



The role of pre-existing veining in the localization of auriferous vein systems: Examples from the Canadian Shield.

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Outline

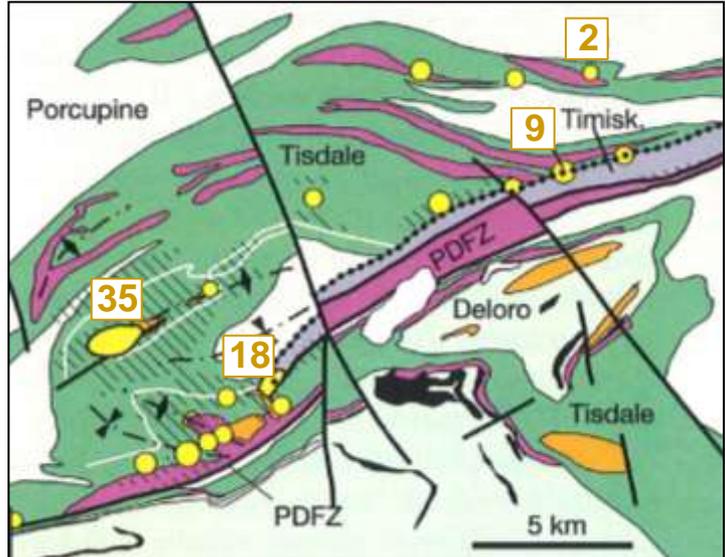
- Typical structural setting of shear zone hosted gold deposit:
 - Association with crustal scale shear zones;
 - Vein geometry in shear zones;
 - Controls on ore plunge;
- Competence contrasts in gold deposits:
 - Vein control on later vein deposition;
 - Needed for world-class deposit?
 - Potential for localizing late stage gold enrichment;
 - Influence on ore plunge.
- Controlling geometries; and
- Examples:
 - Detour Lake gold deposit, Ontario;
 - Seabee gold deposit, Saskatchewan; and
 - Con gold deposit, Northwest Territories.



Crustal Scale Faults



20 District/deposit size in Moz of gold



Distribution of gold deposits in the Timmins camp

Gold camps and deposits are spatially associated with second-order structures in close vicinity to crustal-scale structures.

Figures modified from Robert et al., 2005
Deposit/district sizes from Gosselin and Dube GSC Open File 4894 (2005)

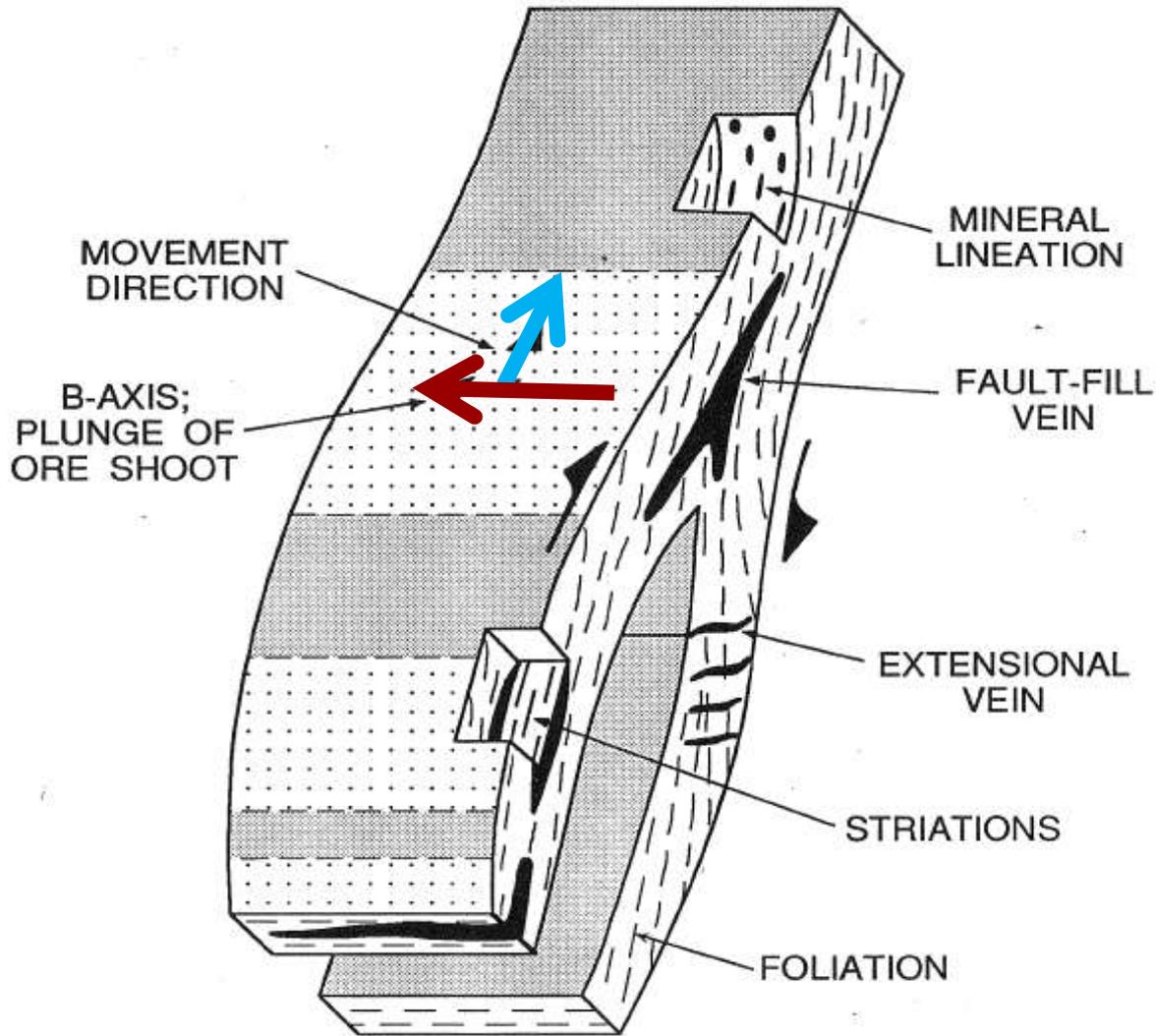
Veins in fault zones

- Veins form in or adjacent to both brittle and ductile fault zones;
- Veins generally form oblique to their related fault, and the sense of obliquity is related to fault movement direction/sense; and
- With continued deformation the veins will fracture, fold and boudinage.



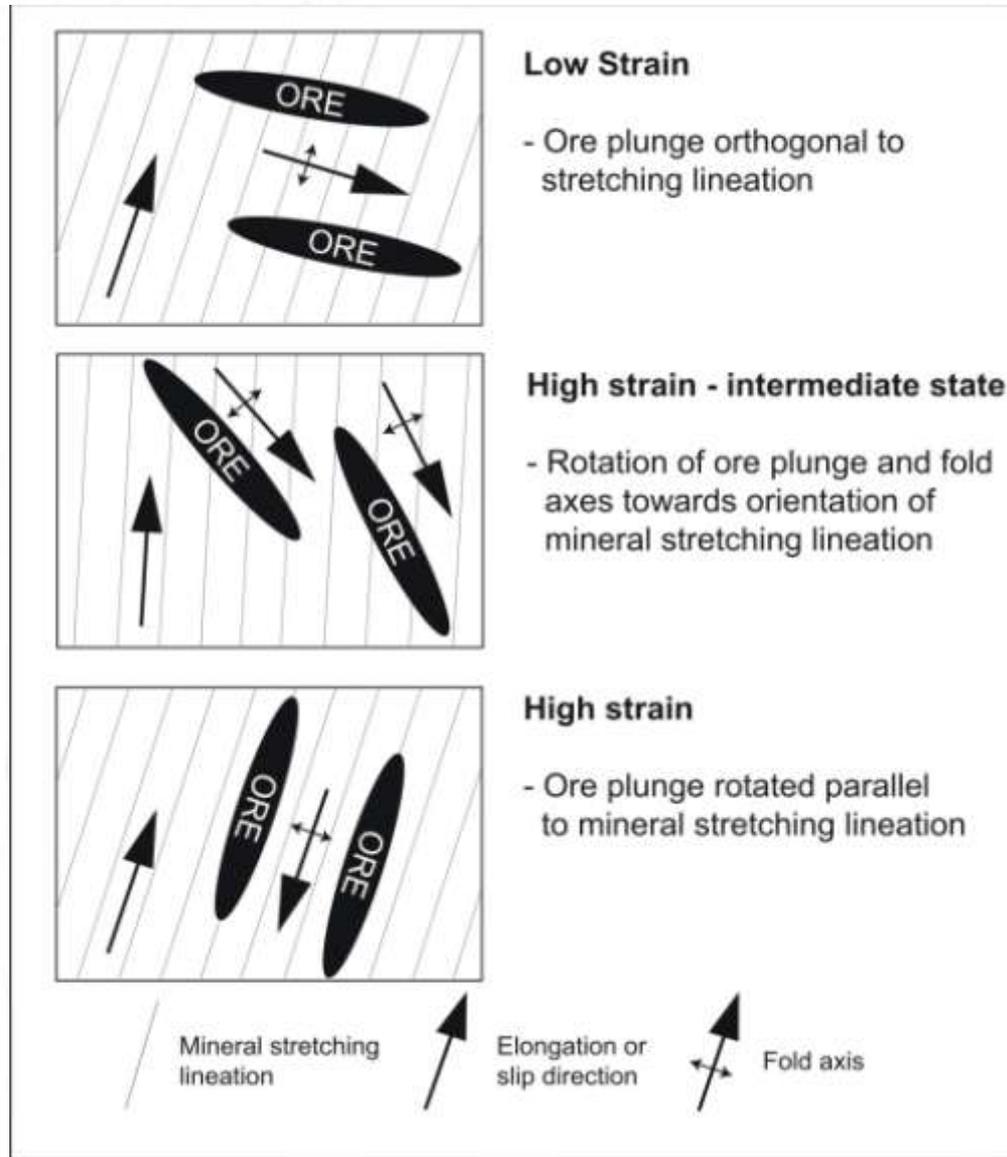
Ore Plunge Control

From Poulsen and Robert (1989)



In a low strain, shear zone hosted, deposit the ore plunge will be aligned with the intersection of the foliation with extensional veining, normal to the stretching lineation (transport direction).

Ore Plunge Control



With increased progressive strain the ore plunge will rotate as fold and boudin axes in auriferous veins rotate parallel to the stretching lineation (transport direction).

Competence contrasts in ductile fault zones

- Formation of a quartz-carbonate vein in a schistose fault zone (e.g. biotite, chlorite, sericite) creates a large competence contrast between the **strong vein** and the surrounding **weak schist**;
- This creates a **positive feedback** mechanism where during subsequent deformation the vein will **fold/boudinage/fracture** creating **low stress sites** that will focus the deposition of subsequent hydrothermal fluids.



Quartz vein in graphitic schist, Obuasi, Ghana



Pyrrhotite infilling boudin necks in a quartz vein, Detour Lake, Ontario

Veins exploit pre-existing veins



Quartz-tourmaline vein xc boudinaged ankerite vein, Red Lake



Quartz-amphibole vein infilling boudin necks in ankerite vein, Red Lake



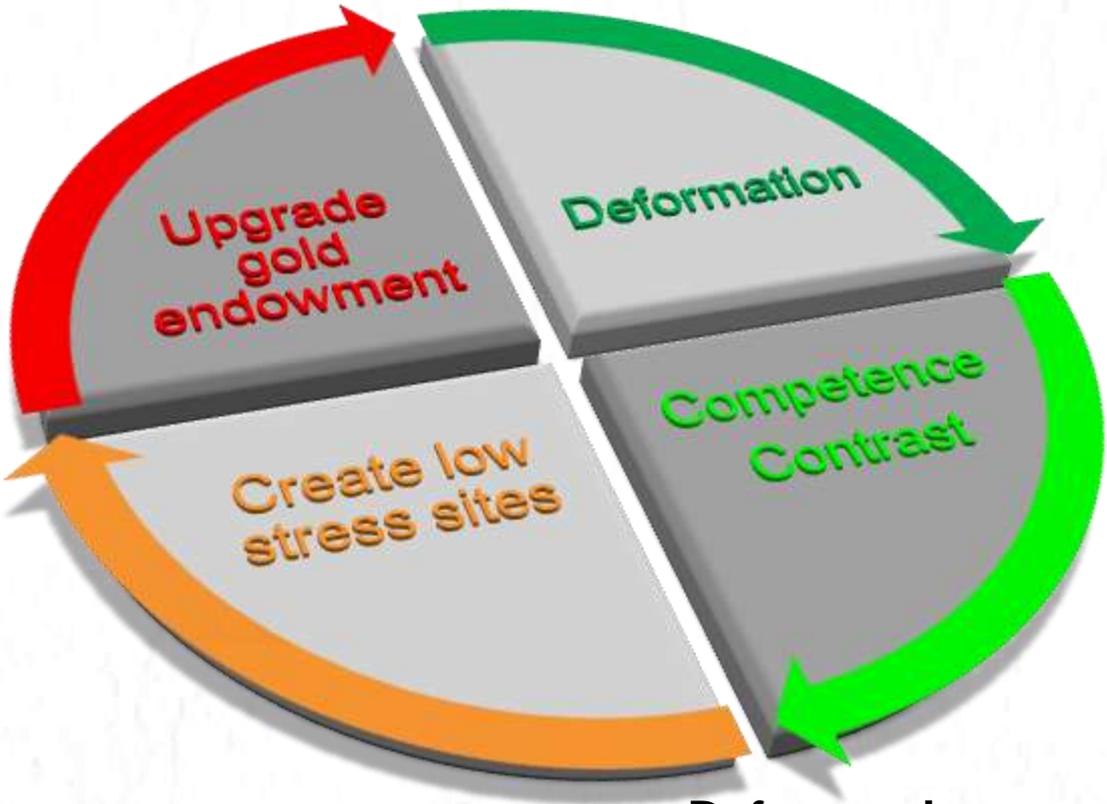
Quartz-tourmaline vein xc boudinaged ankerite vein, Dome, Timmins



Quartz vein xc quartz vein, Con, Yellowknife

Positive feedback

Deform ductile shear zone



Deposit vein system (barren or auriferous)

Deposit veins localized on 1st/2nd/3rd vein system

Deform vein system

Significant gold enrichment?



Con, Yellowknife

- Related to orders of magnitude variation in gold grade (~10 g/t to 1500 g/t); and
- Often associated with chalcopyrite, sphalerite and galena.

Significant gold enrichment?



DETOUR GOLD



- Chalcopyrite-pyrrhotite-pyrite infilling extensional fractures and boudin necks in deformed quartz veins; and
- Related to orders of magnitude variation in gold grade.

Detour Lake, Ontario



Significant gold enrichment?

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- Related to orders of magnitude variation in gold grade.



Flat-lying cpy-py veins x-c quartz vein.



Flat-lying cpy-py veins x-c quartz vein.

Seabee, Saskatchewan

Timing and gold endowment

- It is important to understand the **timing** relative to deformation of the vein generations, and the controlling **kinematics** of the deformation at that time.
- It is also important to understand the relative **gold endowment** of the different vein generations; e.g. barren-auriferous, auriferous-auriferous.



Folded gold with axial planar cleavage, Rainy River gold deposit, Ontario



Gold in cross-cutting fracture, Rainy River gold deposit, Ontario

Controlling Geometry? – Red Lake



Folded ankerite vein, CARZ zone, Phoenix Island, Red Lake (Rubicon Minerals Corp. exploration property)



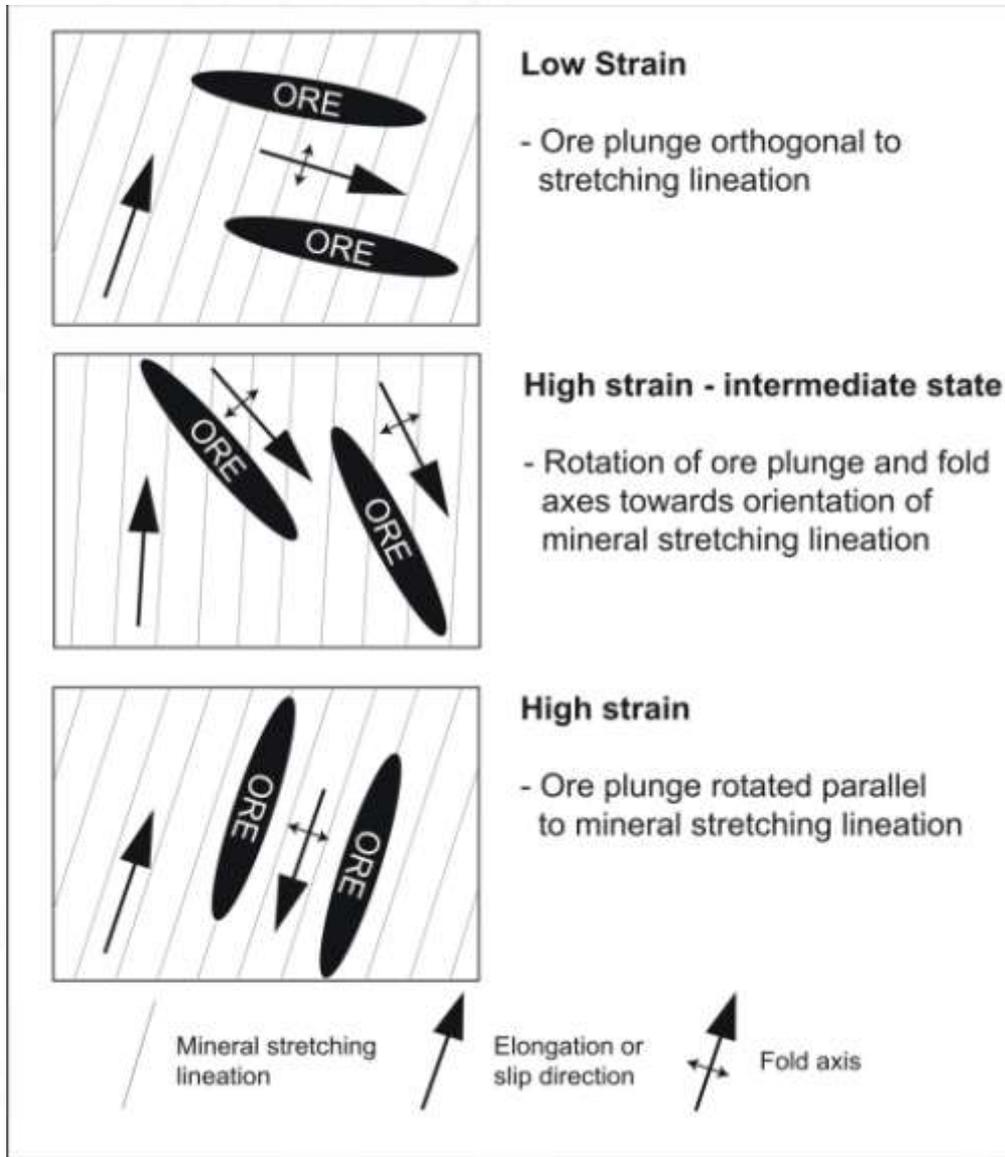
Conjugate quartz-amphibole veins within ankerite vein



Folded ankerite vein crosscut by quartz-tourmaline veins

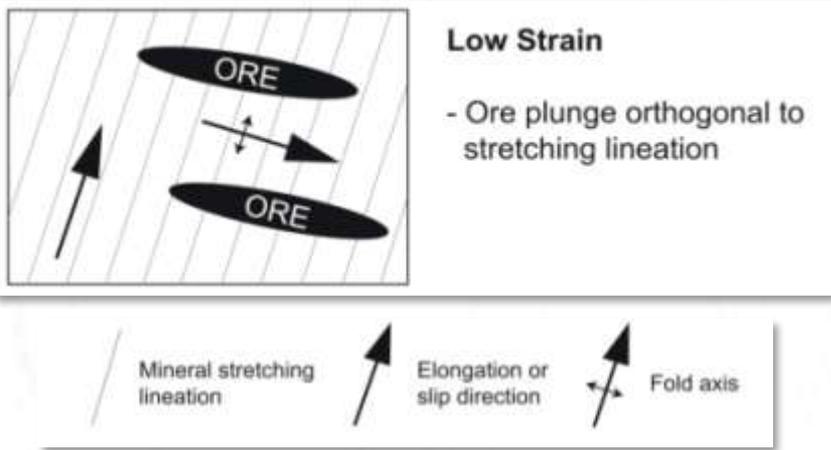
Overall geometry of later vein system can be strongly controlled by geometry of earlier deformed (folded/boudinaged) vein system

Ore Plunge Control

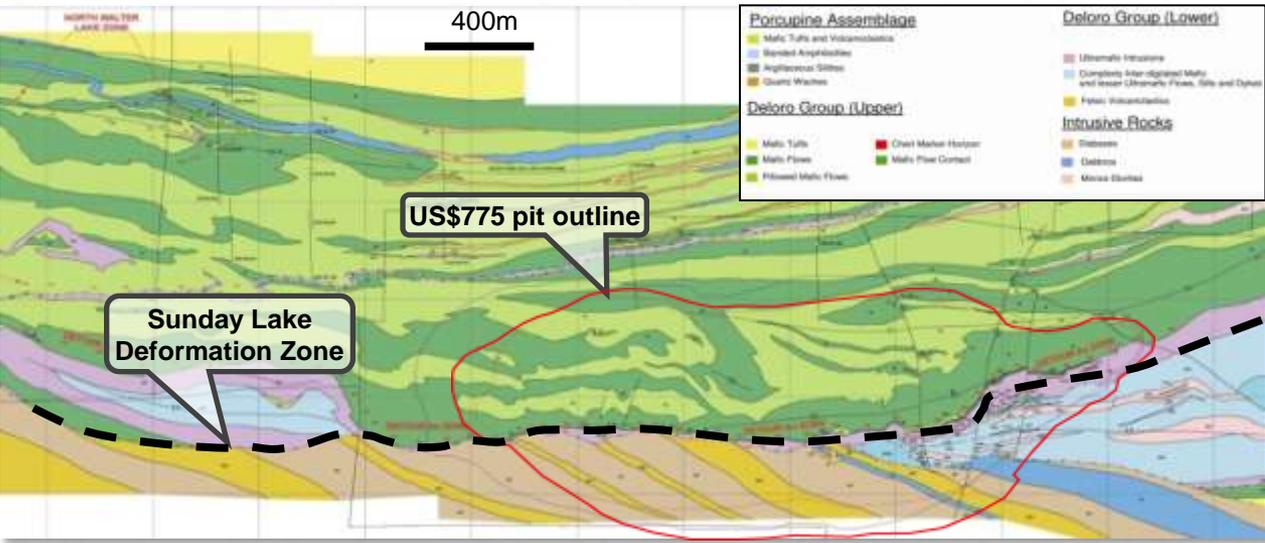


- It is important to document the **strain state** of the different vein generations, in particular the competent veins that host the later vein generations; and
- As the competent veins deform with increased progressive strain their fold and boudin axes will **rotate** parallel to the stretching lineation.

Low strain setting – Detour Lake, Ontario



Placer Dome open pit, Detour Lake



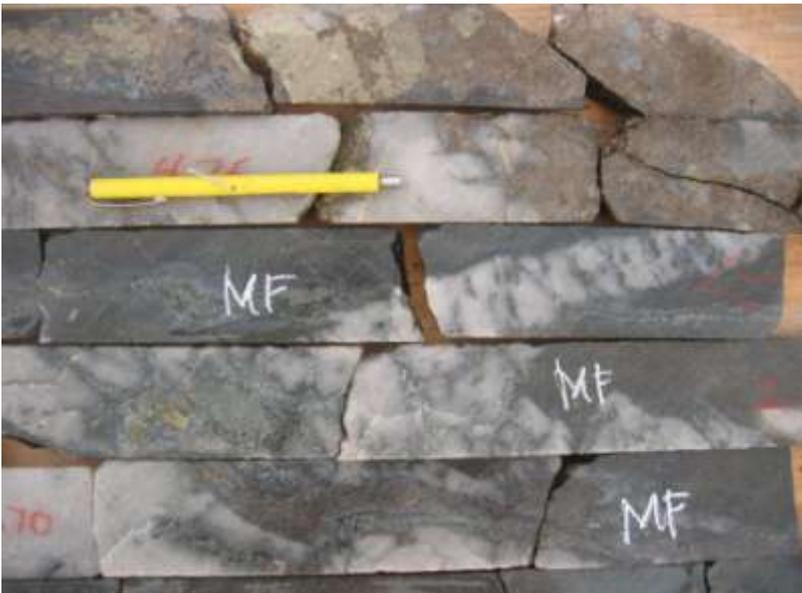
Deposit scale geological map, Detour Lake

Gold mineralization occurs in a vein field that extends at least across a strike length of 3 km's, a width of 200-350 m and 1 km below surface.

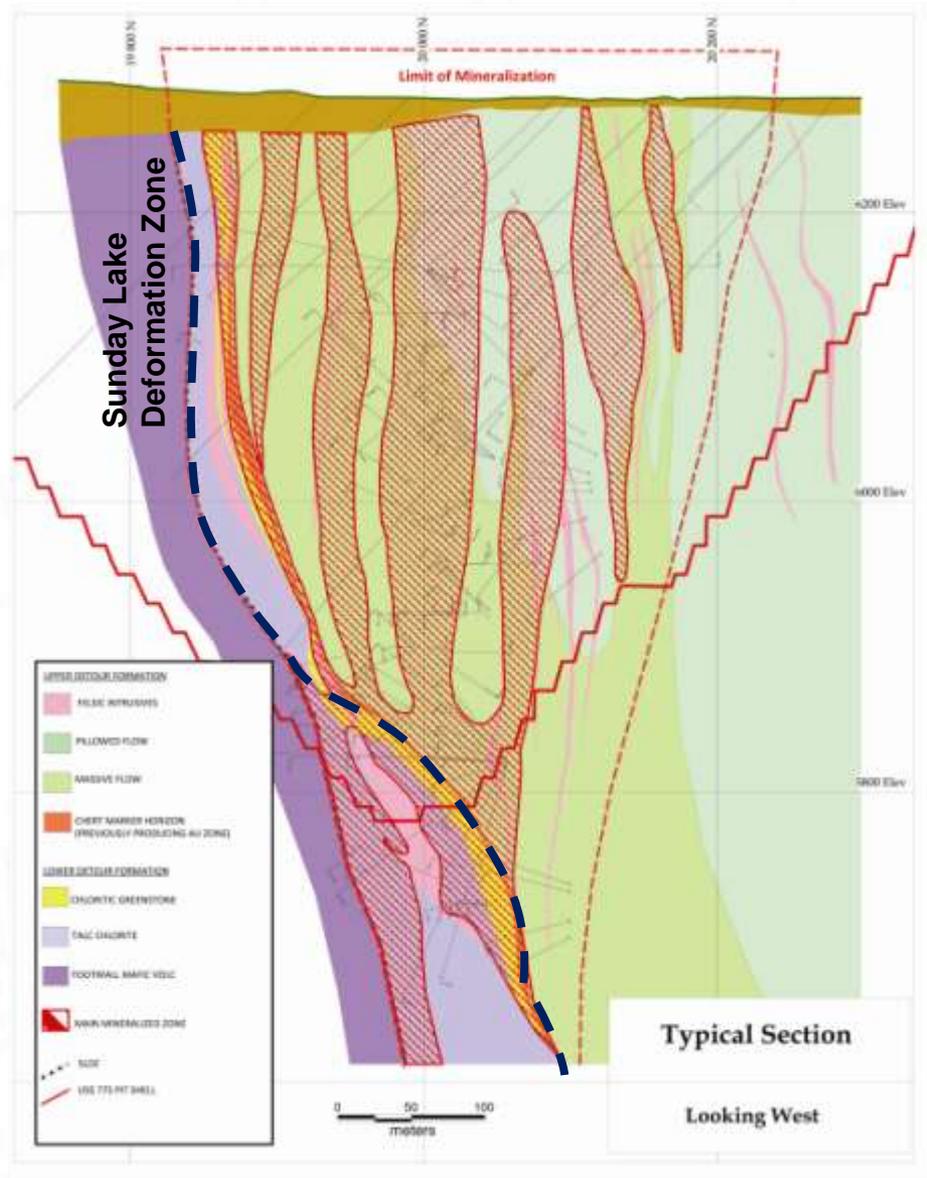
Detour Lake – Gold mineralization



- Broad stockwork of overall east-west striking quartz-carbonate veins developed along sub-parallel biotite shear zones in hanging wall of the Sunday Lake Deformation Zone.

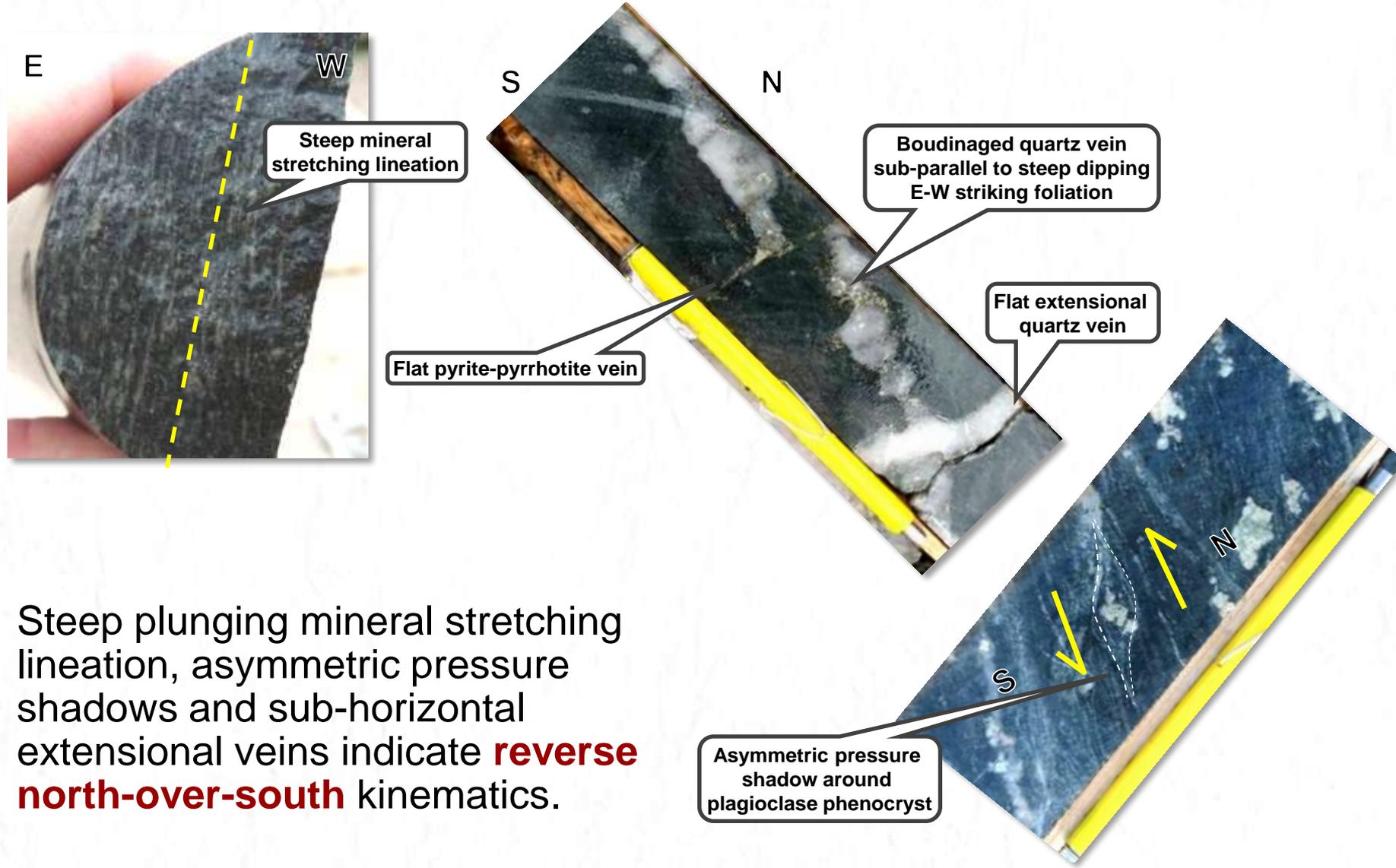


Quartz-carbonate and sulphide veins, Detour Lake



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Detour Lake – Deformation

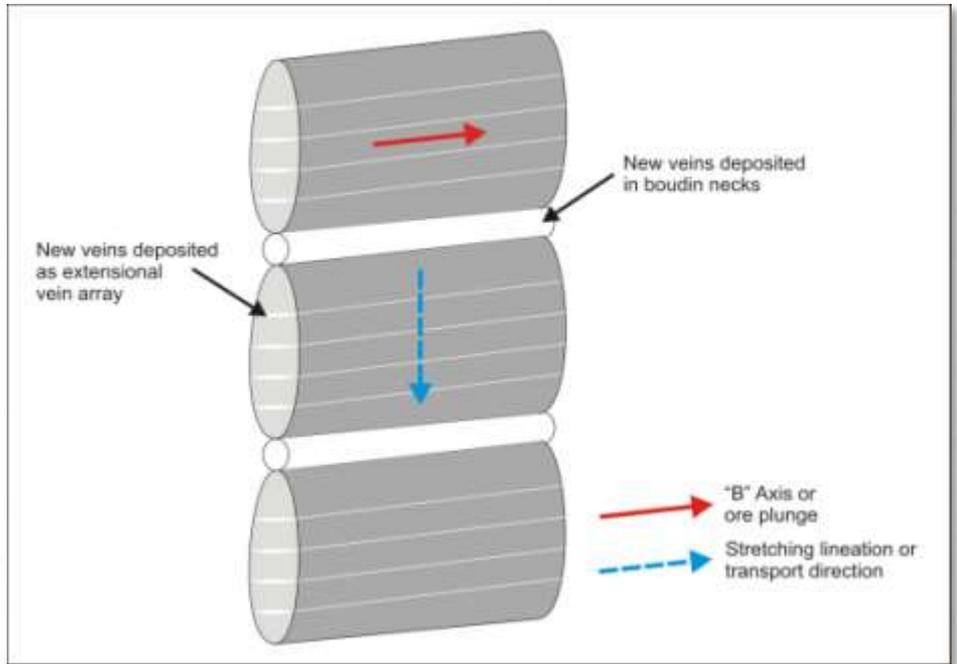


- Steep plunging mineral stretching lineation, asymmetric pressure shadows and sub-horizontal extensional veins indicate **reverse north-over-south** kinematics.

Detour Lake – Gold enrichment?



Pyrrhotite infilling a boudin neck in quartz vein

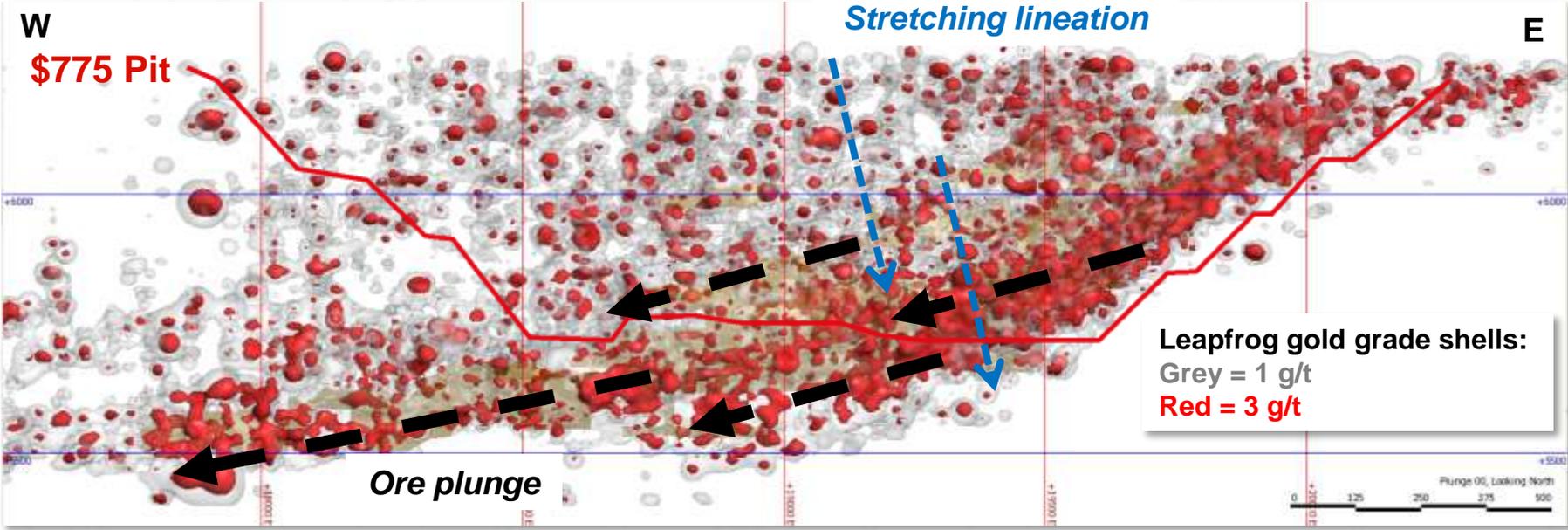


Structural Framework in low strain-late extension setting



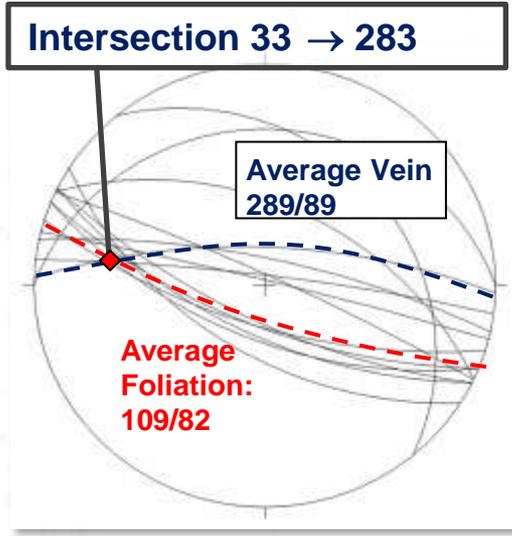
Pyrrhotite-pyrite-chalcopyrite extensional vein array

Detour Lake – Ore Plunge

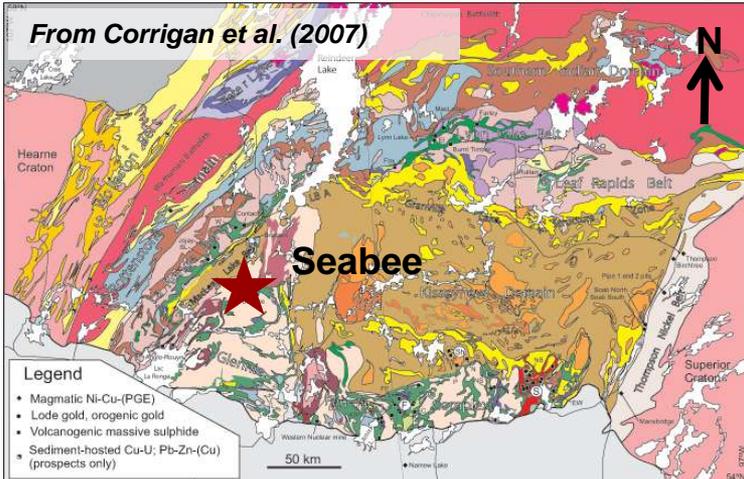
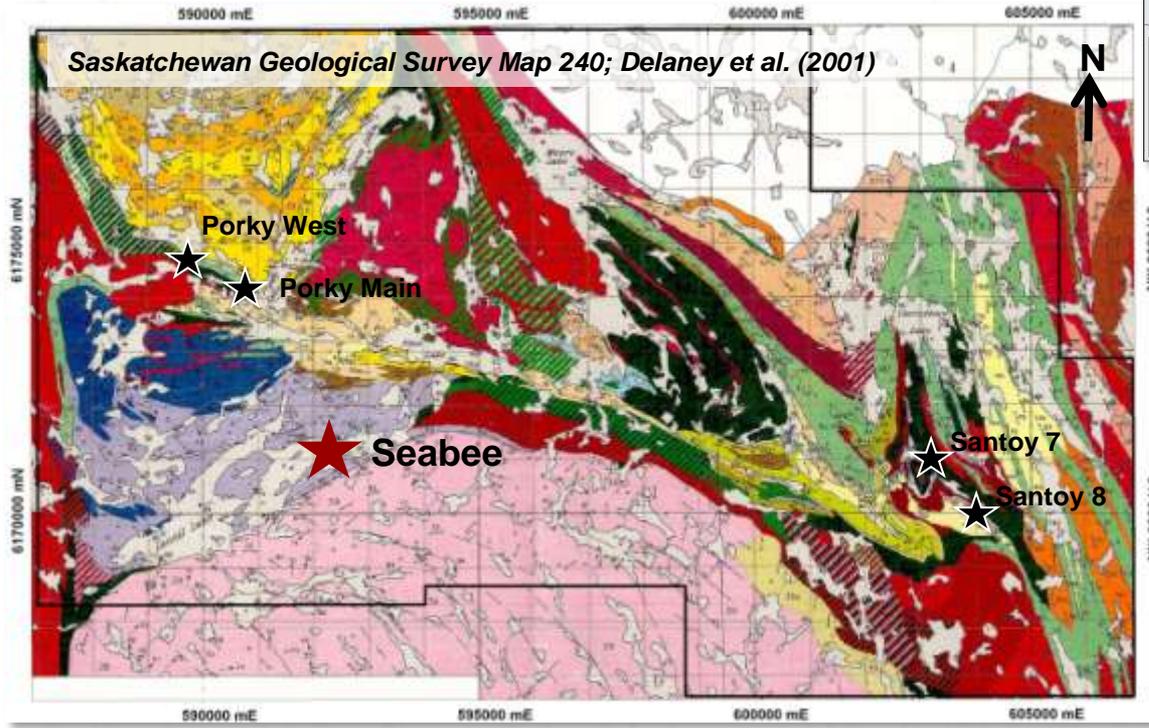


Long Section showing Leapfrog gold grade shells

Boudin and fold axes of auriferous quartz veins, and quartz vein intersections plunge moderate to the west corresponding to the ore plunge, which is orthogonal to the stretching lineation.

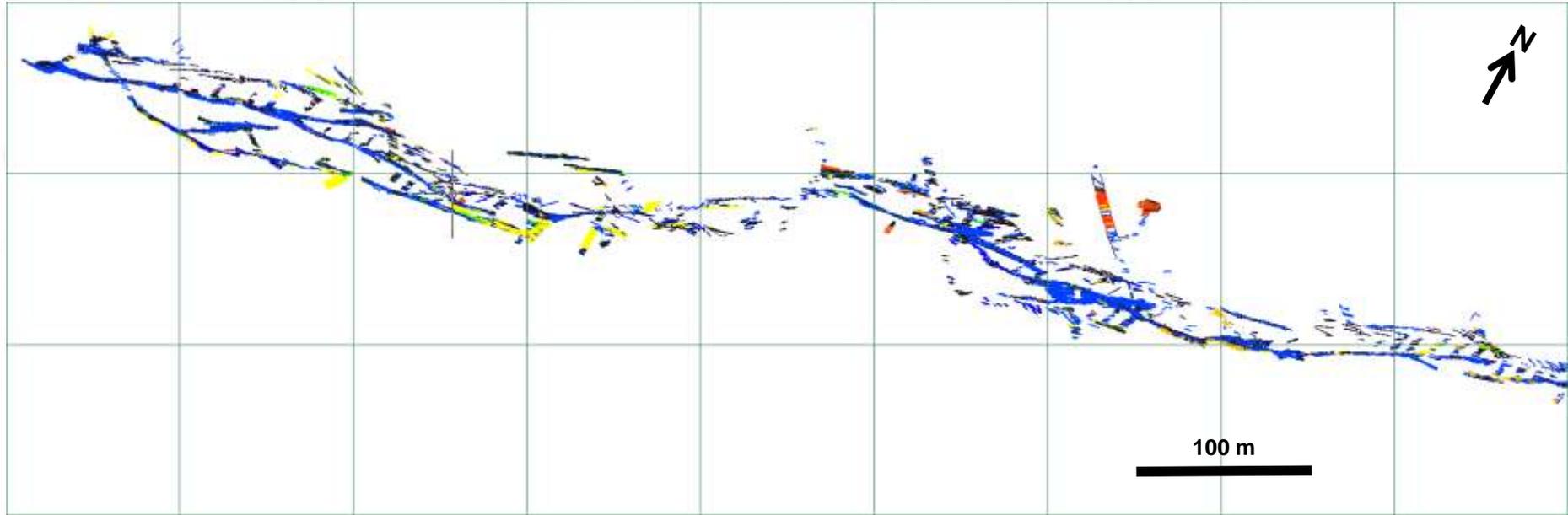


High strain setting – Seabee, Saskatchewan



- Laonil Lake intrusion is a multiphase intrusive complex (1889 ± 9 Ma) composed of gabbro, quartz diorite and diorite hosting the Seabee deposit.
- Eyahpaise intrusion is composed of granodiorite and tonalite (1859 ± 5 Ma).
- Pine Lake greenstone belt: 1889-1846 Ma mafic to intermediate metavolcanic and volcanoclastic rocks; and
- Porky Lake metasediments: >1845 Ma arenites, wackes, conglomerates and biotite schist.

Seabee – Geology



- ENE striking, steeply south dipping anastomosing biotite-actinolite-chlorite shear zones containing quartz veins (blue) crosscutting Laonil Lake intrusive complex (“LLIC”, 1889 ± 9 Ma).
- LLIC is a gabbro, quartz diorite and diorite composite intrusion.

Seabee – Deformation



Hornblende-biotite-plagioclase stretching lineation along foliation plane.



Horizontal extensional quartz veins



Asymmetric quartz boudins indicating south over north shear sense.

- Steep down-dip stretching lineation, horizontal extension veins, and asymmetric boudins indicating **reverse, south over north** displacement.

Seabee – Vein system



Isoclinally folded and transposed quartz vein.



Boudinaged and isoclinally folded quartz vein.



Boudinaged and isoclinally folded quartz vein .

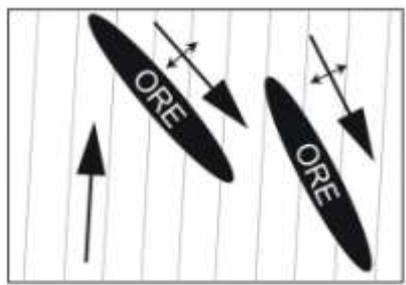
Seabee – Ore plunge



Eastward plunge of folded quartz vein (XS in inset)



Eastward plunge of boudin in quartz vein



High strain - intermediate state
 - Rotation of ore plunge and fold axes towards orientation of mineral stretching lineation



Seabee – Gold enrichment?



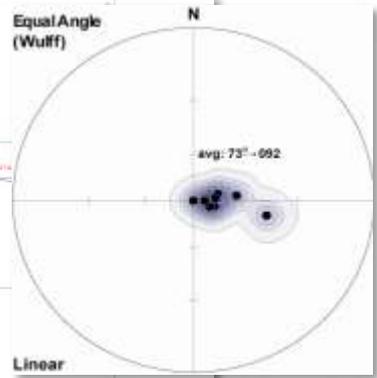
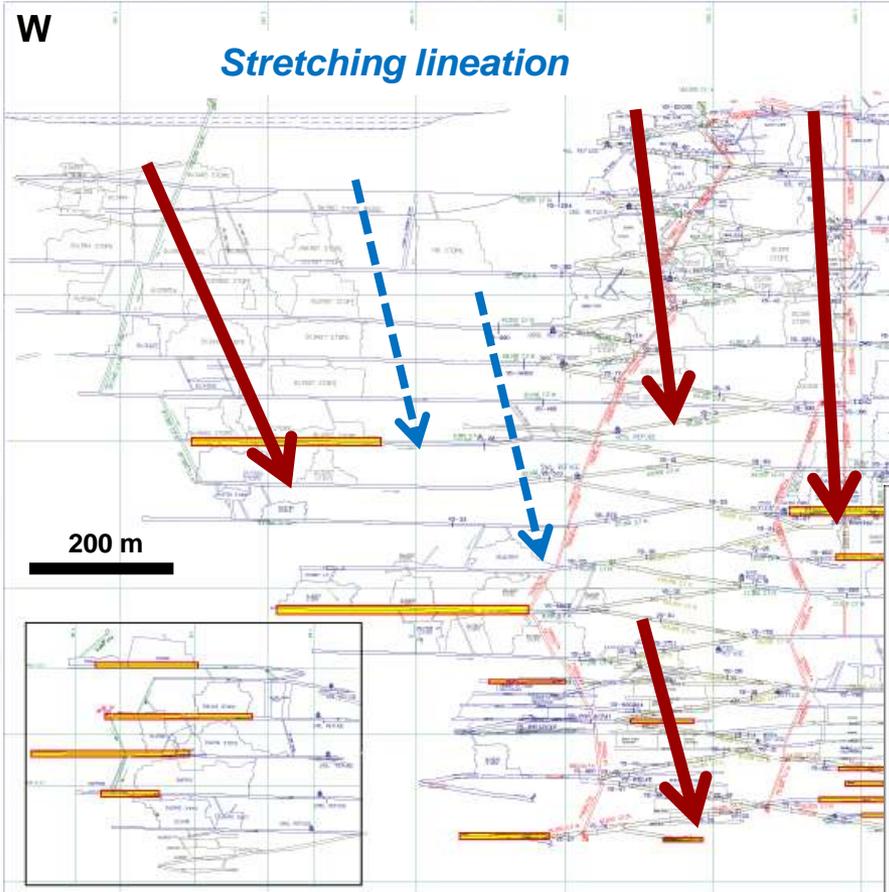
Flat-lying cpy-py veins x-c quartz vein.



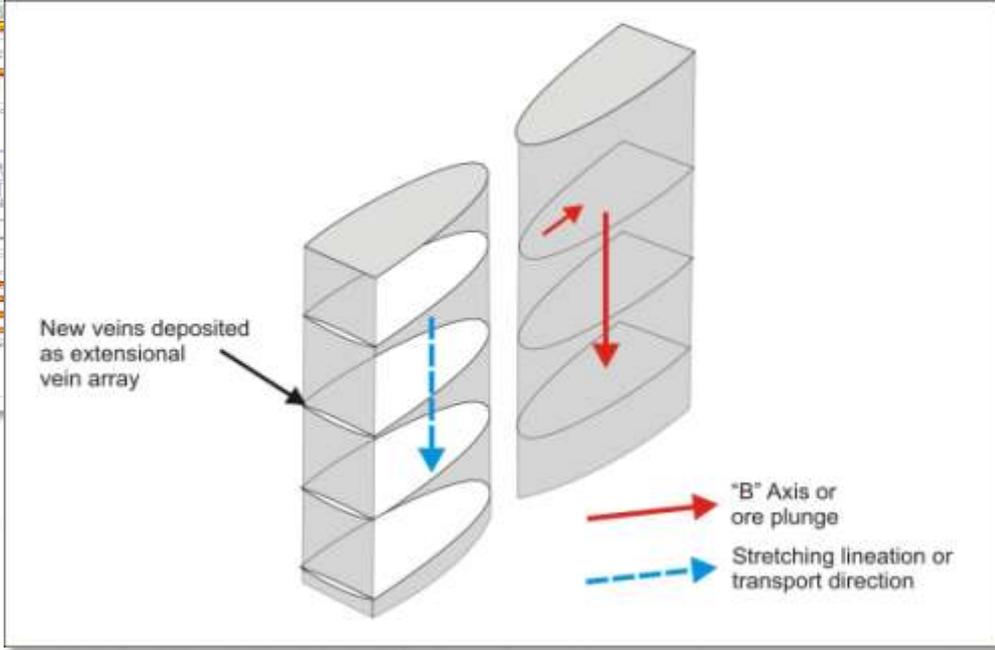
Flat-lying cpy-py veins x-c quartz vein.

Seabee, Saskatchewan

Seabee – Ore Plunge

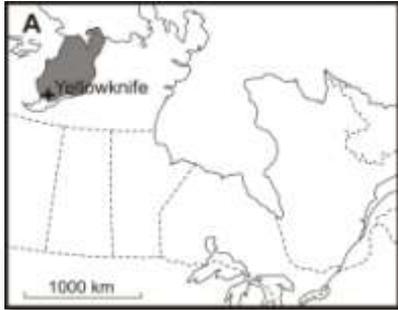


Long Section showing mined stopes and resource blocks

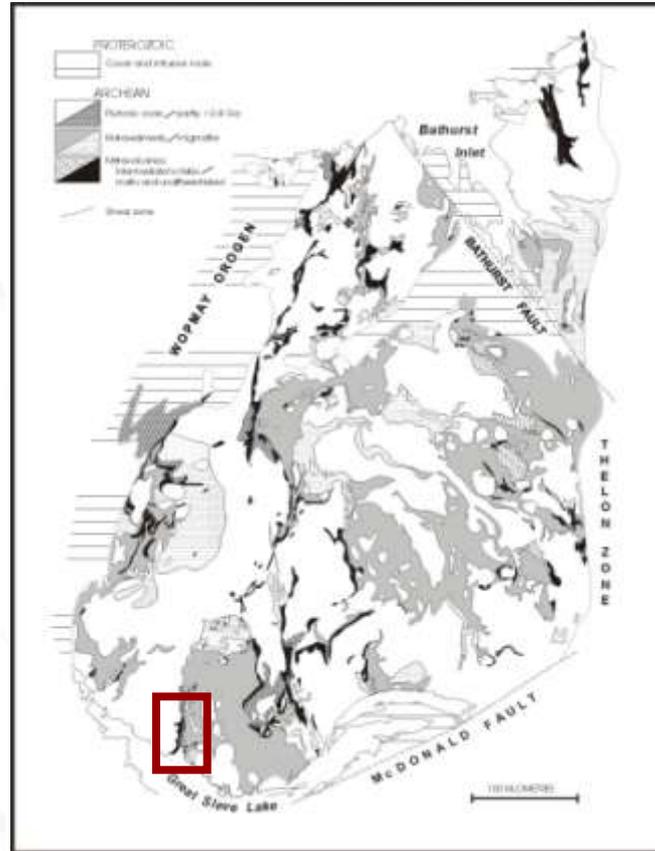


Structural Framework in high strain-late extension setting

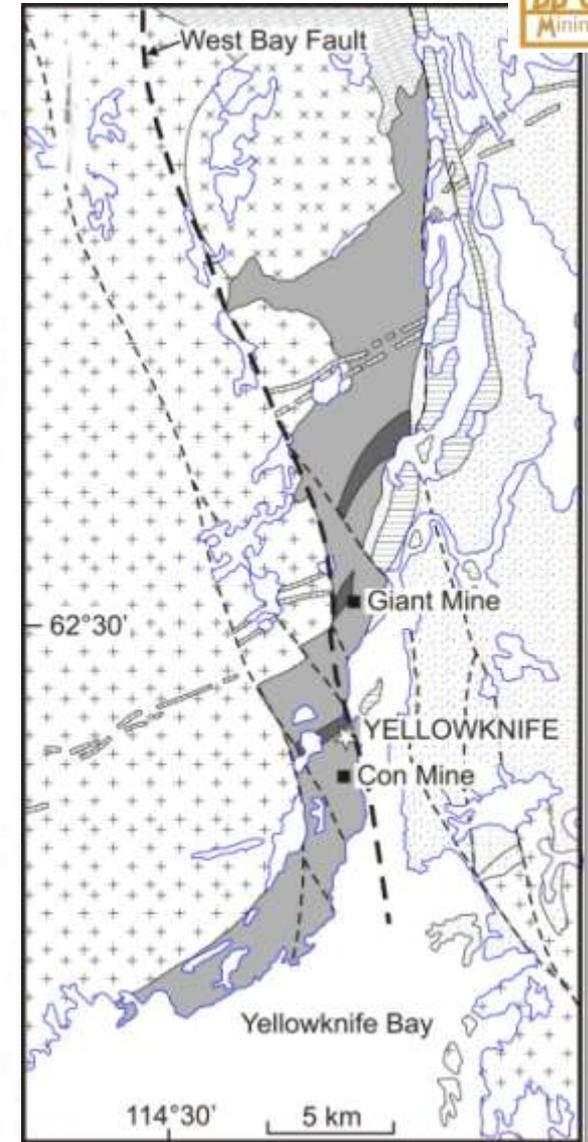
High strain setting – Con, Yellowknife



Yellowknife location

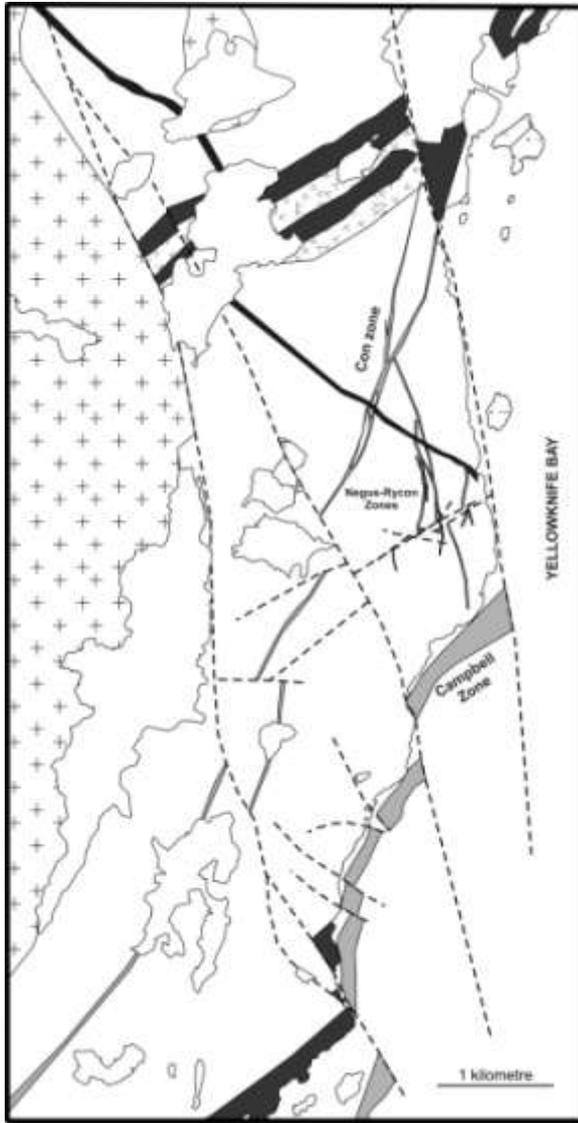


Slave Province

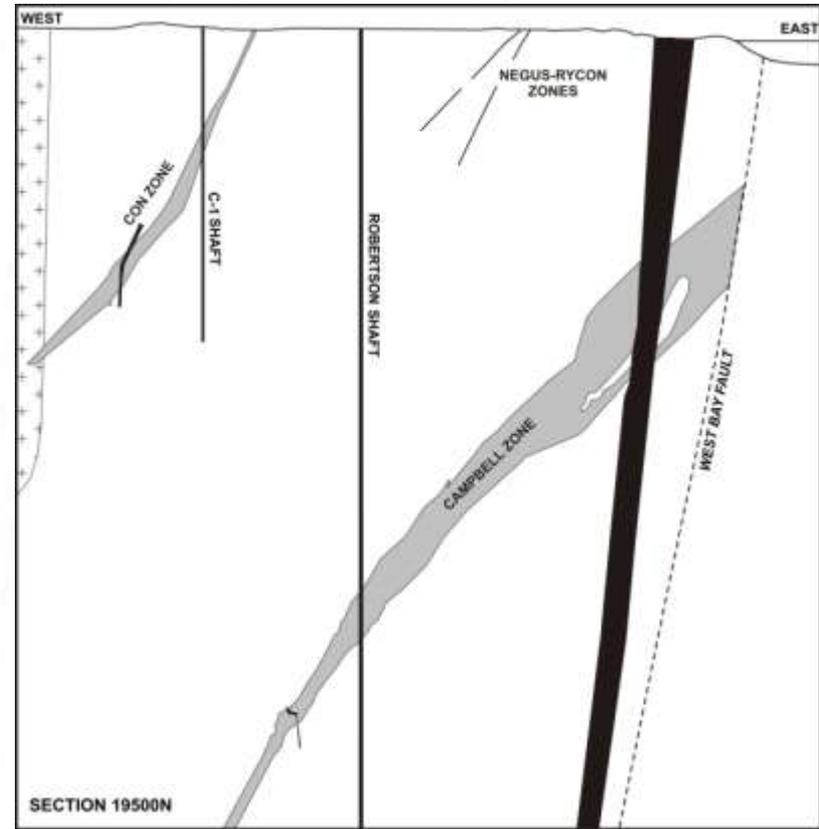


Yellowknife Greenstone Belt

Con – Geology



Geological Map



Geological Cross-section

- Produced 5.5 million oz's Au.
- Strike length: 10,000 ft.
- Depth: 6500 ft.
- Refractory gold in arsenopyrite and free-milling gold.

Con – Deformation

3 deformation phases:

- D₁ Early extension;
- **D₂ Reverse-dextral shearing; and**
- D₃ Proterozoic brittle faulting.



Con – Vein system



Boudinaged "fishhook" fold in quartz vein



Boudinaged and isoclinally folded quartz vein.



Transposed and boudinaged quartz vein



Transposed and boudinaged quartz vein

Con – Gold enrichment?

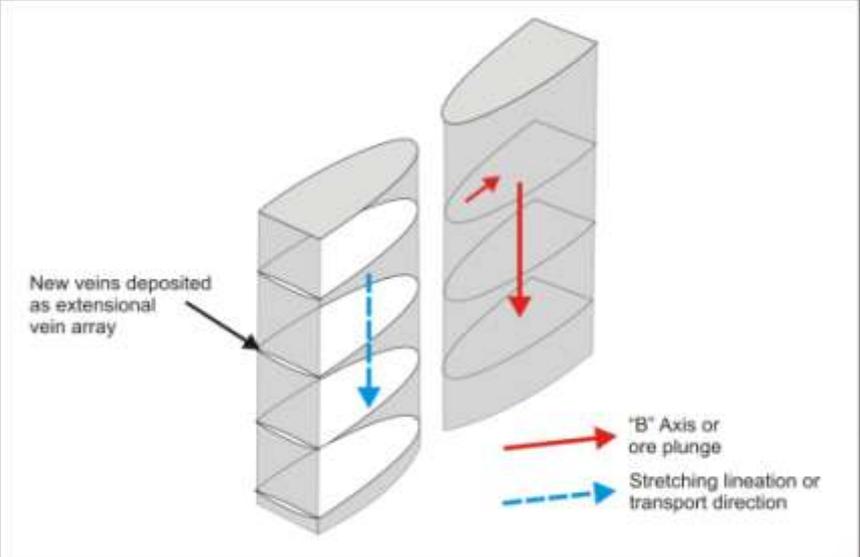


Con, Yellowknife

- Three phases of auriferous quartz-carbonate veining associated with free-milling gold.
- Often located in extensional settings created during deformation of pre-existing veins.

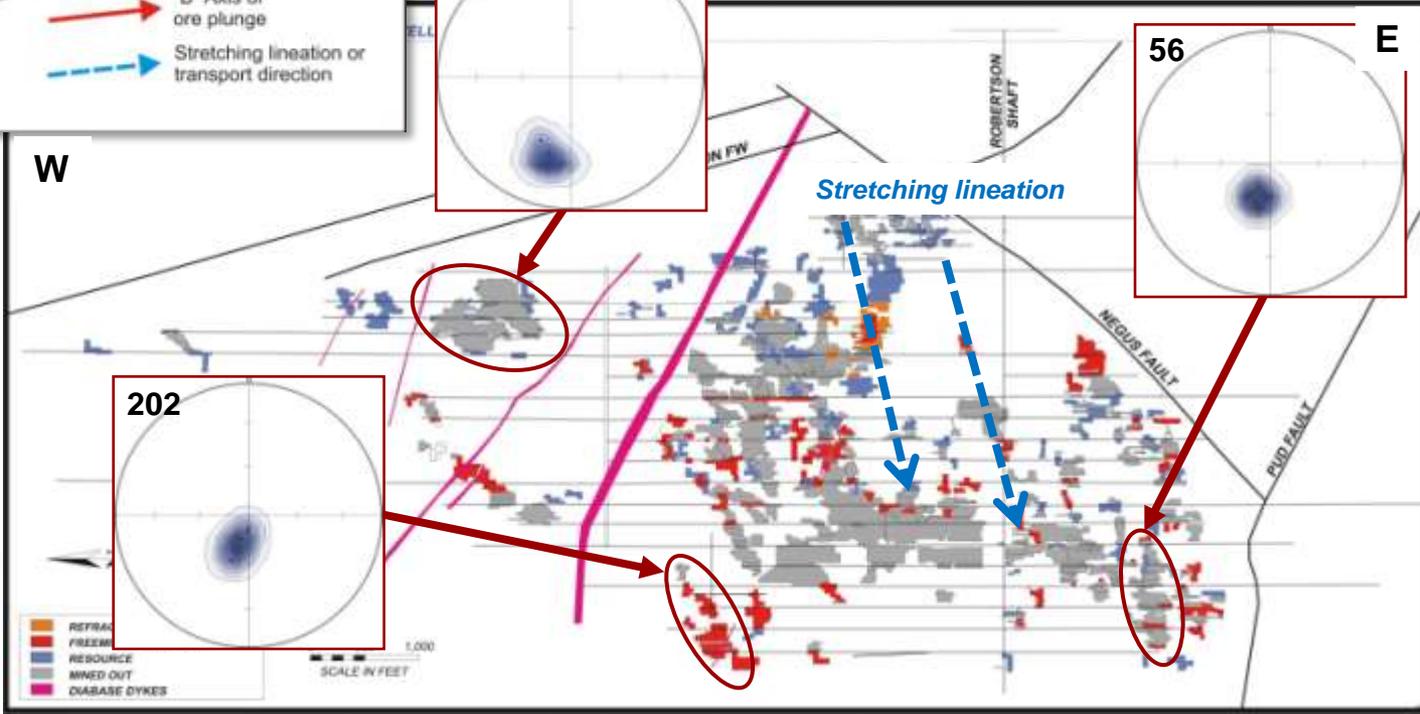


Con – Orientation of Fold & Boudin axes



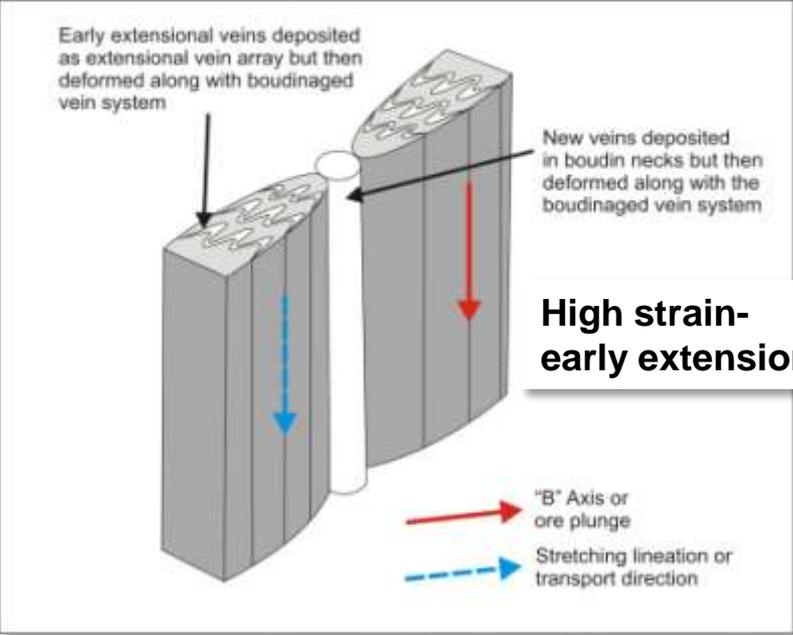
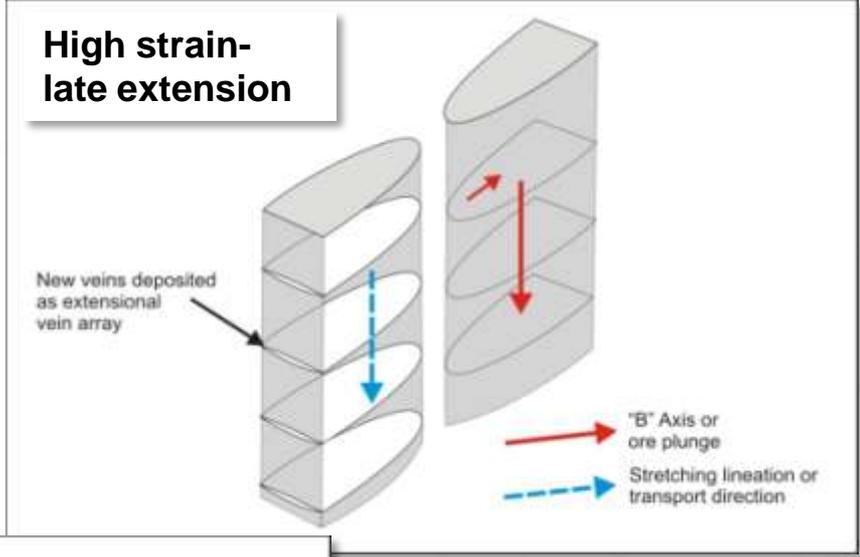
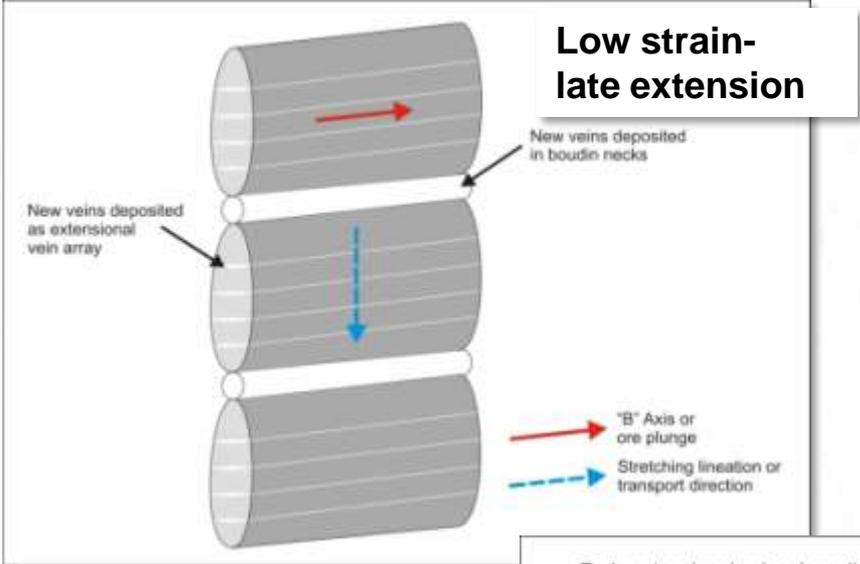
High strain-late extension setting

Equal angle stereonet display fold/boudin plunge in auriferous veins



Long Section showing mined stopes and resource blocks

End Members



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Conclusions

- **Competence contrast** between veining and schist creates a **positive feedback** where during subsequent deformation the vein will **fold/boudinage/fracture** creating **low stress sites** that will focus the deposition of subsequent veining;
- Later gold rich hydrothermal fluids are often associated with an abundant sulphide (cpy-po-py) phase;
- The influence on ore plunge is controlled by the gold endowment of each phase of mineralization and the strain state of the vein systems; and
- For which there are 3 principal end members:
 - **Low strain-late extension** (ore plunge parallel to the intersection of extension and shear veins, orthogonal to the stretching lineation)
 - **High strain-late extension** (deposit scale ore plunge parallel to the boudin&fold plunge/stretching lineation; stope scale ore plunge can be parallel to the intersection of extension veins and boudinaged veins); and
 - **High strain-early extension** (ore plunge parallel to the boudin&fold plunge/stretching lineation).



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