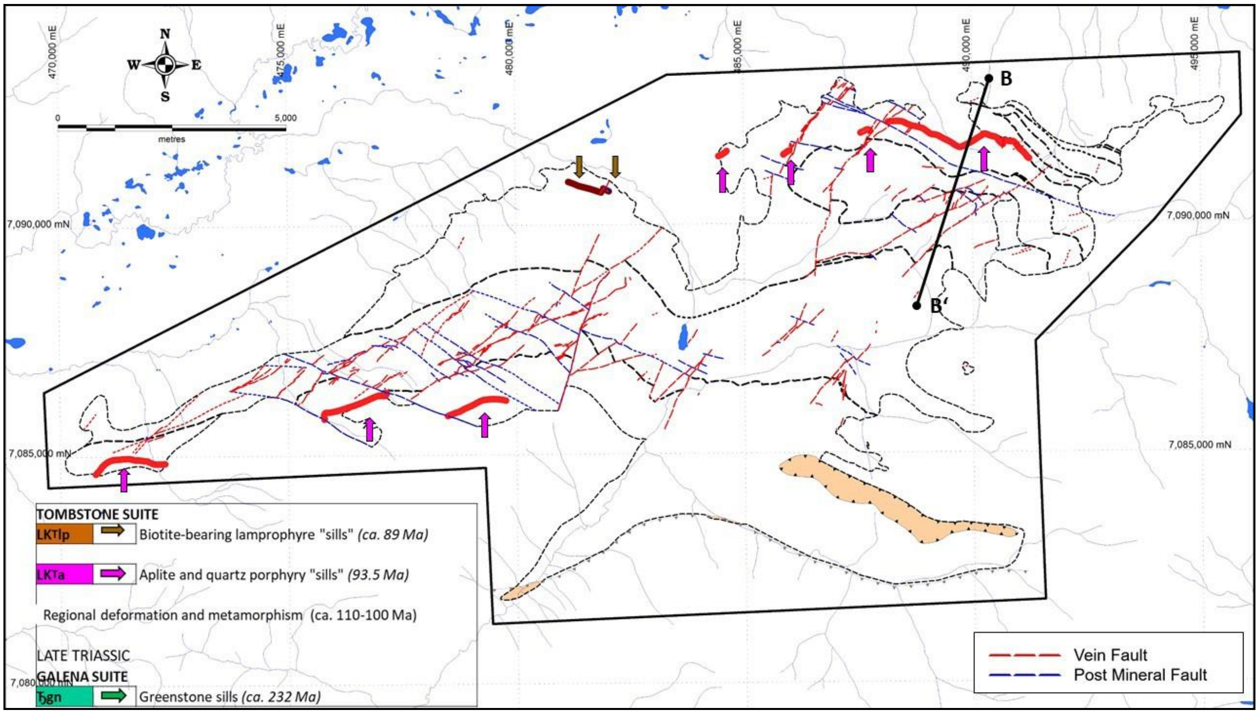
i. Greenstone Sills (Map 4)



Map 4. *Greenstone Sills geology.*

- Greenstone (**Ђgn**), locally with the phaneritic texture of a meta-diabase occurs as sills up to a hundred metres in thickness.
- Overburden drilling shows that the greenstones are not blobs as previously mapped but are continuous sills of which the longest is nearly 8 km long stretching from the Bellekeno deposit on the eastern edge of the map-area to the centre of the map-area at the Bermingham deposits shown by the green arrows.
- As the map shows, they are widespread in the Earn Group, Basal Quartzite Member and just get into the Marker Schists of the Sourdough Hill Member. This stratigraphic control on the uppermost limit greenstone sills mimics that found by Tempelman-Kluit (1970, Geological Survey of Canada, Bulletin 180) in the Tombstone River area where a single greenstone sill in the Keno Hill Quartzite underlies about 1300 square kilometres and changes about 60 m in stratigraphic level.

ii. **Aplite "Sills"** (Map 5)



Map 5. *Aplite and Lamprophyre "sills" geology.*

- Aplite and quartz eye porphyry form a few "sills". As shown by pink arrows, one is in the Earn Group on the north edge of the map-area where its acutely cuts across the Silver Basin Anticline for 5.5 km from beyond the eastern edge of the map-area to southwest of the Sadie Ladue deposit. A second is on the southern edge of the map-area in the Sourdough Hill Member. It starts near the centre of the map-area and extends to the west southwest for over 8.5 km and is still going strong well beyond the map-area.
- The aplite sills are pre-mineralization and at 93.5 Ma yield a maximum age on mineralization.

iii. **Lamprophyre "Sills"** (Map 5)

- At the Formo Deposit, south of Christal Creek a single lamprophyre "sill", shown by brown arrows, extends for about a kilometre where it is offset by the Formo vein fault
- It is a phlogopite-bearing minette and is reported by Boyle to be hydrothermally altered by the mineralized vein fault.
- This lamprophyre is thus the youngest pre-mineralization intrusion at 89±0.3 Ma and gives the youngest maximum age for mineralization in the mining camp.

(e) NEOPROTEROZOIC TO LOWER CAMBRIAN

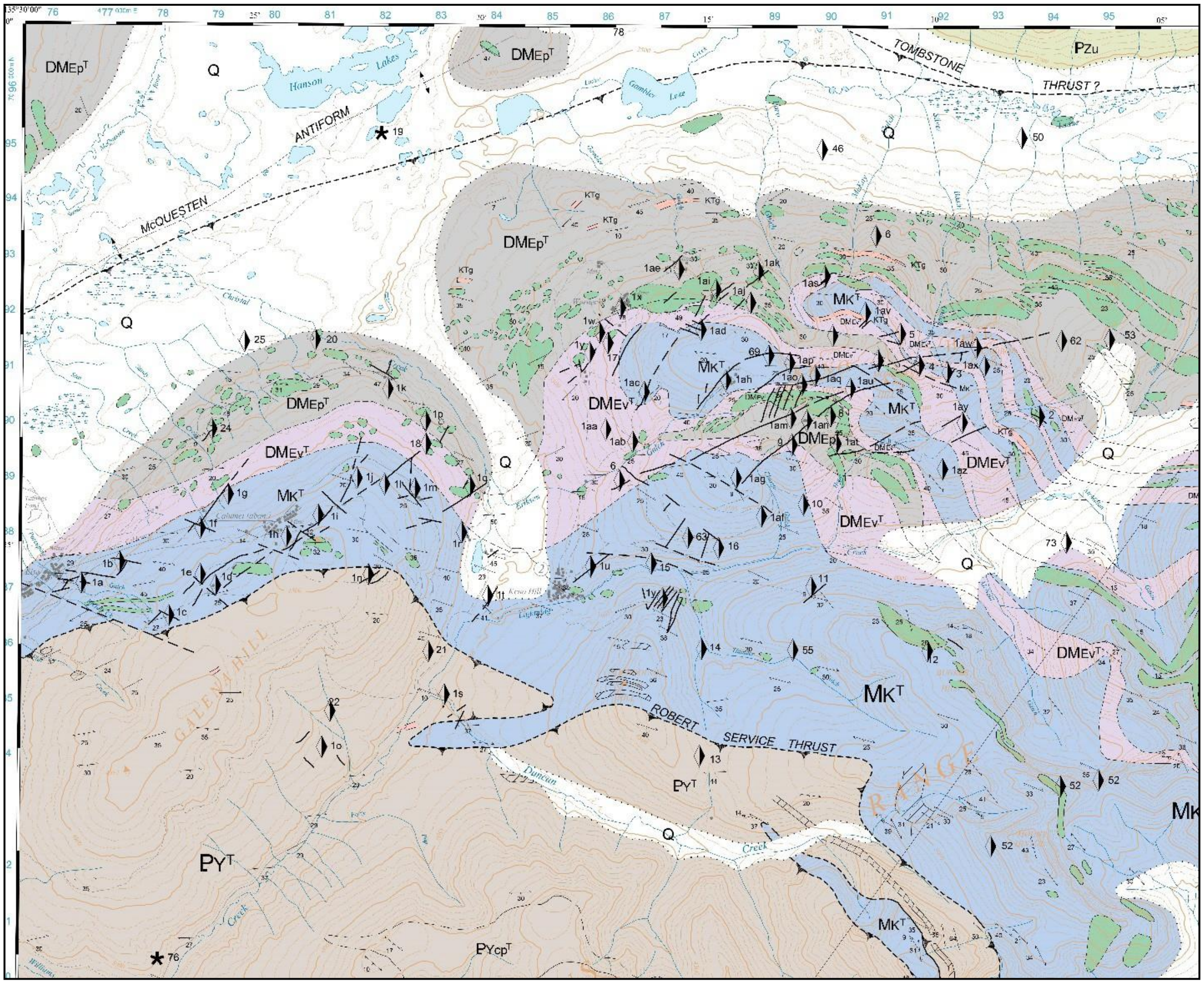
HYLAND GROUP – Yusezyu Formation (Map 5)

This unit outcrops above the Robert Service Thrust on the southern limit of mapping and in a klippe to the north. The typical rocks are pale green chlorite-muscovite schist, clear and blue quartz grain gritty schist and meta-grit unfortunately very like the Sourdough Hill Member. Graphitic schist is absent.

STRUCTURE

(a) INTRODUCTION

- The structure is divided into folding and faulting. Although the two types of structures are intertwined, the major portion of the folding is first and thus will be discussed first.
- Regionally the Keno Hill Mining Camp lies in a moderate southerly dipping sheet between two major thrusts (Murphy *et al.* 1997 Map). It is bottomed by the Tombstone thrust on the north and topped by Robert Service thrust on the south with the latter setting Neoproterozoic to Lower Cambrian Yusezyu Formation on the Mississippian to Permian? Sourdough Hill Member.



Murphy et al. 1997 Map. *Tombstone fault and splay on north and Robert Service thrust on south.*

(b) FOLDING

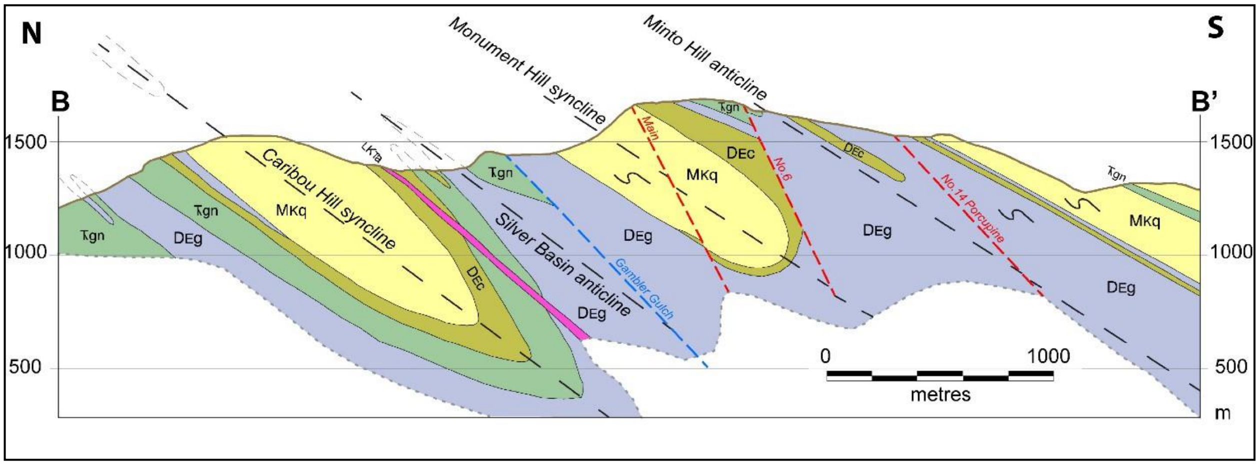
i. **Early Folding (F_0)** (photo 1)

- A few mesoscopic early phase folds have been found in drill core as illustrated.
- Because of the scarcity of these folds and an uncertainty as to whether they are of tectonic or soft-sediment origin, their implications for regional structure are unknown.

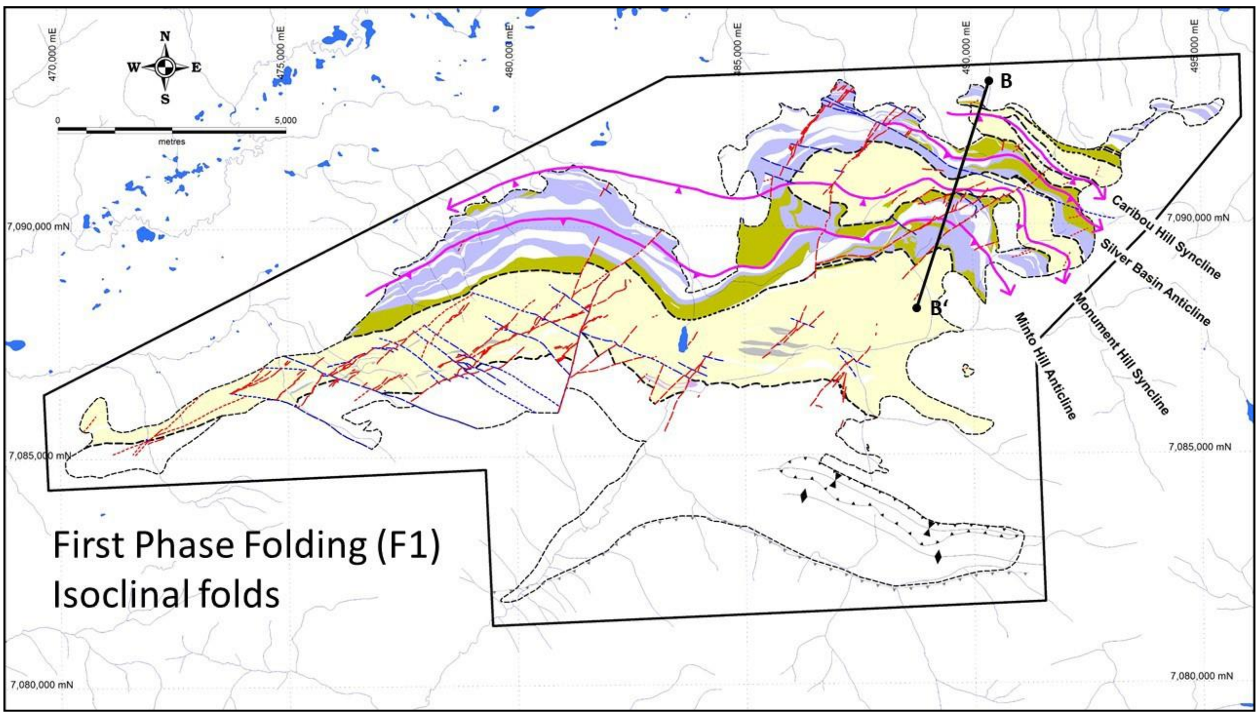
Photo 1. *Early folding (F_0).*

ii. **First Phase Folding (F_1)** (section 6)

- First phase foliation has a moderate 25 to 35° southerly dip throughout the mining camp.
- Isoclinal folds are overturned to the north.



Section 6. *First phase folding (F_1), north-south through Keno Hill.*



Map 7. *F_1 isoclinal folds.*

- On Keno Hill, the anticlinal cores of Earn Group (violet and olive) and synclinal cores of Keno Hill Quartzite (yellow) outline a series of isoclinal folds starting in the south with Minto Hill anticline, then Monument Hill syncline, Silver Basin anticline and finally Caribou Hill syncline.
- Galena and Sourdough hills preserve the upright limb of Galena Hill syncline, but the trace of the axial plane cannot be shown because it is truncated by the Robert Service thrust.
- The cores of these first phase synclines are important because they preserve the Basal Quartzite, the host rock of 90% of the mineral deposits.
- Regionally the folds plunge very gently east to southeast.

- On the stratigraphically upright limbs of macroscopic folds, rootless mesoscopic first phase folds are common with a typical sense of asymmetry indicating an anticline to the north (Photo 2, looking to the west).
- On the inverted limbs of macroscopic folds, mesoscopic folds are rare implying that the overturned limbs are exceedingly attenuated.

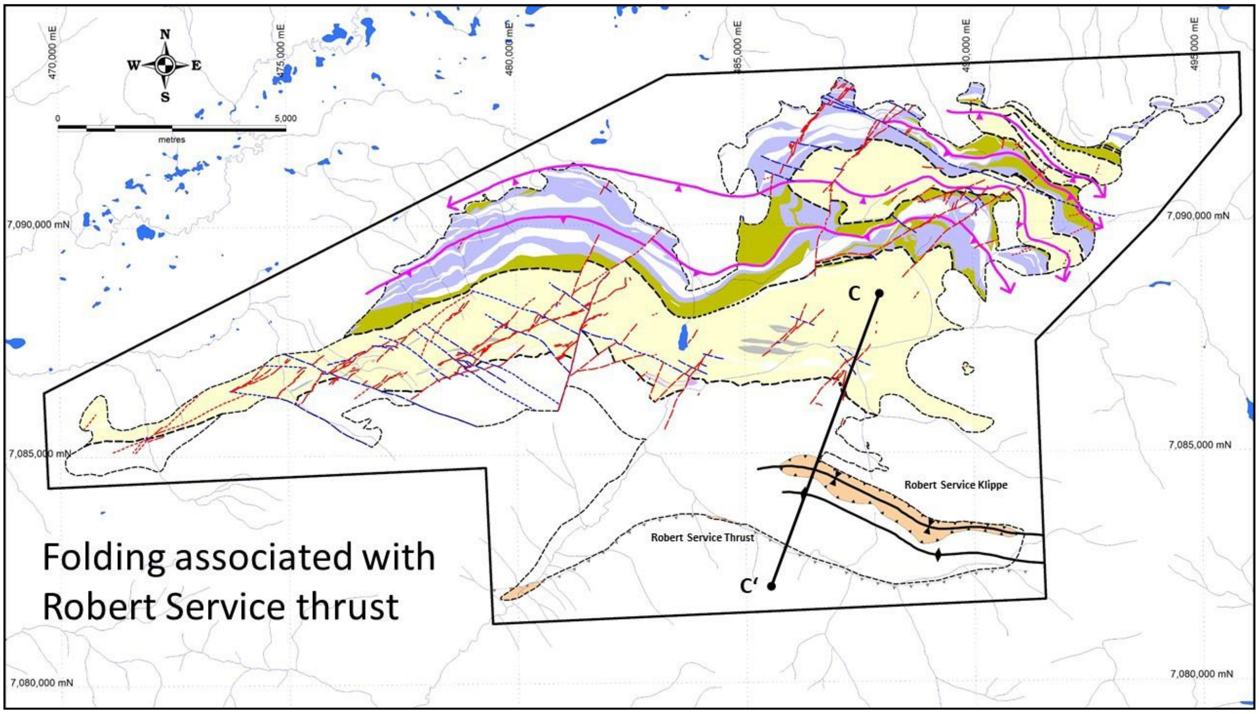
Photo 2. *First phase rootless asymmetric folds noted by F_1.*

iii. **Second Phase Folding (F_2)** (photo 3)

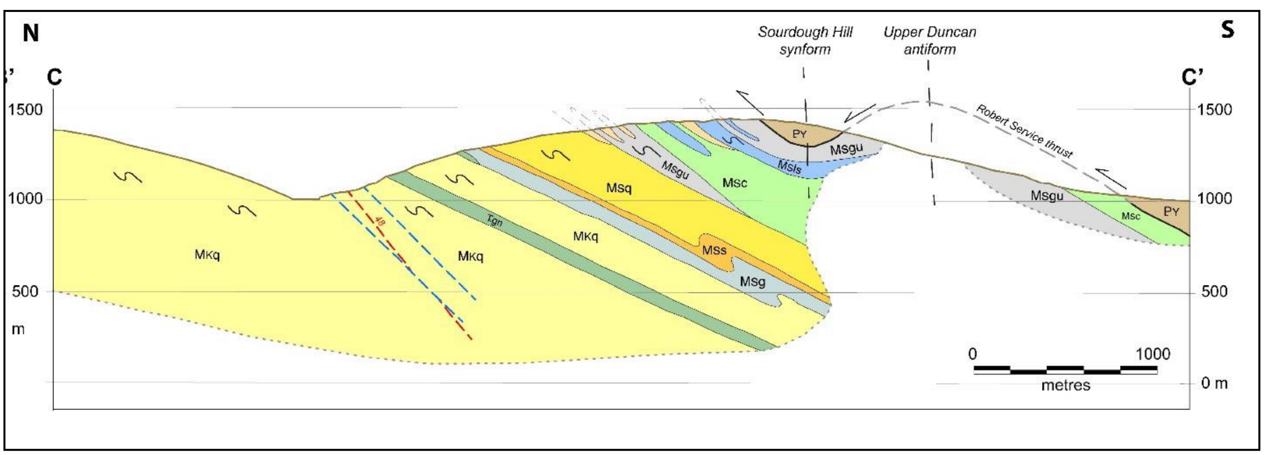
- Viewed to the southeast, second phase folds are present on mesoscopic scale only and are upright southeasterly plunging crinkle folds.
- Beyond the map-area to the southeast, these southeast plunging folds become macroscopic.
- At present, they are considered pre-Robert Service thrust in age.

Photo 3. *Second phase folding (F_2).*

iv. **Folding Associated with Robert Service thrust** (Map 7 repeat)



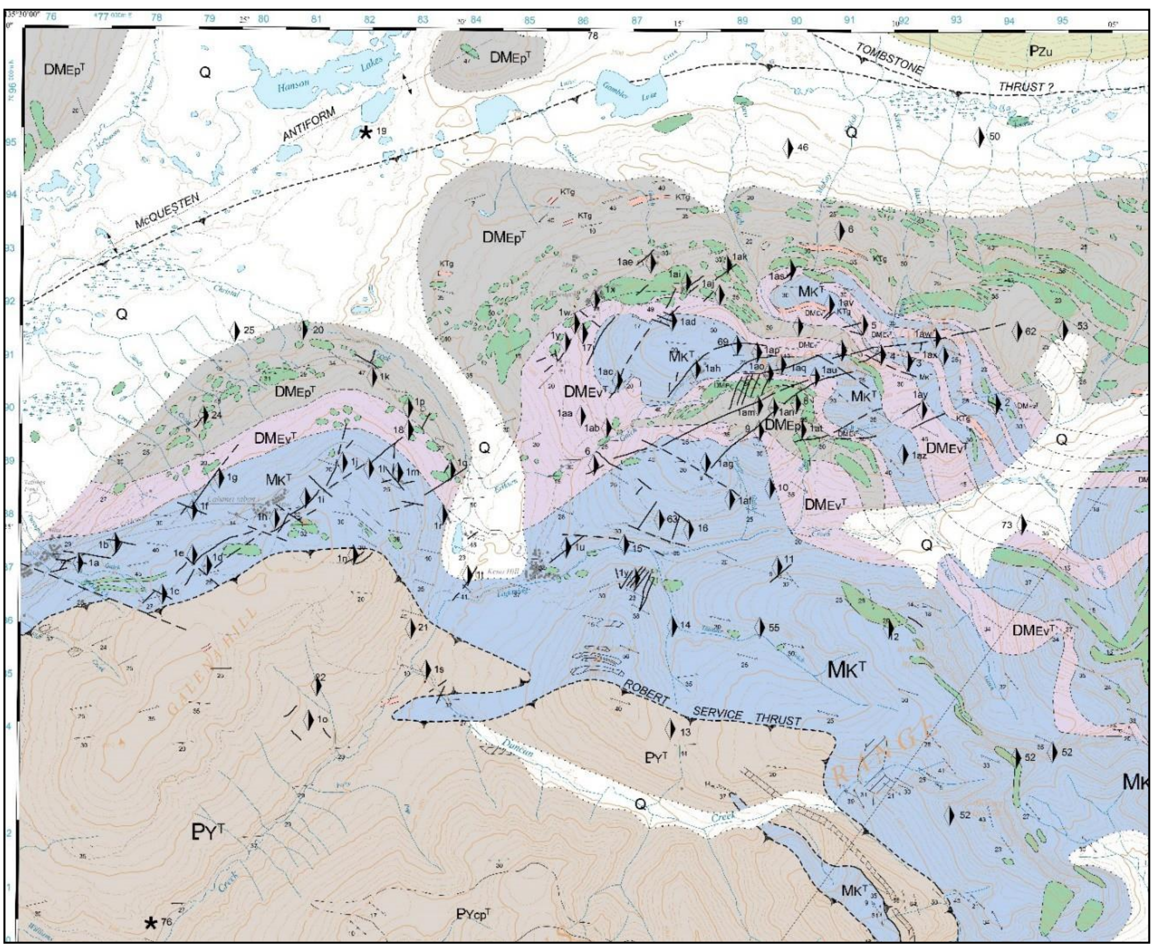
- Spatially associated with Robert Service thrust, in the hanging wall, are an antiform-synform pair as seen in the map and shown in south end of Section C-C' (Section 8).
- The folds are upright and open as outlined by the gently folded first phase foliation.
- They might correspond in genesis to the McQuesten antiform spatially associated in the footwall of the Tombstone thrust north of the mining camp.



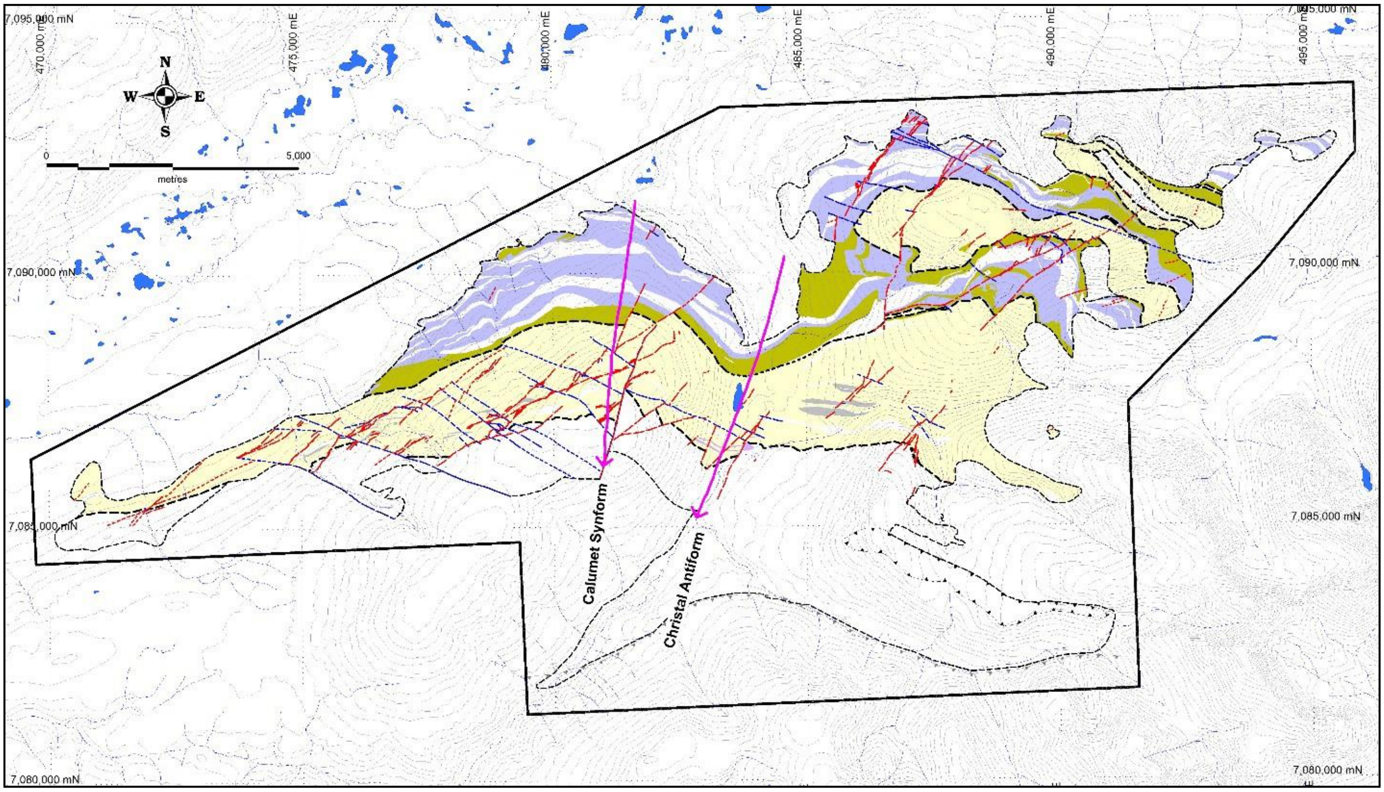
Section 8. *North-south section through folds in lower right corner of map.*

v. Broad Warping

- If you consider the regional mapping and look at the Robert Service thrust forming the southern boundary of the violet unit you can clearly see the change in direction as you proceed eastward (Murphy *et al.* 1997 map and Map 9).
- At the west end of the mining camp the folds trend east-northeasterly and at the east end of the camp they trend southeasterly.
- This change in trend is accomplished by three very open, upright concentric warps plunging to the south (Map 9).
- The most westerly of these is Calumet synform with a fairly tight warp particularly of units **Mss** and **Ђgn**. The fold broadens northward towards Christal Creek.
- The next eastward is Christal antiform passing through Christal Lake with a concentric fold broadening southward along the trace of its axial plane.
- Finally to the east another broad warp must be present to warp the first phase folds into their east-southeasterly trend, but its exact position is uncertain.
- The timing of the development of these warps is considered as after the Robert Service thrust but before the vein faults, which appear undeflected by the warps.



Murphy et al. 1997 map



Map 9.

(c) FAULTING (Table 3)

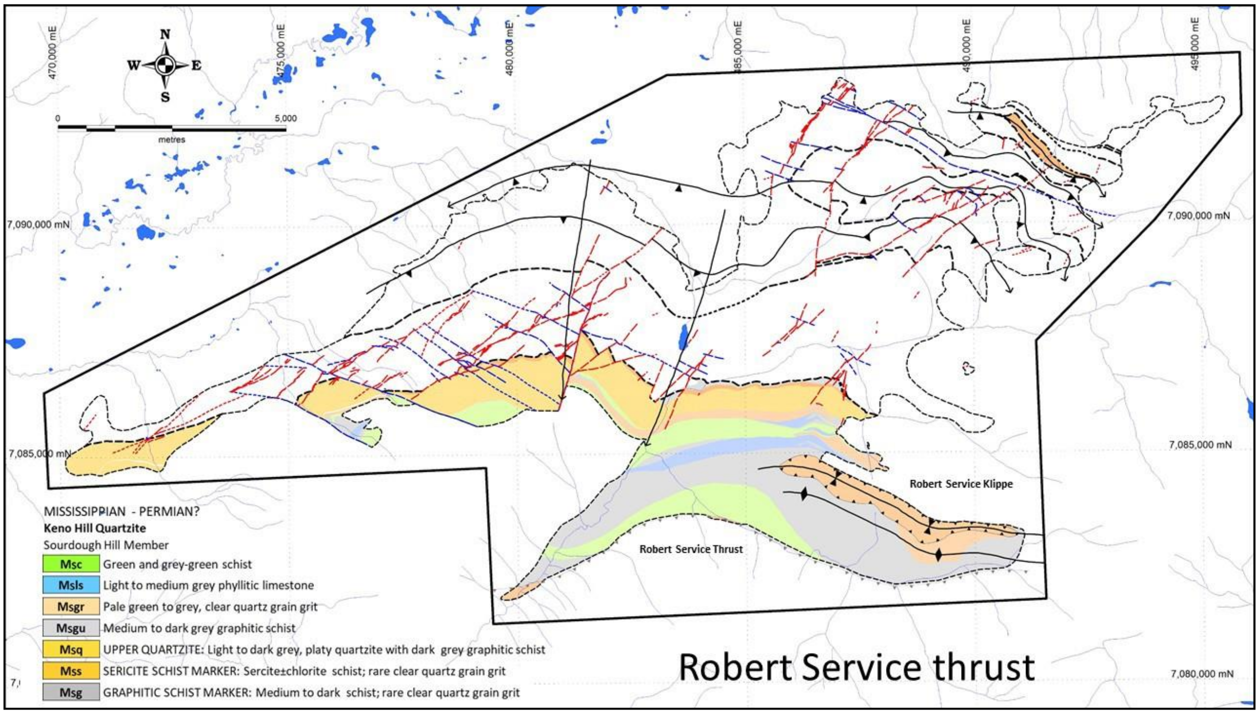
- There are at least five stages of faulting with two of the stages associated with vein faulting.

Table 3. *Stages of faulting.*

Fault Event	Age Range (Ma)
Robert Service thrust	100 to 94
Longitudinal vein faults	89 to 68
Transverse vein faults	<89 to 68
Transverse faults	<61
Longitudinal faults	<61

i. Robert Service thrust (Map 3 repeat)

- The Robert Service thrust sets the Neoproterozoic to Lower Cambrian Yusezyu Formation on the Sourdough Hill Member along the south edge of the map area.
- It was active after regional metamorphism and first and second phases of folding which occurred in the 100 to 110 Ma bracket and as presently mapped it is plugged outside the map area by the Roop Lakes pluton dated at 94 Ma.

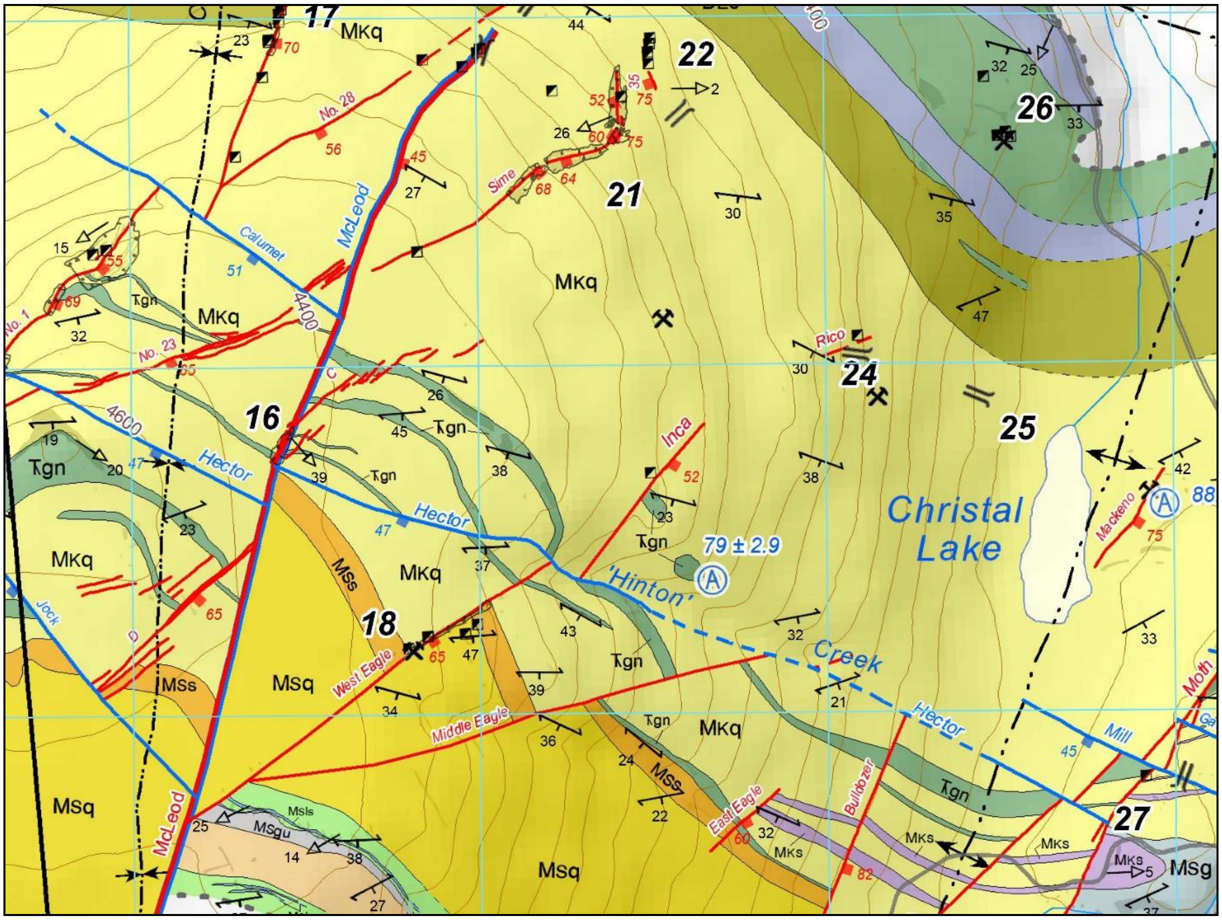


Map 3.

- However, the position of the Robert Service thrust is uncertain to the west of Sourdough Hill where it appears to lie kilometres south of its published position.
- As a result, its position east of Sourdough Hill needs checking as the thrust might not be plugged by Roop Lakes pluton.

ii. Transverse and Longitudinal Vein Faults

- Boyle subdivided vein faults based on strike with the longitudinal set with a northeasterly to easterly strike subparallel to foliation and transverse reserved for those with a northerly to northeasterly strike cross-cutting foliation. All dip southeasterly.
- Because of a lack of fault movement indicators, the map shows that most have left- lateral apparent movement ranging from a few tens of metres for Bulldozer to 700 m for McLeod vein fault and fault (Map 10). THIS LEAVES THE INCORRECT IMPRESSION THAT VEIN FAULTS ARE STRIKE-SLIP.



Map 10. *Apparent movement along faults.*

- For the few vein faults exposed on surface where we have vein fault movement indicators, they are oblique-left normal to dip-slip. They are so rare that I am going to show them to you. Photo 4 shows the West Eagle vein-fault looking west on a wetted surface at rough vein fault slickensides oriented at 077/29NE on a fault surface oriented at 053/59SE.

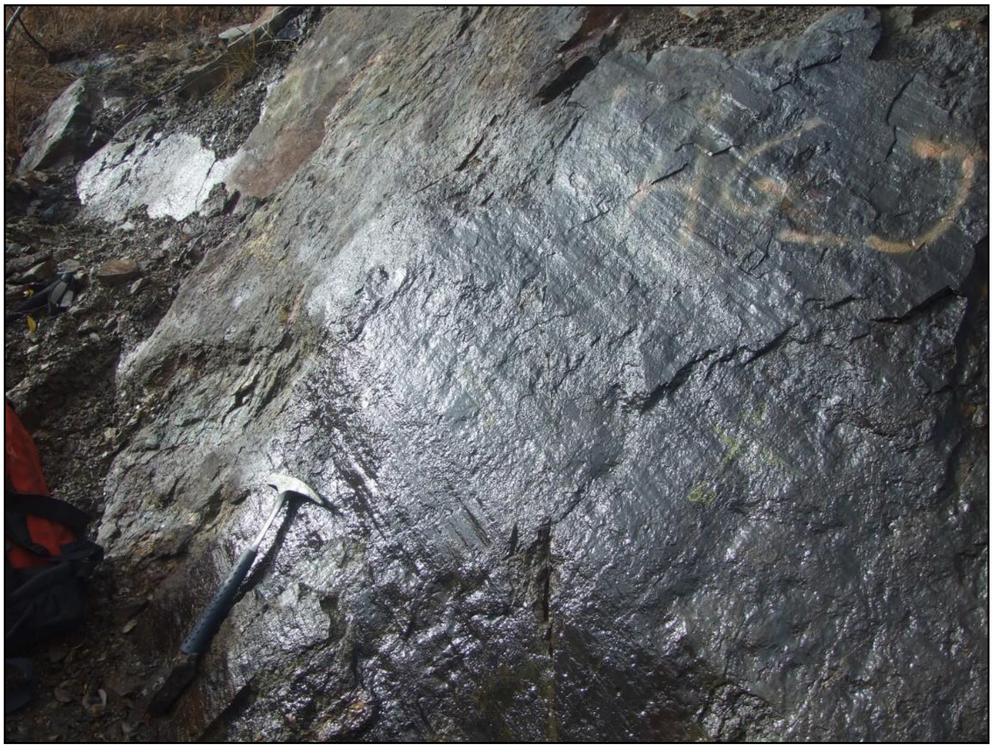


Photo 4. *West Eagle vein fault.*

Photo 5. *No. 9 vein.*

- No. 9 Vein on the top of Keno Hill (photo 5). Here vein fault slickensides form rough corrugations plunging down to the right on the footwall.

- Onek Pit (photo 6) looking at vein fault slickensides on the footwall of the Onek vein fault oriented at 060/60NE on a fault surface at 042/82SE.
- Although the terms longitudinal and transverse are useful geometrically of far greater importance is when the vein fault was open.

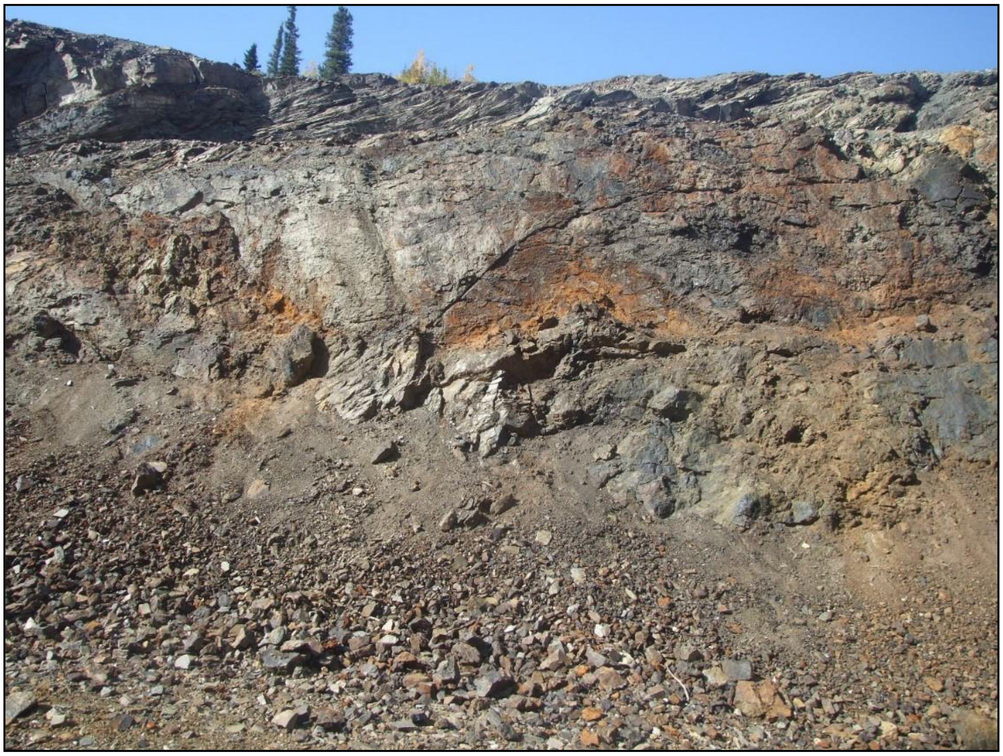
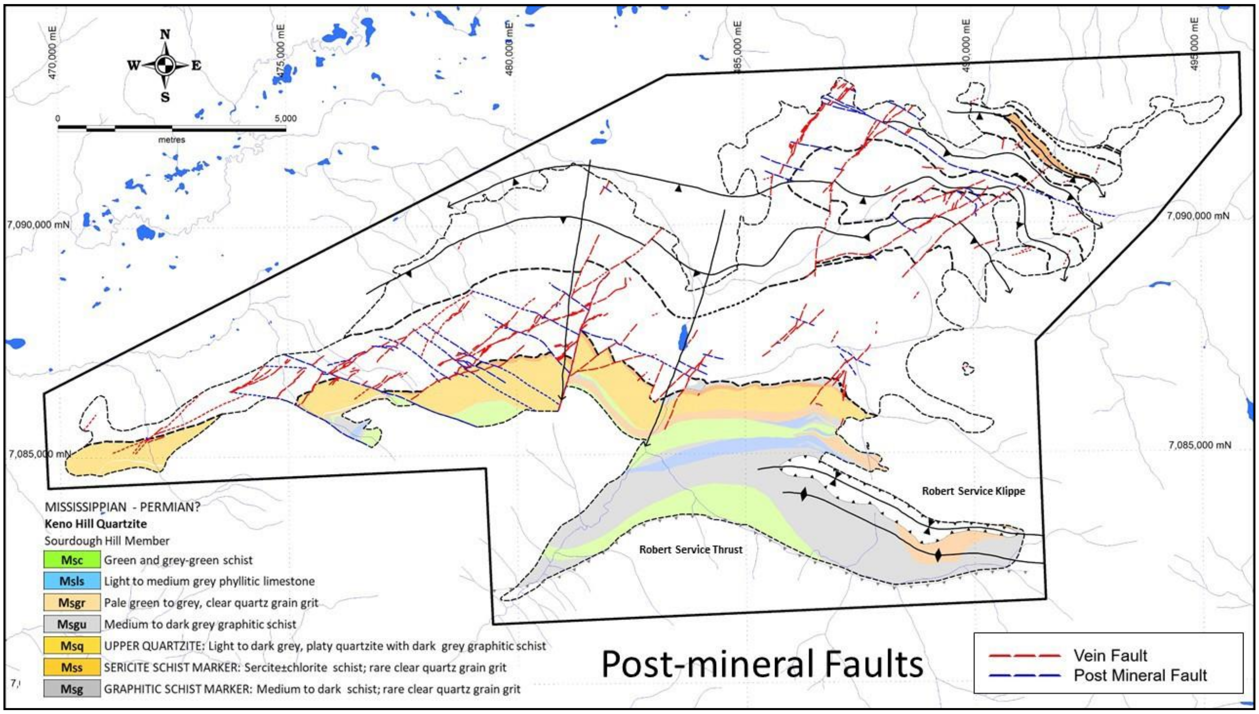


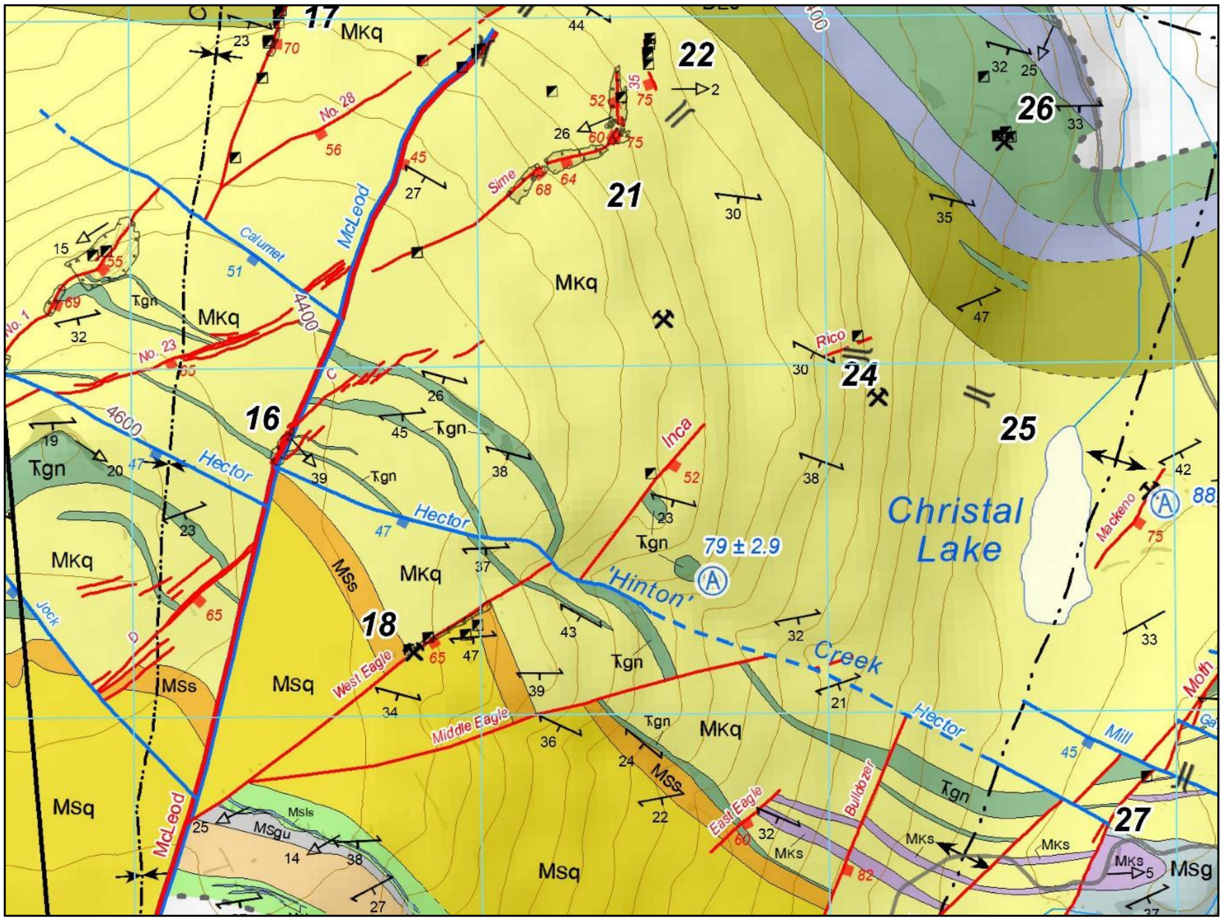
Photo 6. *Onek Pit vein fault slickensides.*

iii. **Transverse and Longitudinal Post-Mineral Faults** (Map 3 repeat)



Map 3.

- Post-mineralization faults are classified as transverse if they obliquely cut vein faults and longitudinal if they subparallel vein faults.
- The transverse faults strike southeasterly and dip southwestward from 30 to 65° and have a right-lateral apparent movement.



Map 10.

- Longitudinal faults (Map 10 repeat) are recognized either from underground openings or in HQ, NQ or larger diameter drilling in the last 20 years. Because of these limitations, only one, McLeod fault, is shown on the map. Parts of the walls of the Flame vein also qualify.
- McLeod fault shows the complexity of post-vein fault movement in which Hector fault is offset but the Jock and Calumet faults are not offset and do not cross the McLeod fault.

- Both fault sets are characterized by spatially associated crush zones but where the bedrock is competent, the fault surface is smooth and highly polished with fine slickensides as shown by the Super Fault at the east end of the Bermingham open pit (Photo 7) with slickensides at 248/47SW on a shining, dry fault surface at 100/52SW.

Photo 7.

- On the footwall of the No. 9 vein (Photo 8), fine post-mineralization slickensides, plunging to the left are developed on a mirror-like post-mineral fault surface. These override the rough corrugations, plunging to the right, associated with movement during vein fault mineralization.

Photo 8. *Fine post-mineralization slickensides on the No. 9 vein footwall.*

- From our perspective any post-mineralization fault with assay values results from mineralization dragged into the fault by post-mineral movement.

MECHANISMS OF VEIN FORMATION

(a) INTRODUCTION

There are various mechanisms for the development of open-space for vein formation:

- Boyle emphasized the importance of vein fault refraction and recently
- Iles (2016 GAC Conference) applied the concept of Riedel shear in a strike-slip system.
- I will introduce another mechanism – Divergence of vein fault movement from the Line of Intersection of vein faults. It probably plays an important role and I will give examples from some of the present- and past-producing mines.

(b) REFRACTION

- Boyle (1965) detailed the important role that rock competency plays in the development of open-space for vein-filling by noting that faults tend to dip steeply in competent rocks such as quartzite (**Mκq**) and dip gently to moderately in incompetent rocks such as schist (**Mκg** and **Mκs**) in the Keno Hill Quartzite (Figure 1a).

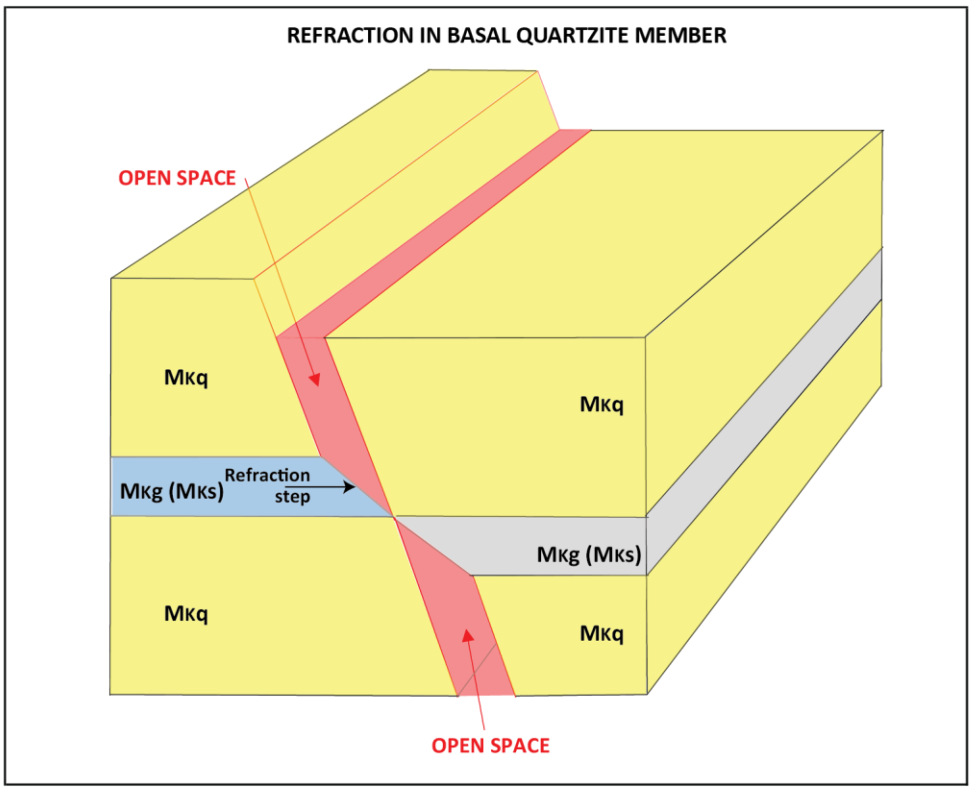


Figure 1a. *Basal Quartzite Member refraction (Boyle, 1965).*

- In the Earn Group, the greenstone sills (**Ђgn**) are competent and the graphitic schist (**DEg**) is incompetent (Figure 1b).
- In incompetent rocks, the veins tend to splay into anastomosing veinlets.
- If the hanging wall block gets hung up on the Refraction Step, two options are possible.

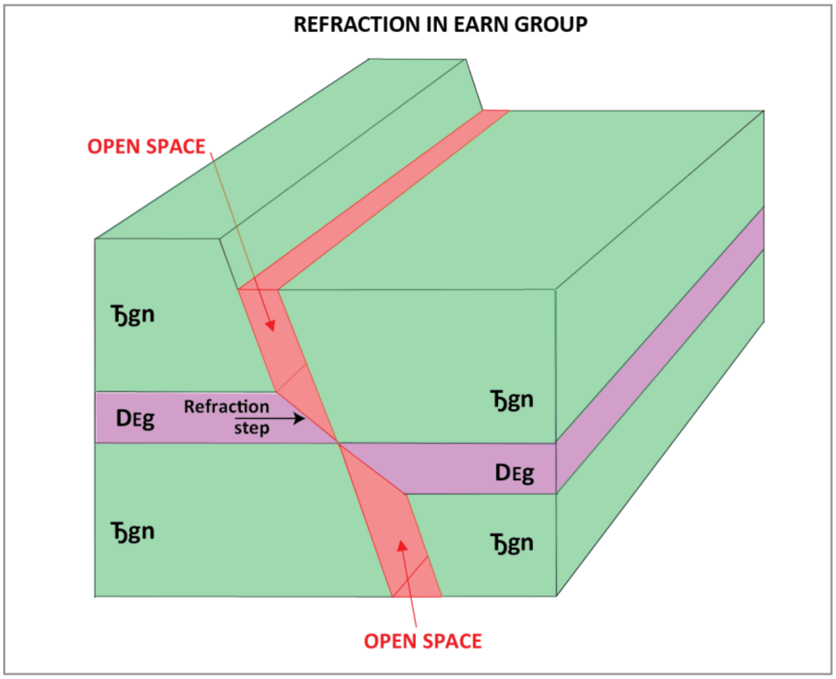


Figure 1b. *Earn Group refraction.*

- If the rock strength of the footwall rocks below the step is exceeded by the weight of the hanging wall block then another fault develops below the step parallel to the initial vein fault as shown in a vertical cross-section oriented looking northeastward along the strike of most of the vein faults in the mining camp (Figure 2a). This arrangement exists in the soon to be developed Bermingham Mine.

- A second possibility exists if the hanging wall block gets stuck on the refraction step. Here the portion of the hanging wall block stuck on the step has a lower rock strength than the rock in the footwall beneath the step (Figure 2b). The result is an antithetic west-dipping, reverse fault develops in the hanging wall block as the block continues its downward movement. West dipping faults are known in the Bermingham and Elsa mines, and Black Cap and Sugiyama open pits.

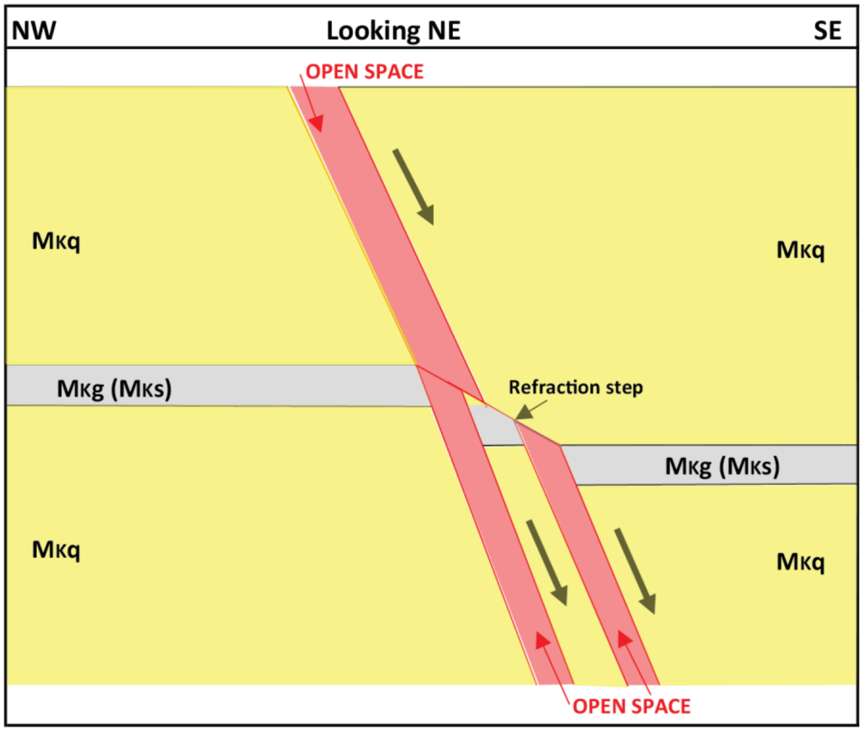


Figure 2a.

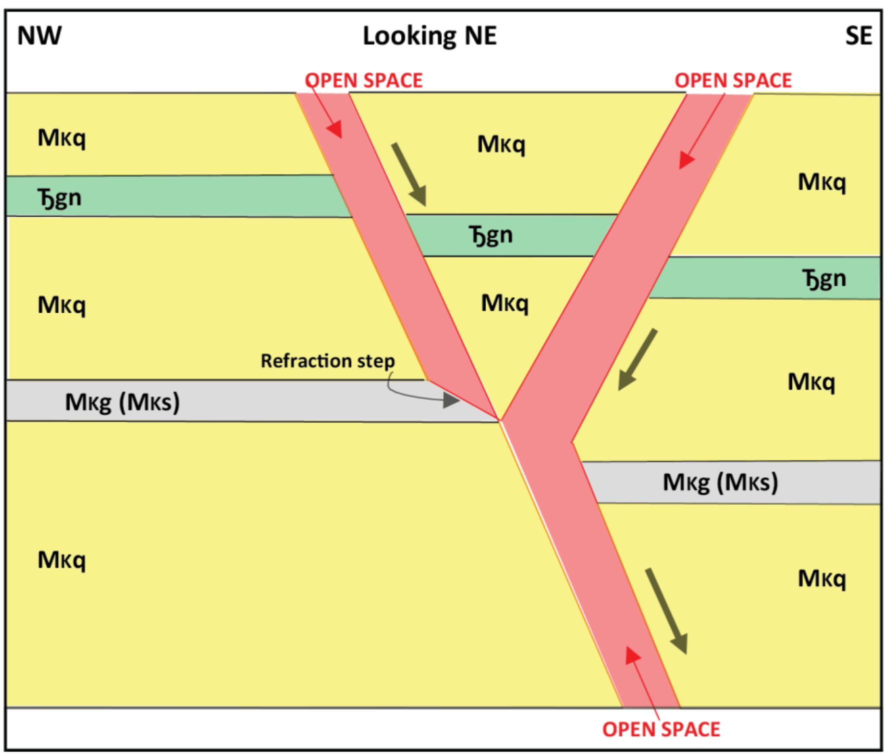
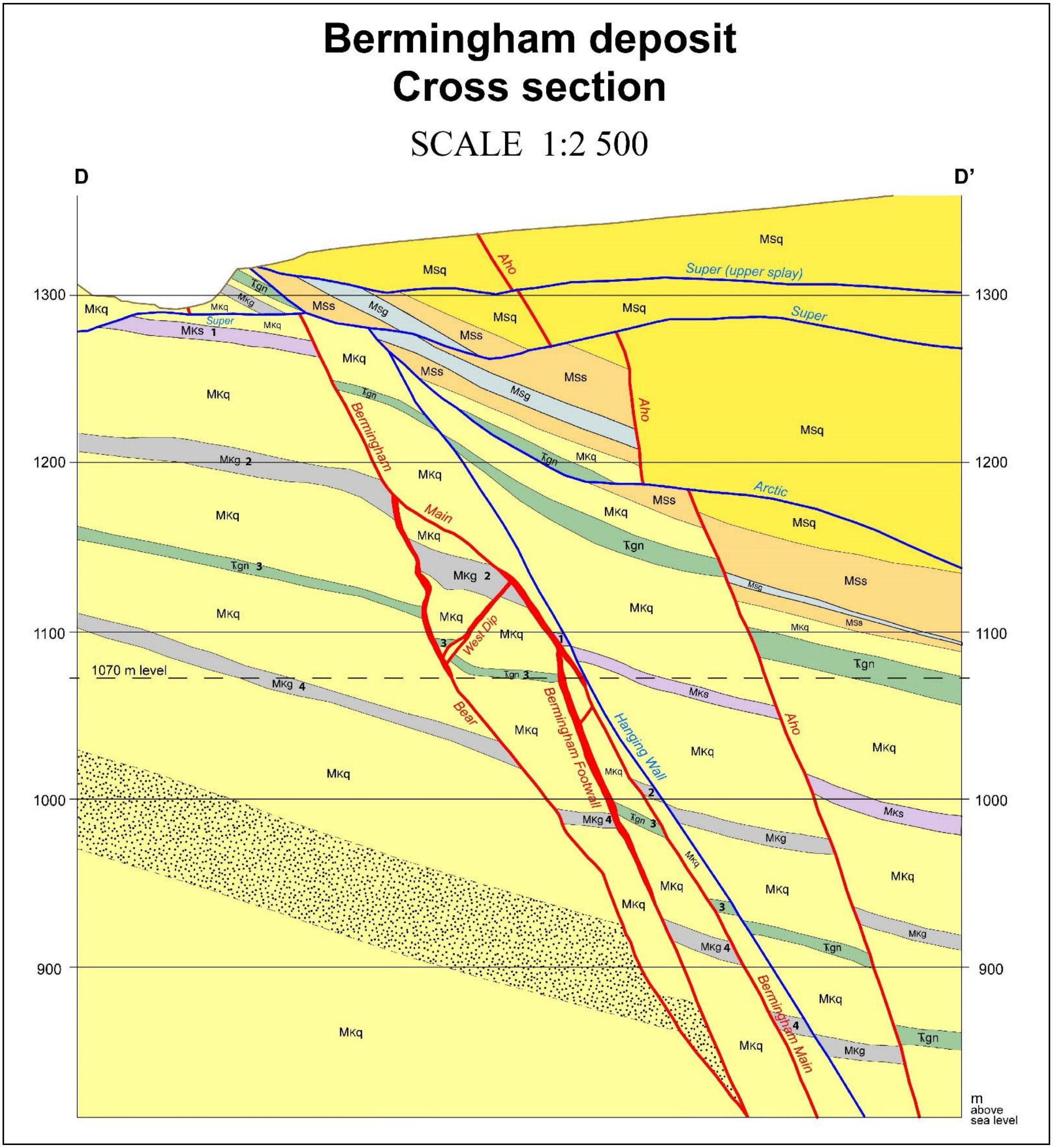


Figure 2b.



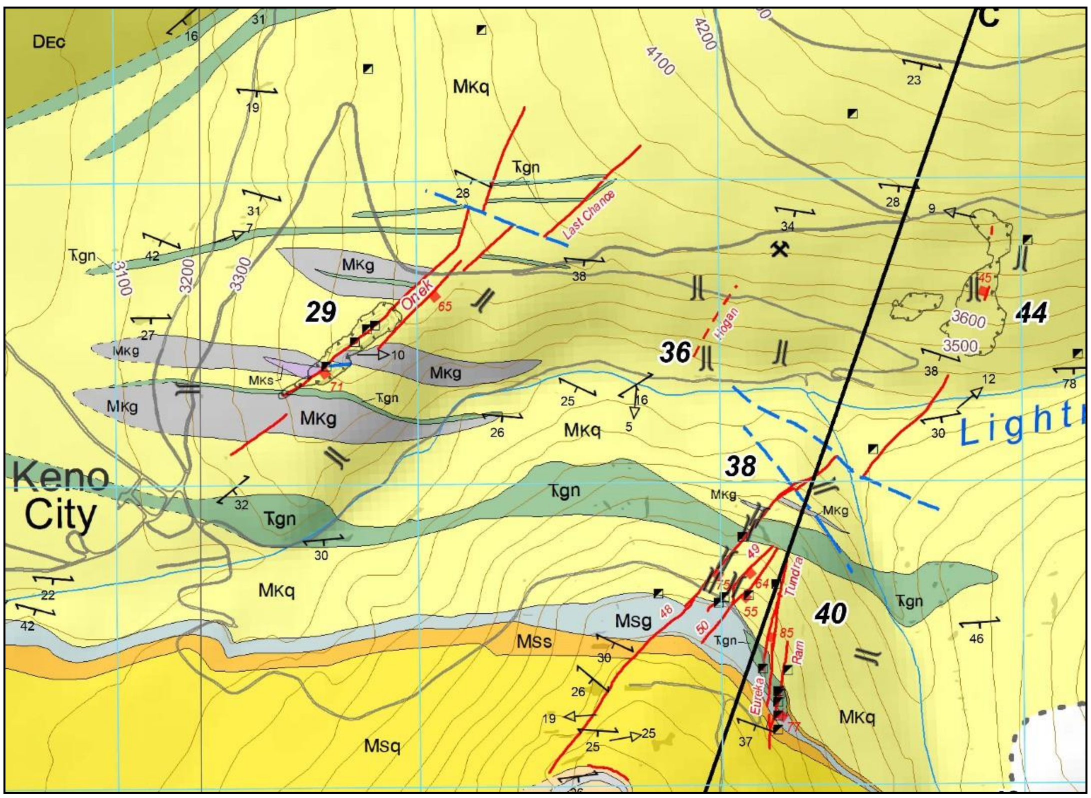
Map 11. *Bermingham deposit cross section.*

- We will leave the cartoons and look at Seymour Iles' work in the cross section of Sheet 2 of the Open File where I have numbered the schist and greenstone sills from 1 to 4 (Map 11).

- It appears that Bermingham Main got hung up twice and developed the Bermingham Footwall and Bear veins as a result in the footwall of Bermingham Main.
- In addition, an antithetic West Dip vein developed with arguably a reverse movement.
- The normal component of movement across the Bermingham vein fault system is about 170 m.

(c) RIEDEL SHEAR MODEL

- The application of Riedel shear to the development of vein faults at Keno Hill was suggested first by Bruce Otto in an unpublished report to Alexco.
- Seymour Iles developed the idea based on detailed vein fault and stratigraphic modelling of the Bellekeno 48 vein fault system, principally the SW Zone which yields tightly spaced data, containing approximately 195 boreholes at 10–15 m spacing and extensive underground development and stoping (Map 12).



Map 12.

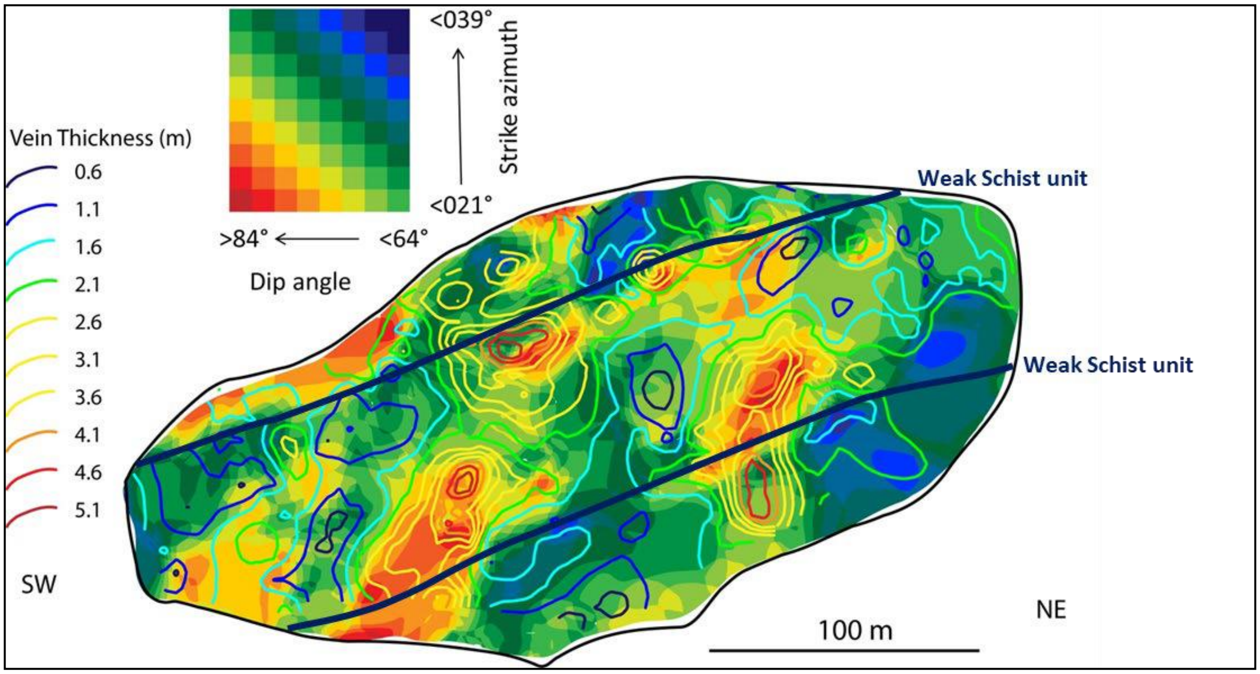


Figure 3. *After Iles, 2016*.

- Figure 3 is an orthogonal view of SW Zone looking at 298/12NW showing the variation in strike and dip of the small segments of the SW Zone, which is highly non-planar. It shows domains characterized by more northerly strike and steep dip in red. The vein thickness contour, with orange and red being thickest, tend to coincide with the red zones representing veins with the most northerly strike and steepest dip. Under left-normal oblique movement, we should anticipate the red zones to be coincident with the areas of thickest veins. Therefore, the distribution of ore in the Bellekeno SW Zone is broadly dictated by the orientation of subareas of the vein.

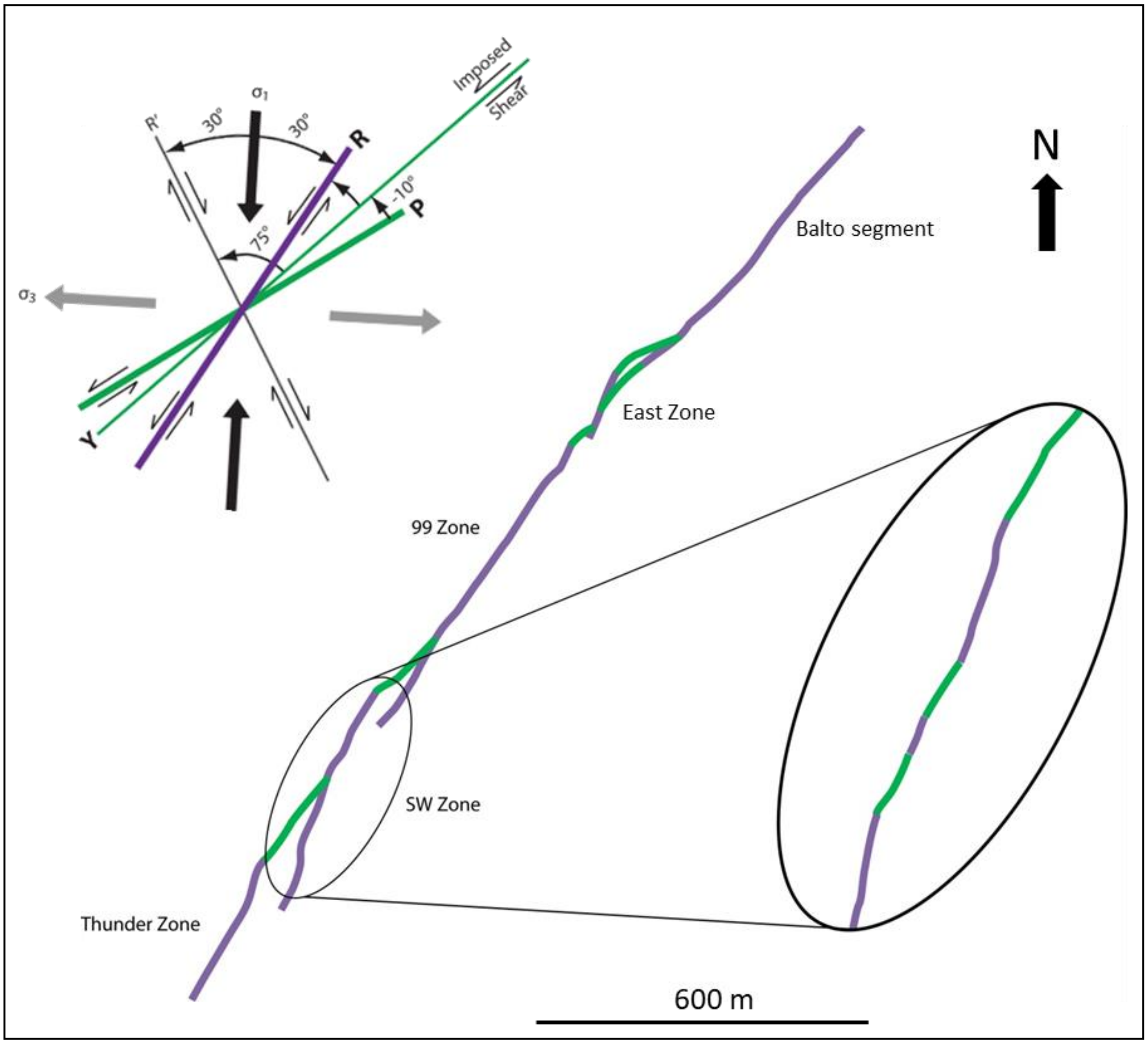


Figure 4. *After Iles, 2016.*

- Bruce Otto indicated that the Bellekeno vein-fault underwent left-oblique movement that displaced the hanging-wall approximately 35 metres along a vector of 080/65NE, or resolved into components, 15 metres of sinistral strike-slip and 30 metres of dip-slip displacements (Figure 4). The deposit consists of at least 4 major right stepping, *en echelon* vein fault lenses, each of these composed of smaller, right-stepping *en echelon* vein fault lenses.

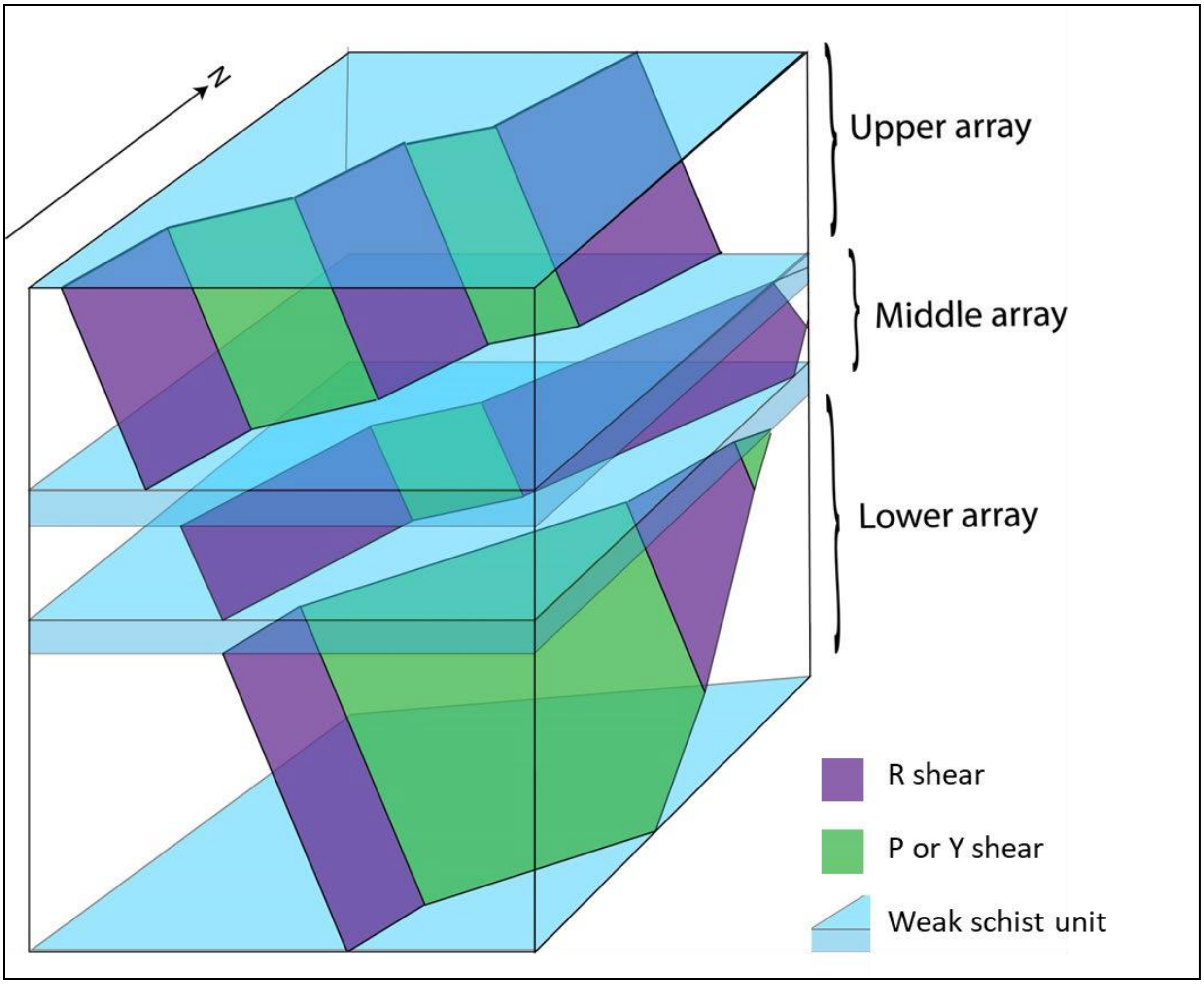


Figure 5. *Isometric schematic of Bellekeno SW Zone showing incipient Riedel arrays separated by weak schist units (after Iles, 2016).*

- At Bellekeno, the non-planar geometry displayed by the SW Zone reflects the fundamental process of its development through the growth of incipient Y, P and R shears and their subsequent linkage (Figure 5). This process appears to repeat at different scales and to be strongly influenced by the mechanical properties of the host stratigraphy.
- In the SW Zone it is postulated that the vertical propagation of Riedel R, P and Y shear arrays in quartzite is limited by the mechanically weak schist units, which form the upper and lower bounds of the arrays. Array geometries vary from level to level depending on the thickness and gross strength of their hosting lithologies.
- Seymour believes that this *en echelon* geometry of vein fault segments is also observed in the Lucky Queen Mine, the Flame and Moth deposit and potentially at Onek and Silver King.

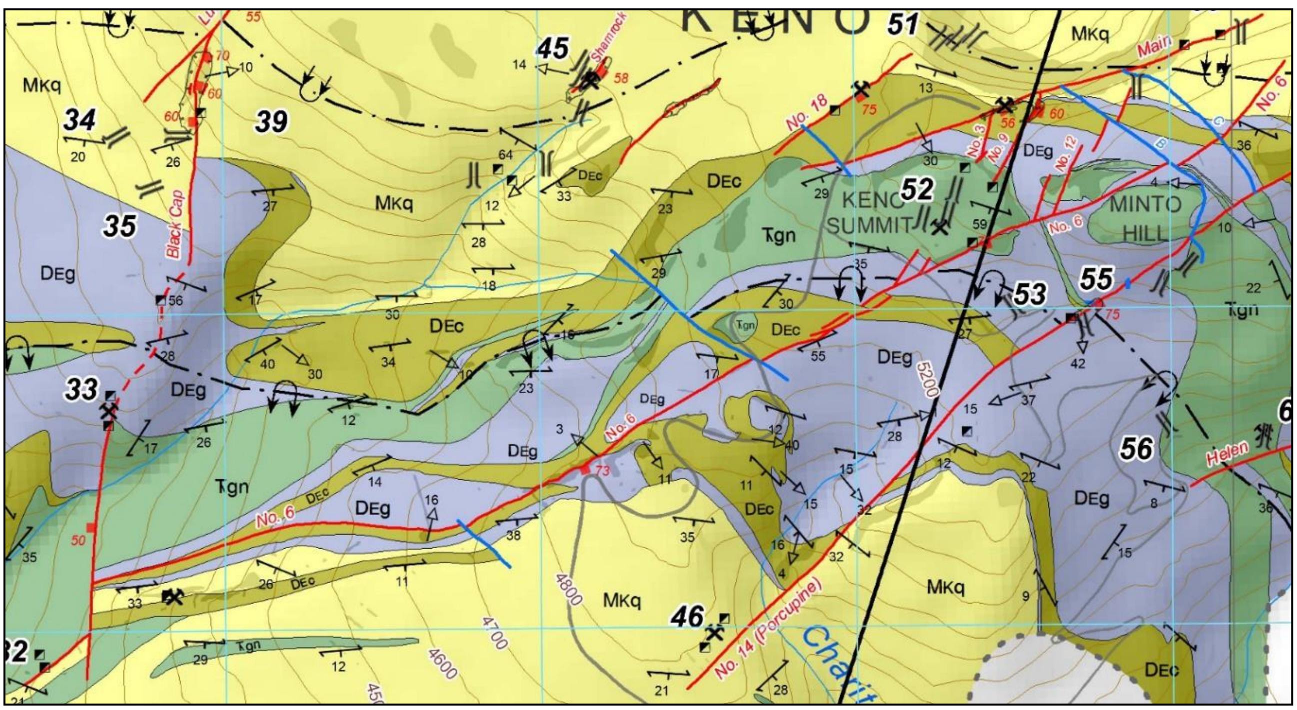
(d) DIVERGENCE OF VEIN FAULT MOVEMENT FROM THE LINE OF INTERSECTION OF VEIN FAULTS

As a background, if you combine the data on:

- Mineral assemblages of the veins.
- Boyle's evidence for two distinct phases of mineralization with the early phase quartz-pyrite-arsenopyrite-gold assemblage and a late phase consisting of an assemblage of siderite-galena-sphalerite-pyrite-freibergite-pyrargarite-dolomite-calcite-quartz.
- The radiometric dating of veins spans from 89 Ma (Mackeno with its dated assemblage of quartz-pyrite-muscovite) to 68 Ma (Elsa with its dated assemblage of quartz-pyrite-galena-sphalerite-muscovite). These dates imply that the two stages of mineralization outlined above may be separated by up to 20 Ma.
- And the formation of the open space for vein filling extends over a period of up to 20 Ma from 89 to 68 Ma.

We will look at a number of vein fault systems with the above evidence in mind. I want to start in detail with the top of Keno Hill.

1. Top of Keno Hill (Map 13)



Map 13.

- The long, east-northeasterly striking Main, No. 6 and No. 14 longitudinal veins all carry Boyle's early phase mineralization with spotty Au values. Where Boyle's late phase mineralization is present in these veins, it cements brecciated zones of early phase minerals or is present in thin separate veins parallel to the veins of early phase.
- The short north-northeasterly striking No. 3, No. 9, No. 10, No. 12 etc. transverse veins all carry Boyle's late phase of mineralization. These are the main stoped veins.

Table 4. *Surface measurements from the No. 9 and Main veins.*

Vein	Structure	Strike/Dip	Trend/Plunge	Pitch
Main	Vein Fault	057/54SE		
	Slickensides		083/31NE	39E
No. 9	Vein Fault	008/62SE		
	Slickensides		081/61NE	
Line of Intersection			141/54SE	86E

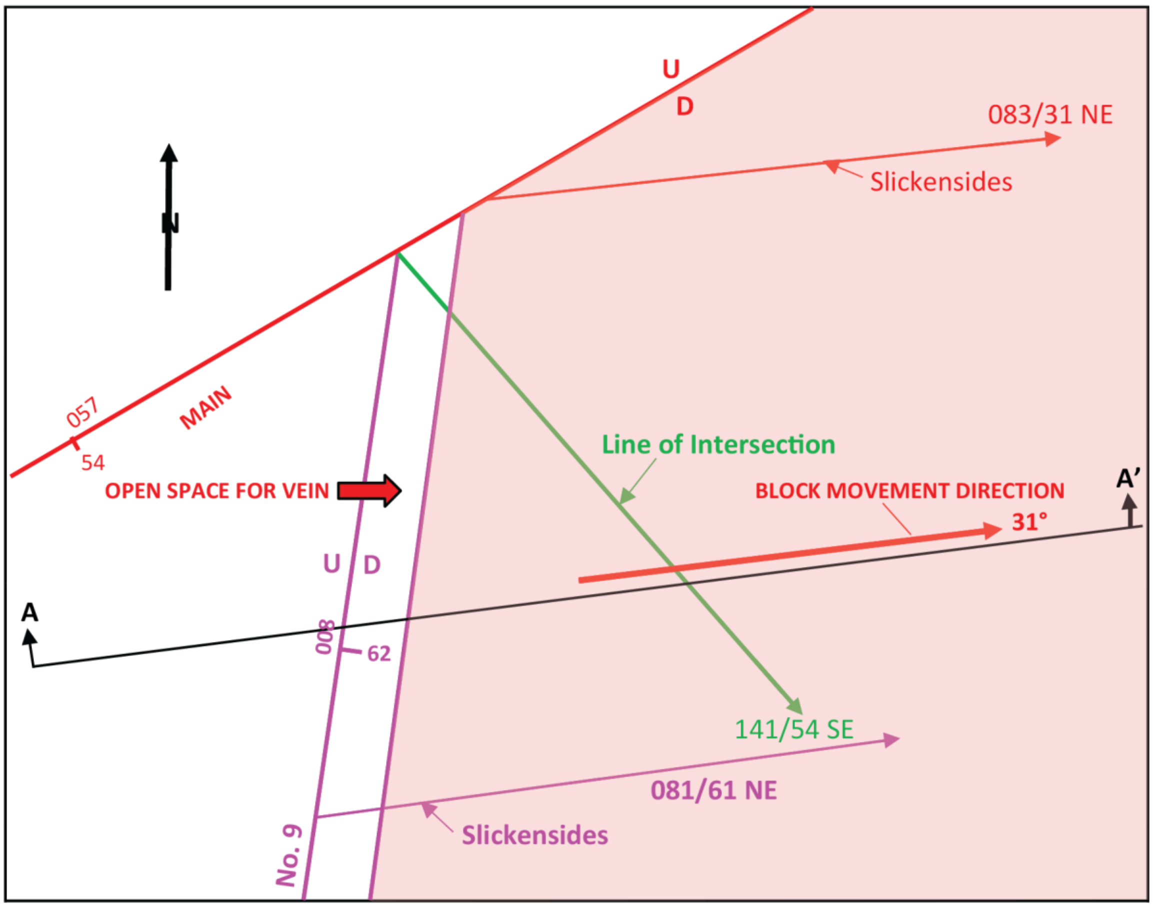


Figure 6a.

- This surface information yields the above map view with the longitudinal Main vein information in red, the transverse No. 9 vein data in pink and the trend and plunge of the Line of Intersection between the two veins in green (Figure 6a).
- **OF EXTREME IMPORTANCE** Please note the parallelism between the trend of the vein fault slickensides on the Main vein at 083° and the trend of the vein fault slickensides on the No. 9 vein at 081°.
- This parallelism tells us that the hanging wall fault block (in pale red) bounded by the No. 9 and Main veins moved in a direction of 082° dropping down a plunge of 31°NE preferentially generating open space for the vein filling along the transverse No. 9 vein fault (Figure 6b).

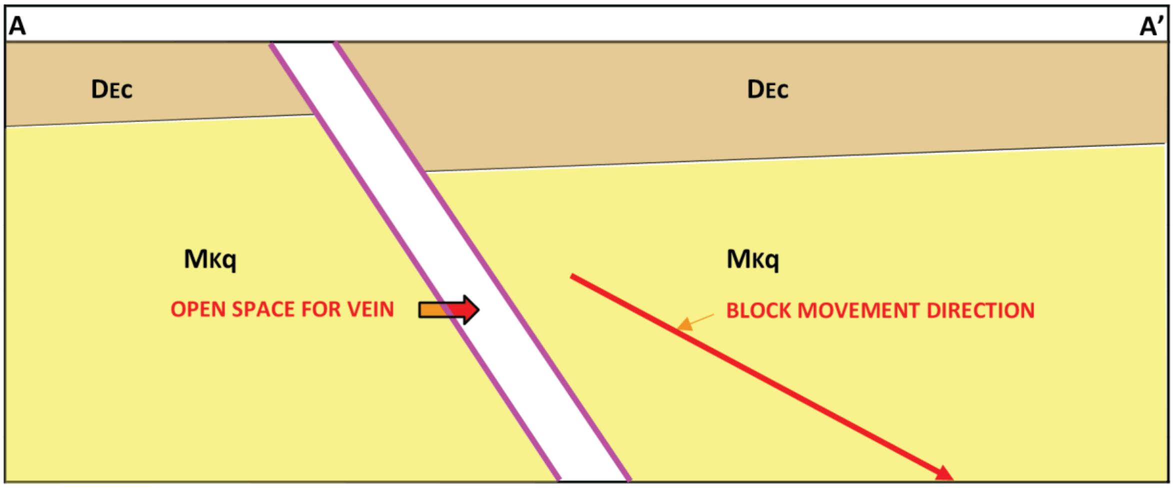


Figure 6b.

- This result allows us to make the following generalizations about the mineralized transverse veins lying between longitudinal veins.
- Where the early or longitudinal vein has a strike length between 5 and more than 10 times longer than that of the late or transverse vein, then the late vein fault movement is controlled by movement direction on the reactivated early longitudinal vein.
- The amount of open space generated for vein filling on the late transverse vein is not only controlled by the movement direction but so is the plunge of the hanging wall block, and by the amount of movement on the reactivated early longitudinal vein.
- The direction of vein fault movement on the re-activated longitudinal fault is likely to be oblique left lateral and that on the late transverse fault closer to dip-slip normal.

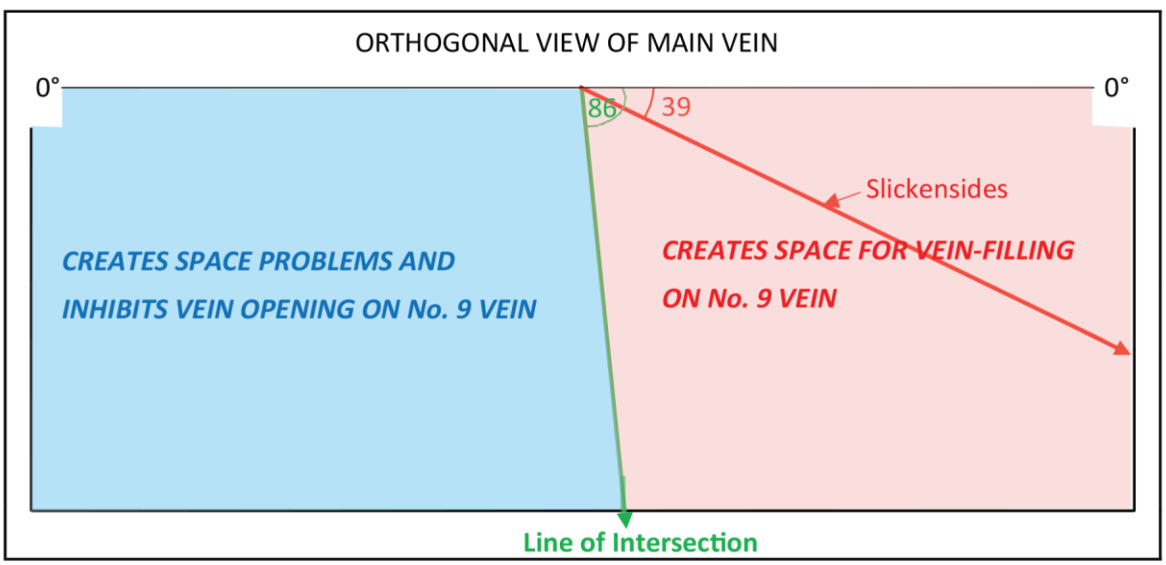
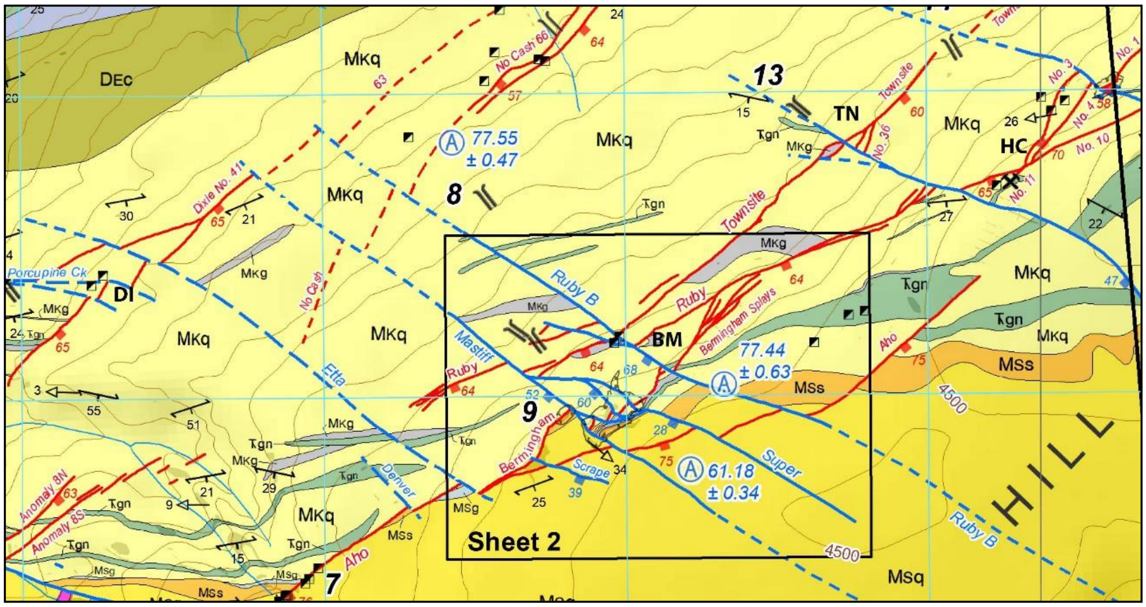


Figure 7.

- Looking at an orthogonal view of the Main vein and the pitch of the Line of Intersection of the No. 9 and Main veins (Figure 7), you can see that the development of open space on the transverse vein depends upon the direction of fault movement on the reactivated longitudinal vein.

- The direction of fault movement on the longitudinal vein must lie between horizontal and the Line of Intersection of the vein faults in the down dropped block (pale red area) to develop open space for vein filling on the transverse vein fault.
- Movement in any other direction (pale blue area) causes the transverse vein fault to close.



Map 14.

- Now a quick skip through the mining camp to show you that this is not an isolated situation (Map 14).
- Turning to Galena Hill, the best example is the Bermingham deposit where the transverse vein fault system lies between the longitudinal early Aho vein on the south and the Ruby vein on the north.
- The Townsite Vein where one of three transverse veins (No. 36) carries the only stope.
- The Dixie where the better one (near D1) of the two stopes lies on a short transverse section in the longitudinal Dixie Vein.
- I suspect that the largest mine of the camp, the Hector-Calumet is a candidate, but I have not studied it yet – because it has been mined out.

(e) Summary

- In summarizing the mechanisms of vein fault formation, I want to stress two important features:
- The first already long known, is that the vein-fault movements are left-lateral oblique normal to dip-slip faults- do not be fooled by the left lateral apparent separations, seen on the map, into thinking that they are strike-slip.
- The second is new - that the vein faults and veins developed over a considerable time span, about 20 Ma, between 68 to 89 Ma.
-

We have looked at three mechanisms for the generation of open space for vein-filling:

- Refraction (Boyle) and I have added the complexity of the hanging wall block sticking on the refraction step.
- Riedel shear (Iles)
- And the consequences of late vein fault movements that Diverge from the Line of Intersection between early and late vein faults.
- In the mining camp, the development of open space for vein-filling employs all of these mechanisms.

Photo 8. Midnight, June the 21st, top of Keno Hill.