

The Watershed tungsten deposit, NE QLD: A Permian metamorphic tungsten upgrade after a Carboniferous magmatic-hydrothermal mineralisation event

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GSQ Seminar

Townsville, Australia

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Location

49.32 Mt @ 0.14% WO₃;
70,400 t WO₃;

Top 10 largest undeveloped
W deposit outside of China

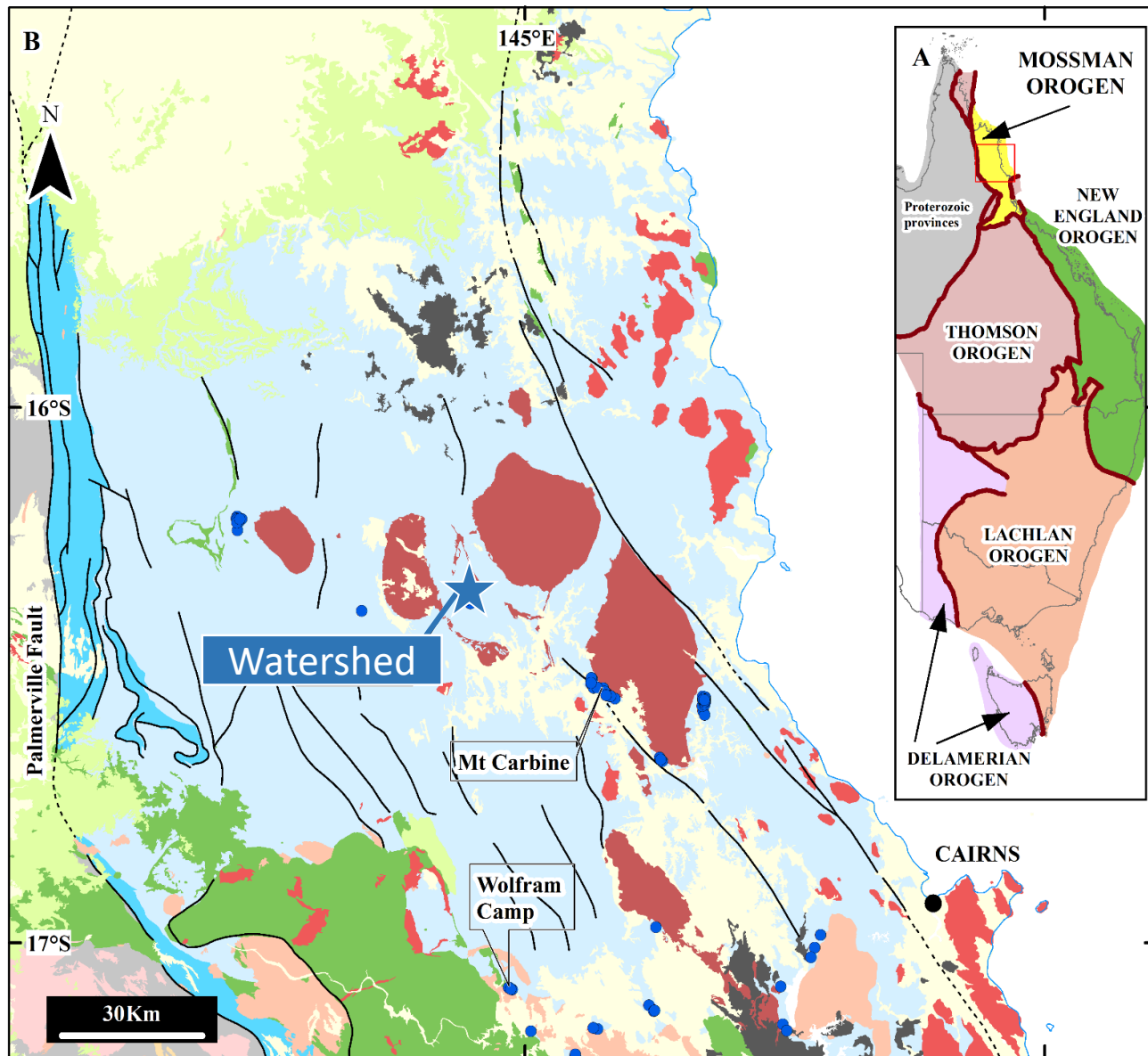
Watershed



From Vital Metals

16°25'S / 144°53'W – Looking NE

Regional Geology



- Tungsten Deposits
 - Coastline
 - Fault
 - - - - Fault (inferred)
- Post-Mesozoic**
- Cenozoic - Quaternary
 - Tertiary basalts
 - Mesozoic sedimentary rocks
- Kennedy Igneous Association**
- Permian volcanic rocks
 - Whypalla Supersuite - Permian
 - Permian
 - Carboniferous - Permian
 - early Paleozoic
- Hodgkinson Province**
- Hodgkinson Fm
 - Chillagoe Fm
- North Australia Craton**
- Precambrian rocks

District Geology

LEGEND

- - - Proposed pits

45 ↘ Layering, strike and dip

— D₄ shear zone

— S₁₋₂

..... S₃

Rock types

■ D₄ Granitic dyke

■ Dioritic porphyry

■ Psammite

■ Skarn-altered conglomerate

■ Slate/Slate-siltstone breccia

■ Felsic volcanic rock

Whole-rock samples

● Diorite

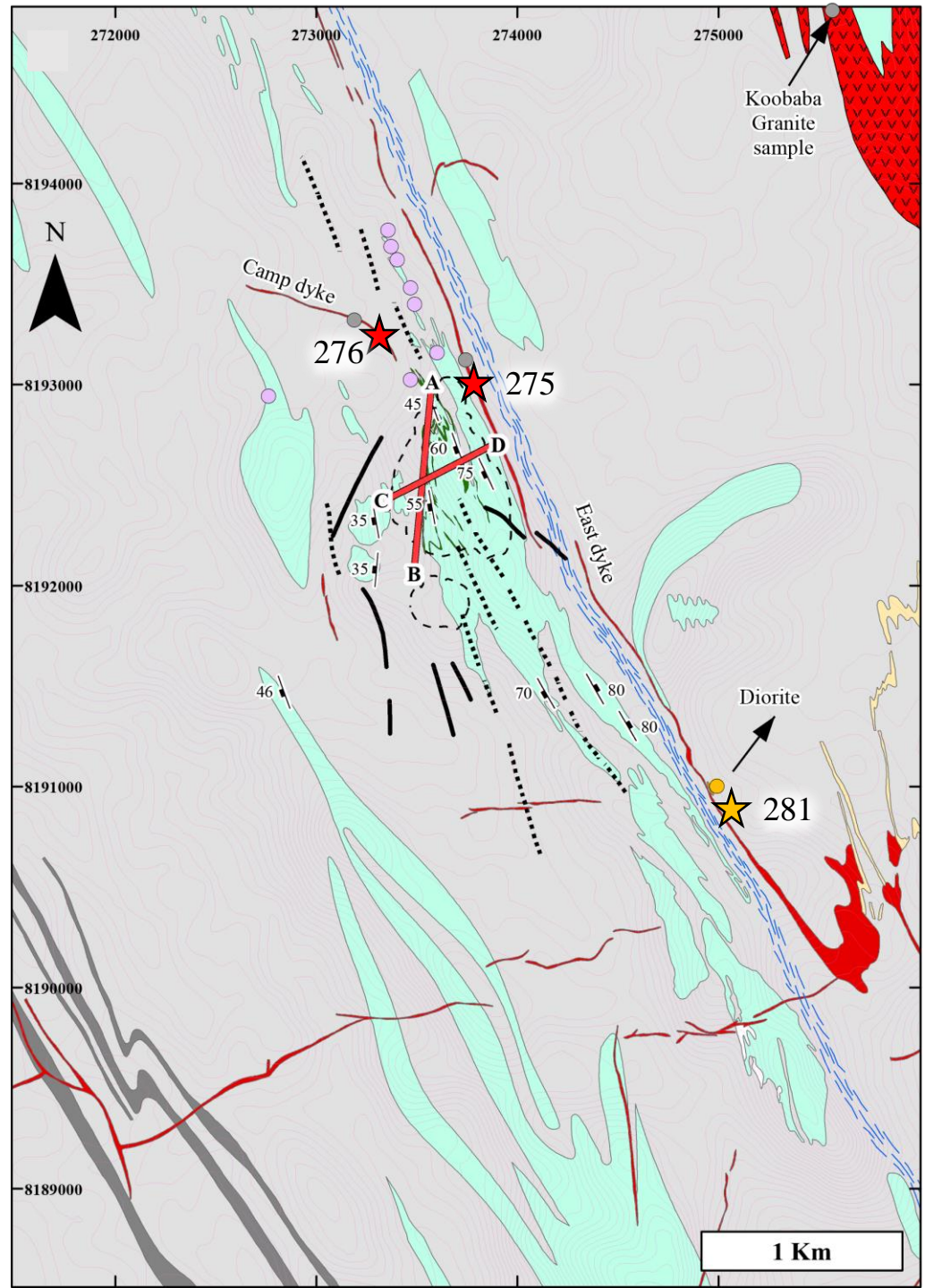
● Granite

● Psammite distal

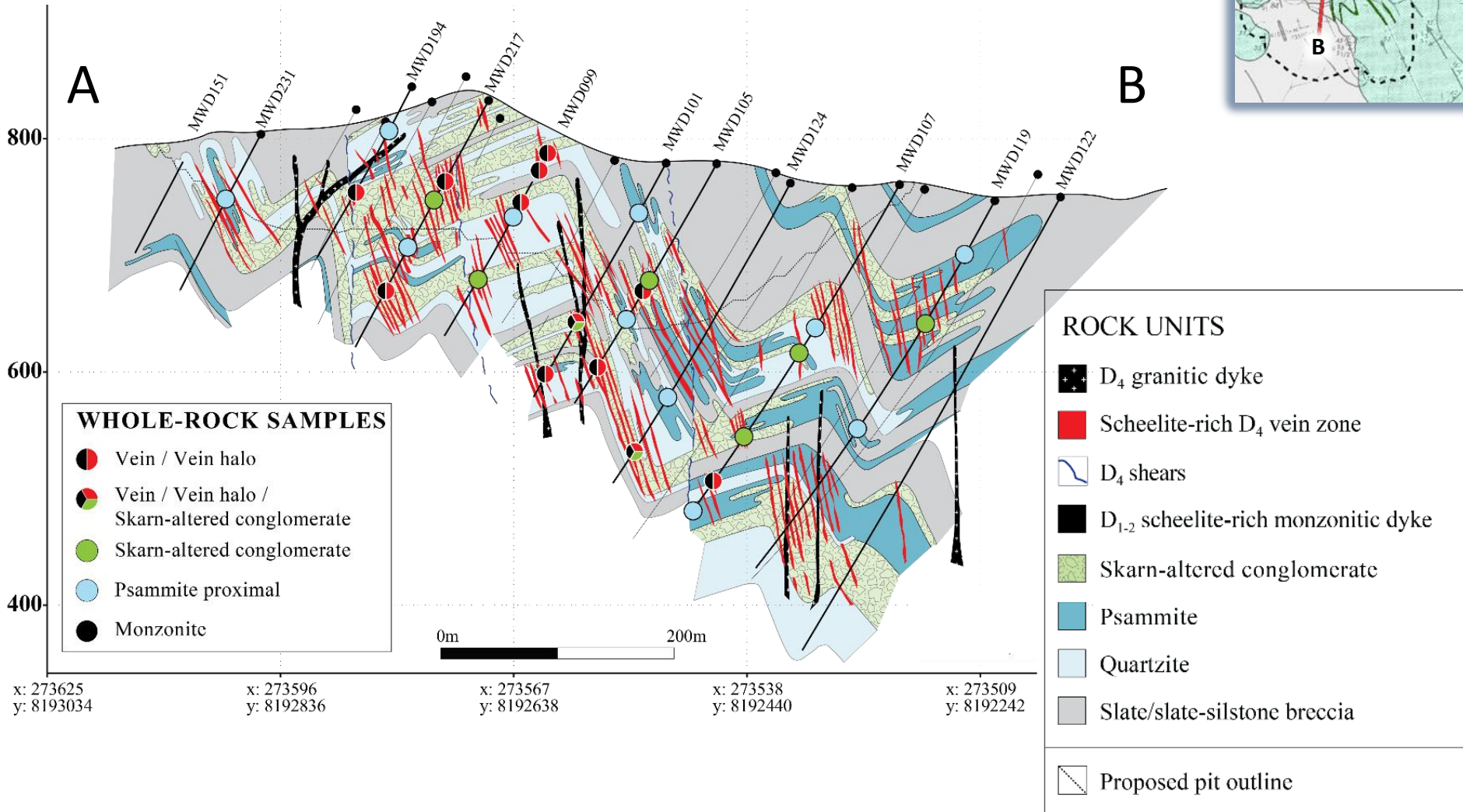
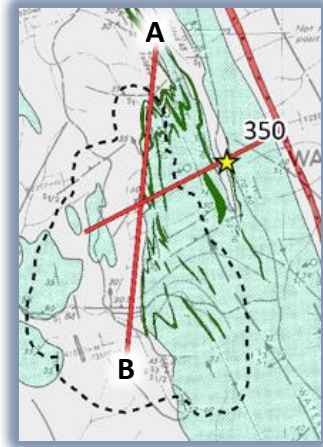
U/Pb dating

★ Granite dyke

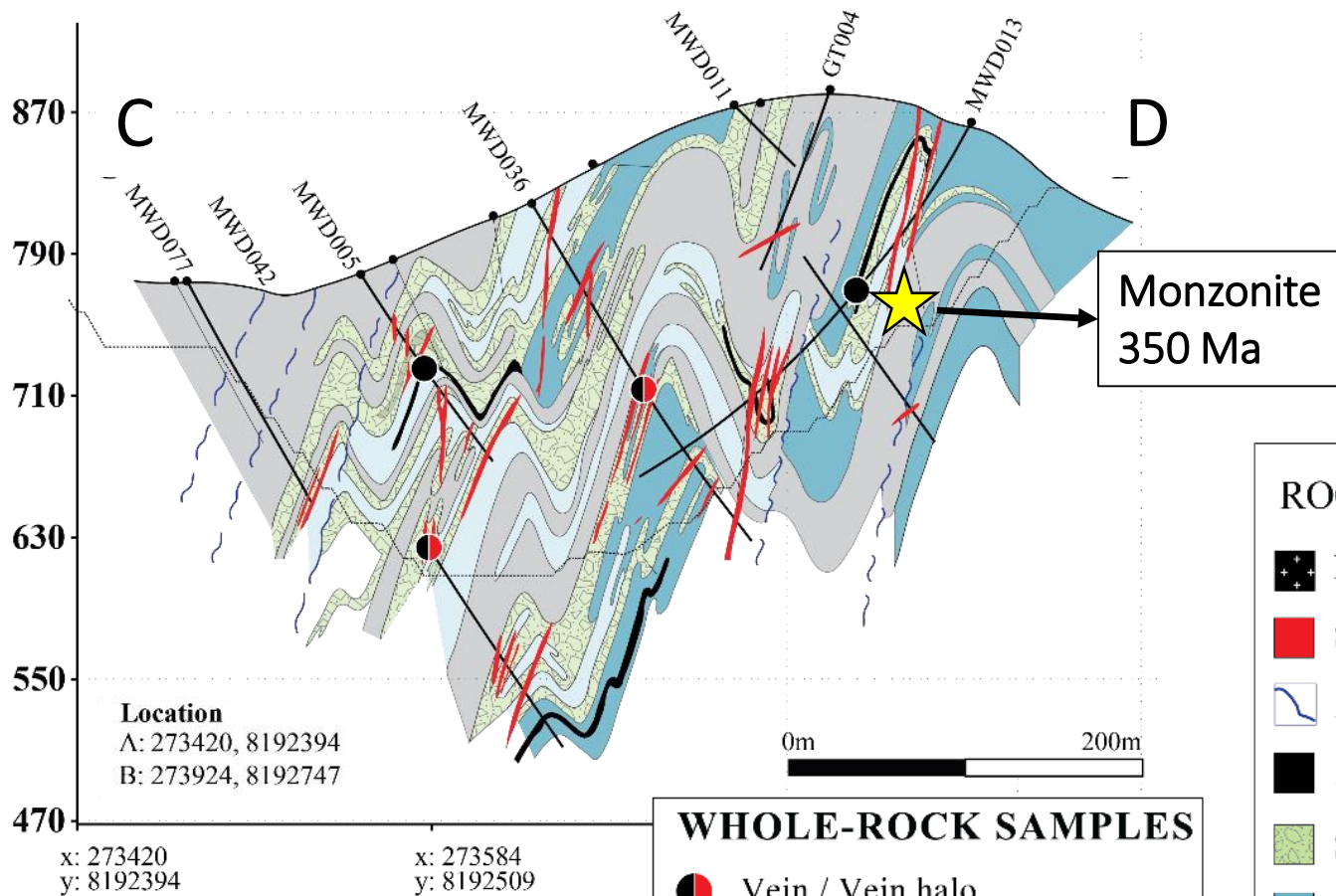
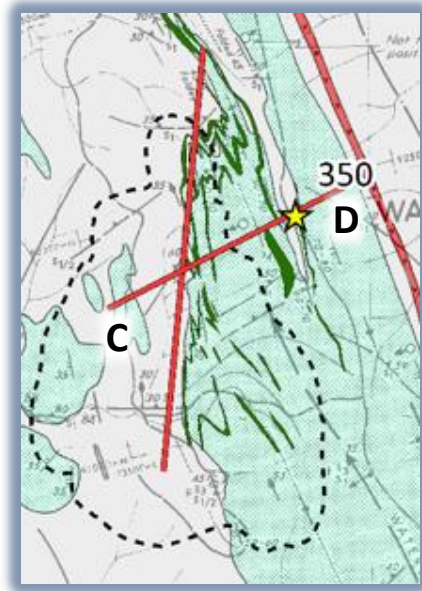
★ Diorite porphyry



Long Section



Cross Section

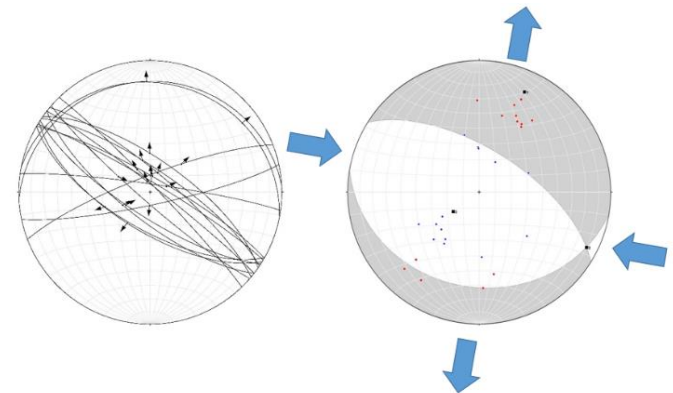
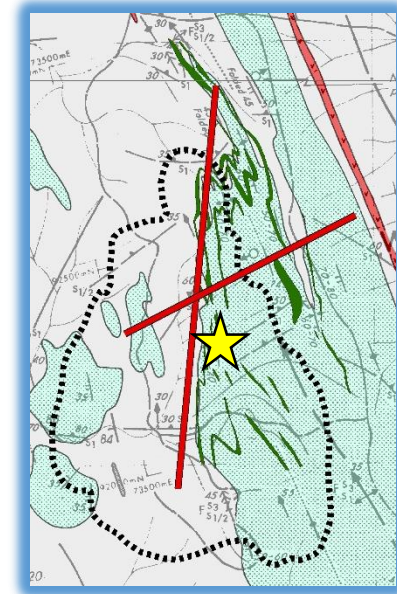
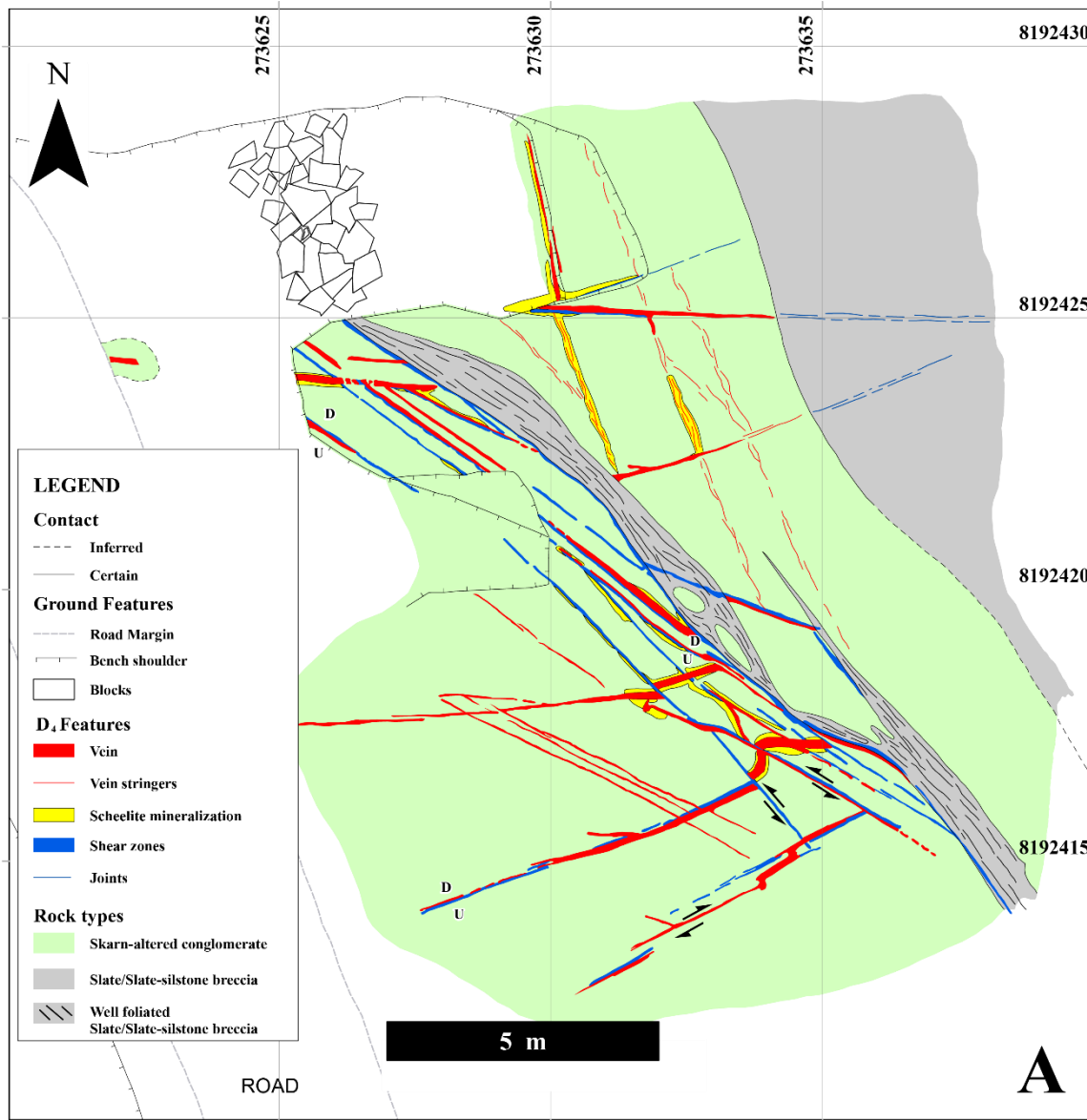


Monzonite
350 Ma

- WHOLE-ROCK SAMPLES**
- Vein / Vein halo
 - Vein / Vein halo / Skarn-altered conglomerate
 - Skarn-altered conglomerate
 - Psammite proximal
 - Monzonite

- ROCK UNITS**
- D₄ granitic dyke
 - Scheelite-rich D₄ vein zone
 - D₄ shears
 - D₁₋₂ scheelite-rich monzonitic dyke
 - Skarn-altered conglomerate
 - Psammite
 - Quartzite
 - Slate/slate-siltstone breccia
 - Proposed pit outline

Outcrop scale map (D₄)

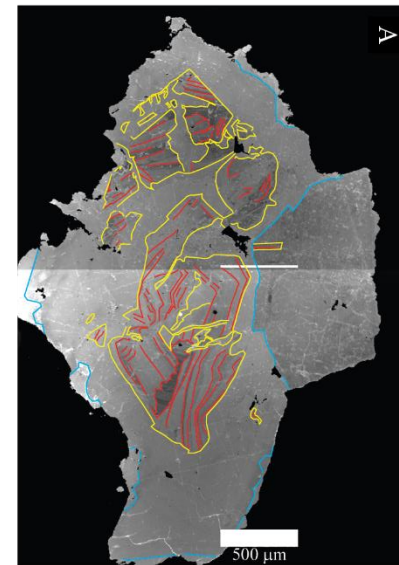


Mineralisation: Scheelite

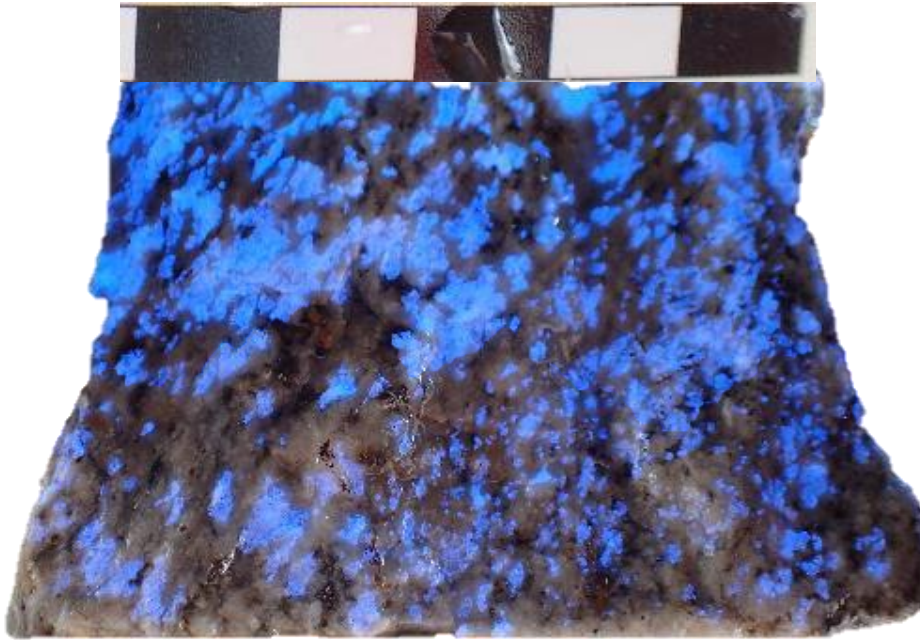


➤ Scheelite in:

- Quartz-plagioclase veins and vein haloes
- Skarn-altered conglomerate
- Monzonite



Early scheelite during ductile deformation (D_{1-2})



MWD013-099

Scheelite in monzonitic dyke (350 Ma U/Pb), pre D_3

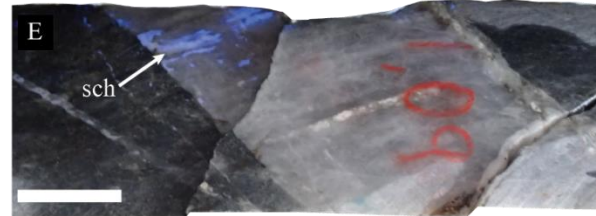
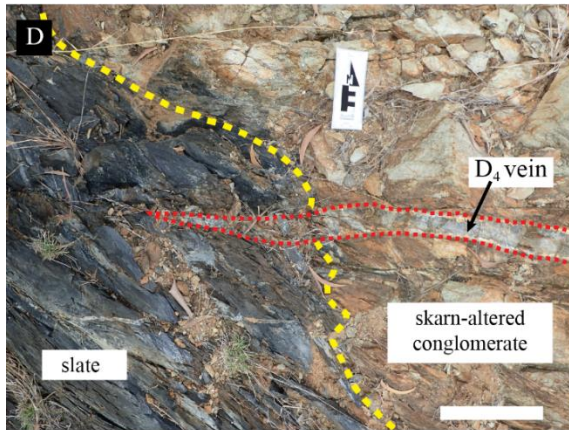


MWD011-147.5

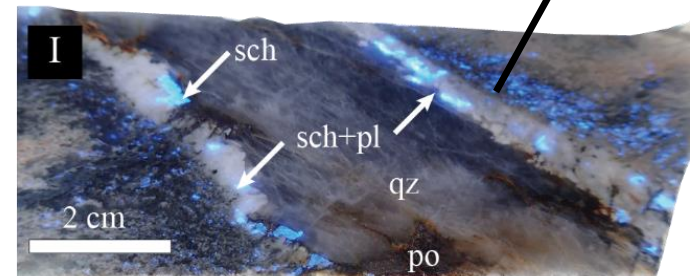
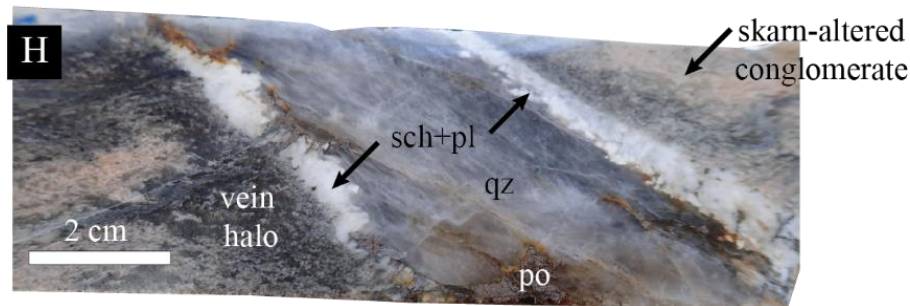


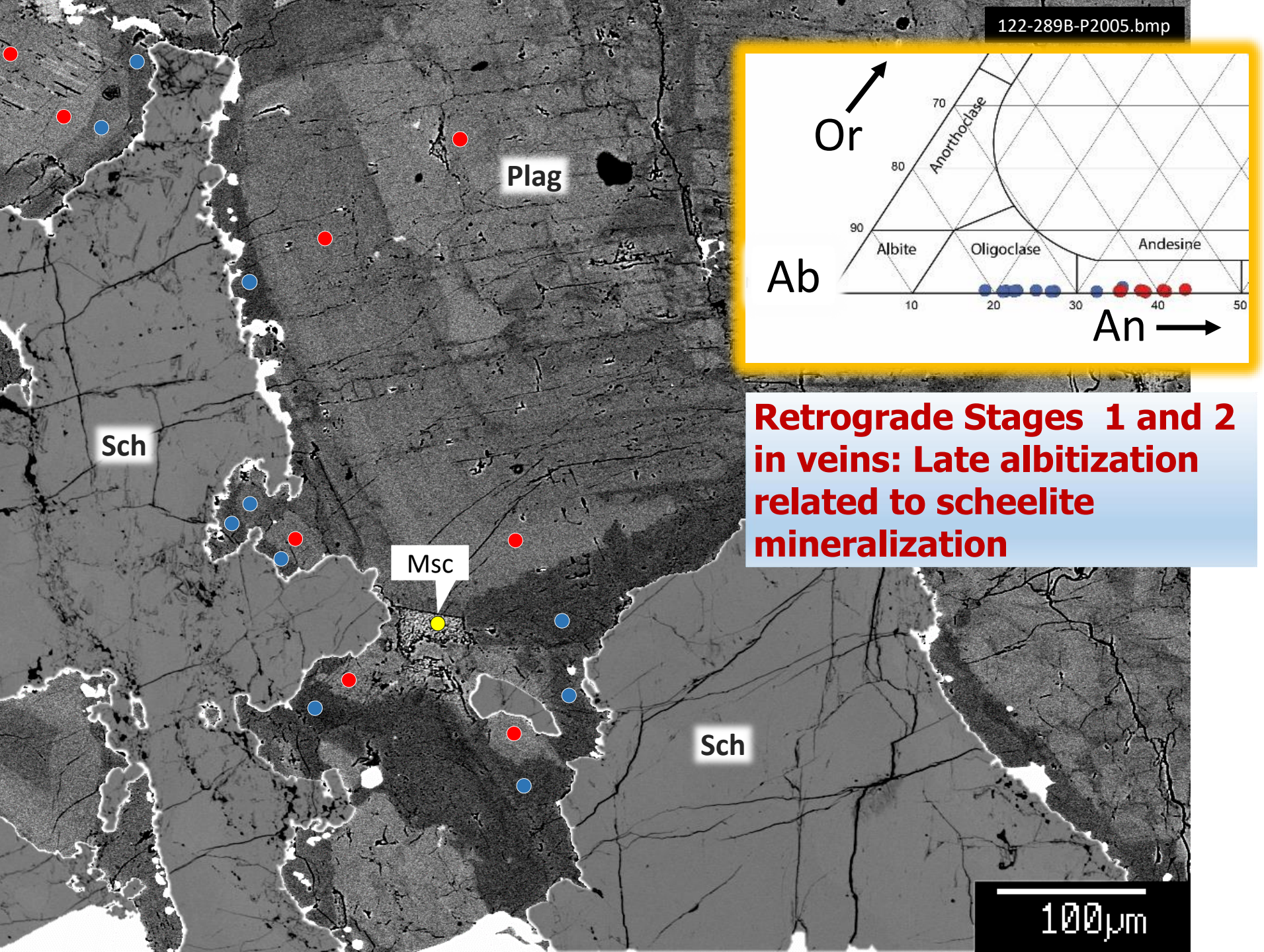
Scheelite in skarn-altered conglomerate

Late scheelite during brittle-ductile deformation (D_4)



Ar-Ar muscovite
in vein halo
275 Ma





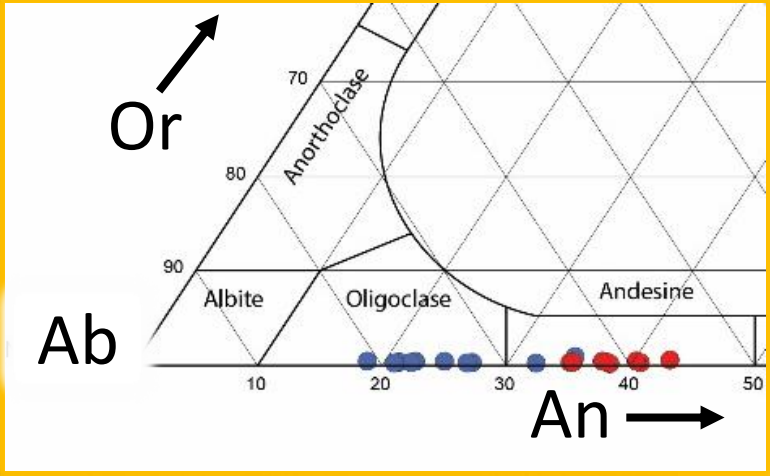
Plag

Sch

Msc

Sch

**Retrograde Stages 1 and 2
in veins: Late albitization
related to scheelite
mineralization**



100µm

**Widespread D₄ clinozoisite
pseudomorphing D₁₋₃ garnet**

Ti

Cz

Ti

Gt

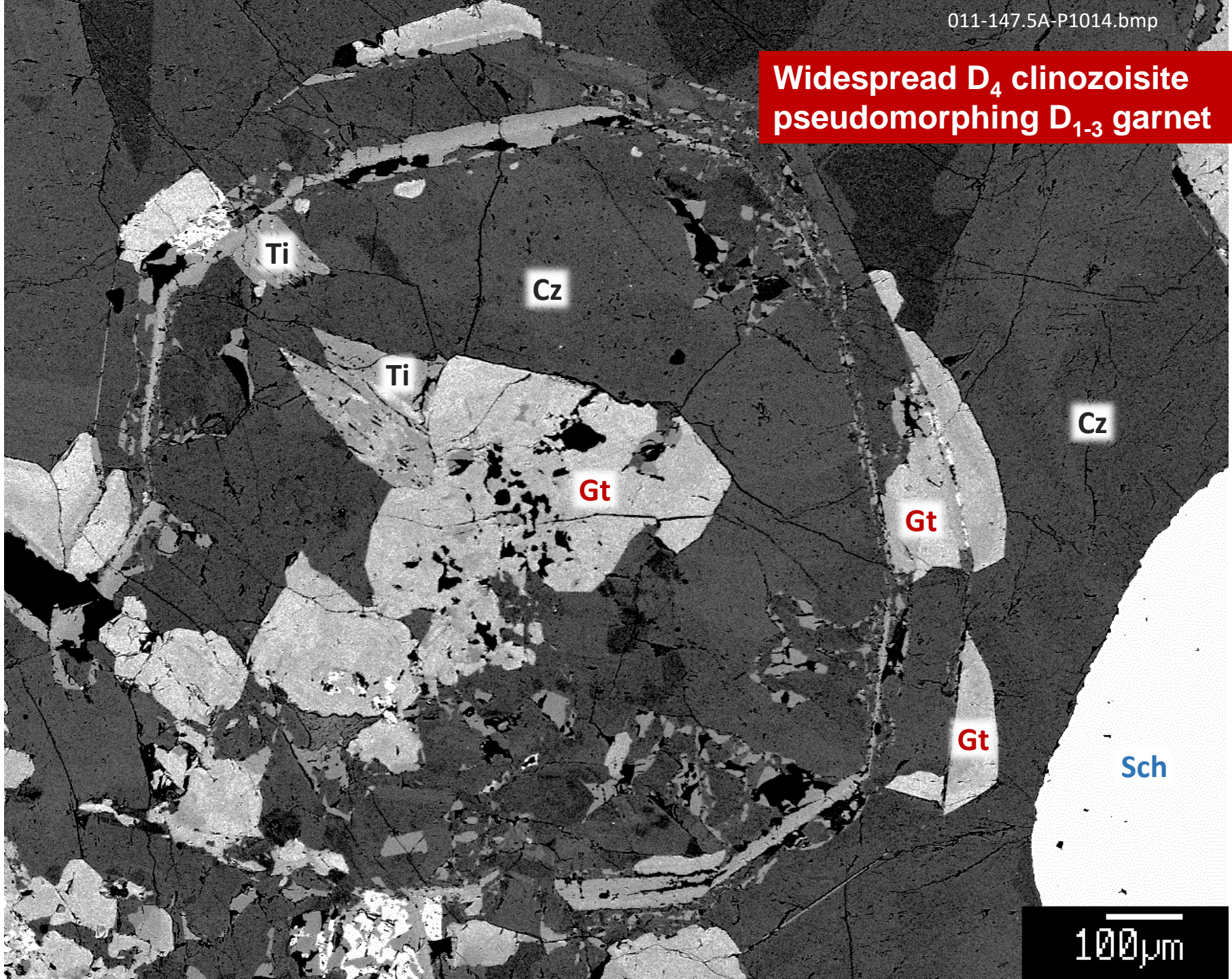
Cz

Gt

Gt

Sch

100µm

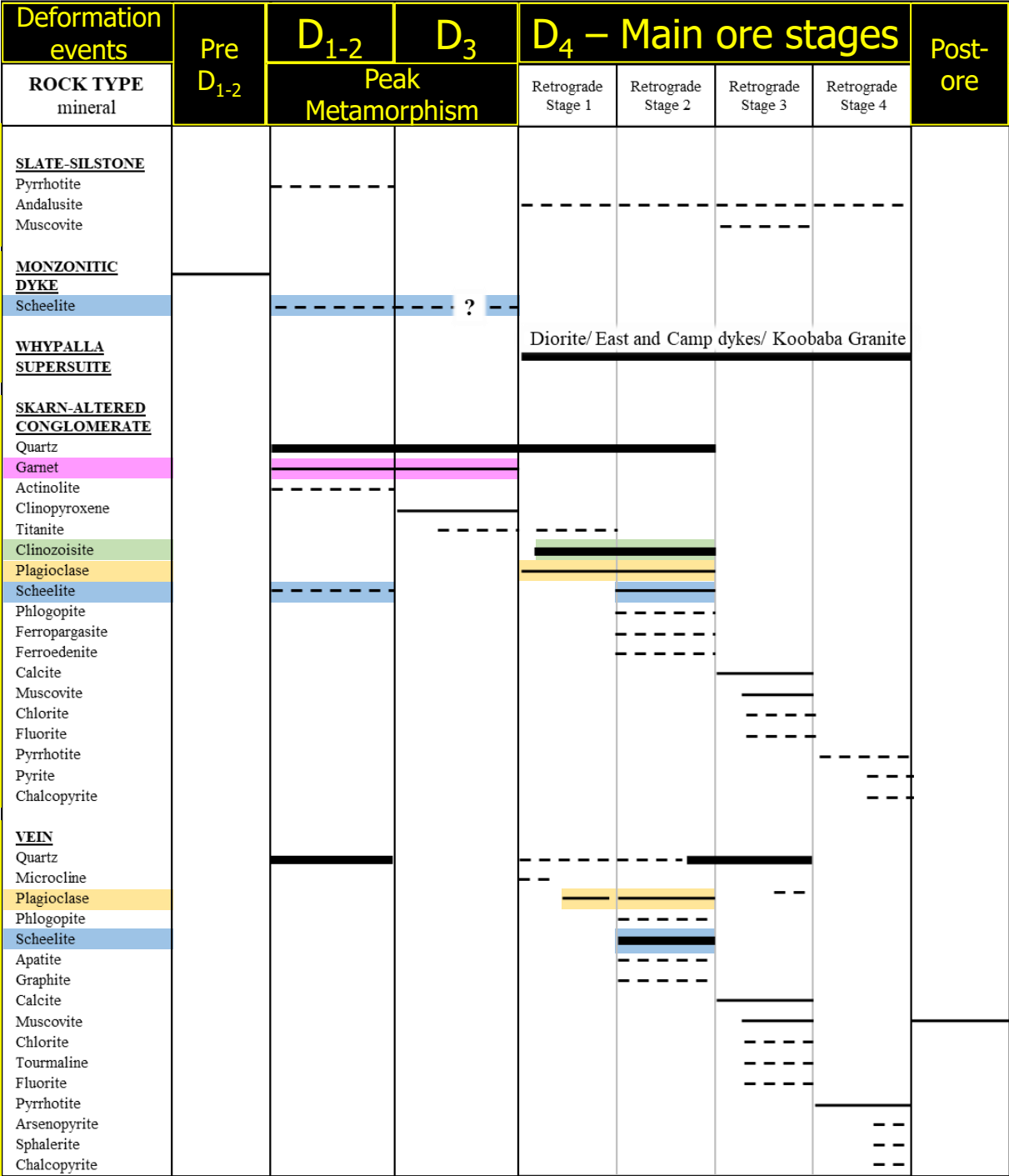


Shale

Intr.

Skarn-altered congl.

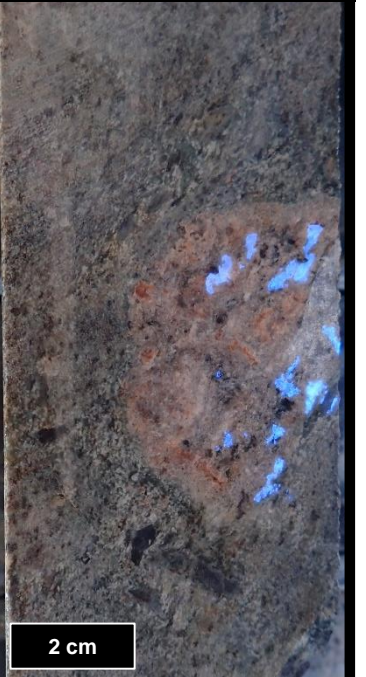
Vein



Garnet replaced by
scheelite in skarn-altered
conglomerate



MWD011-147.5
bottom: under UV light



2 cm

Watershed's geochemical footprint and fingerprint

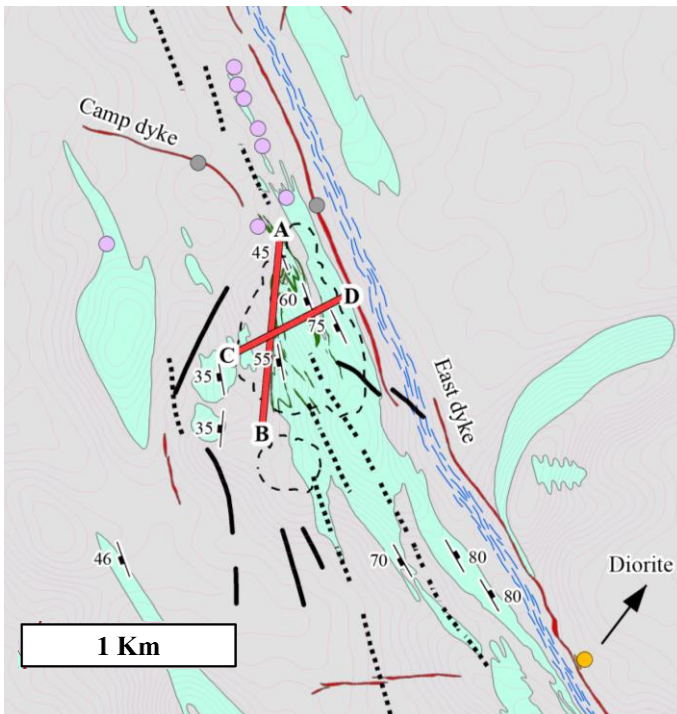
MWD124-266

VEIN
N=14

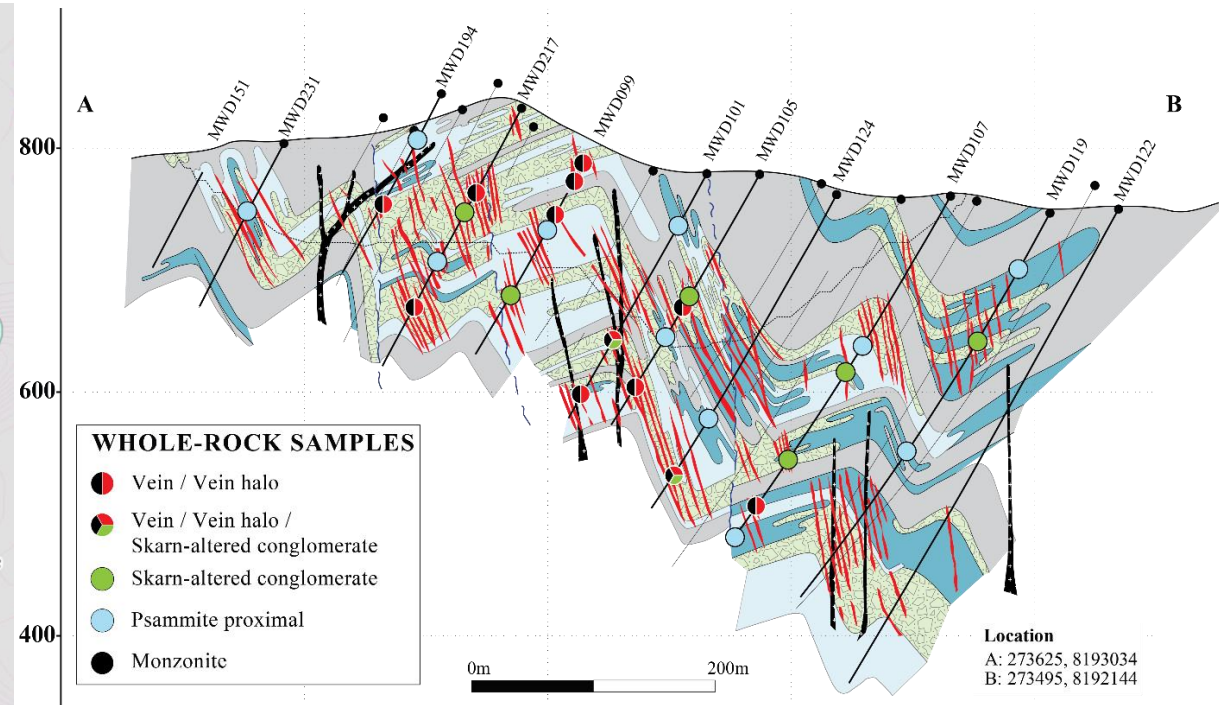
VEIN HALO
N=14

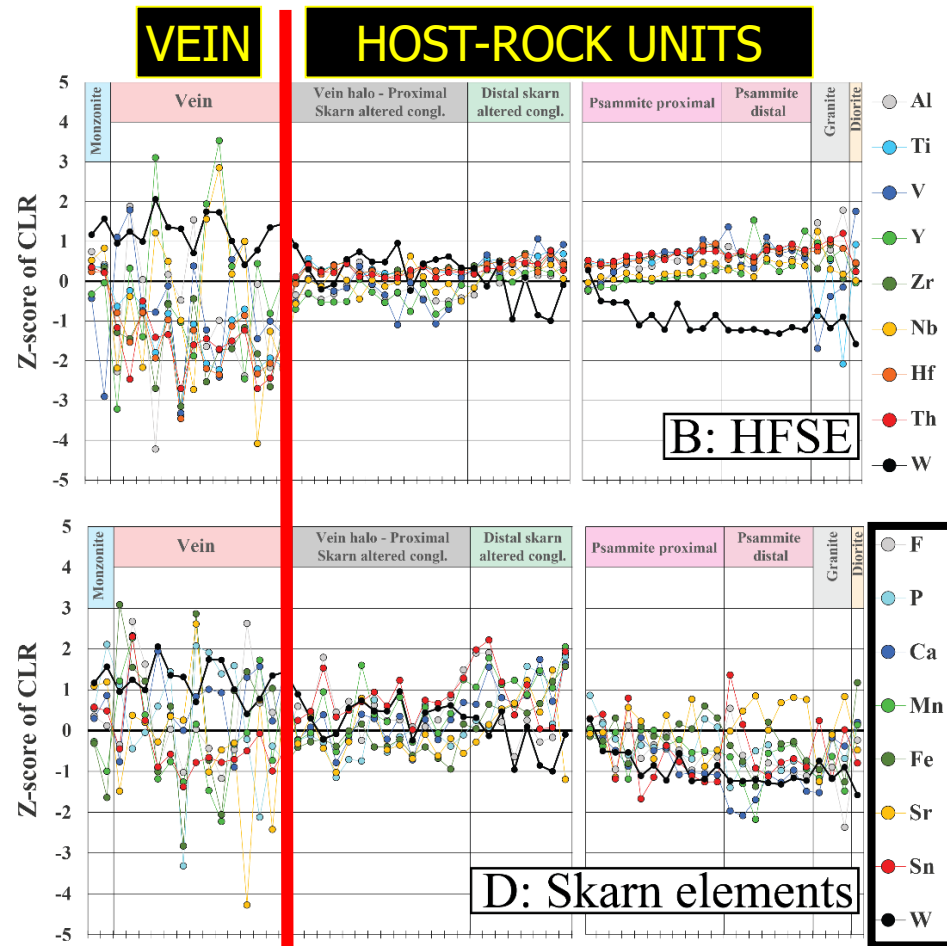
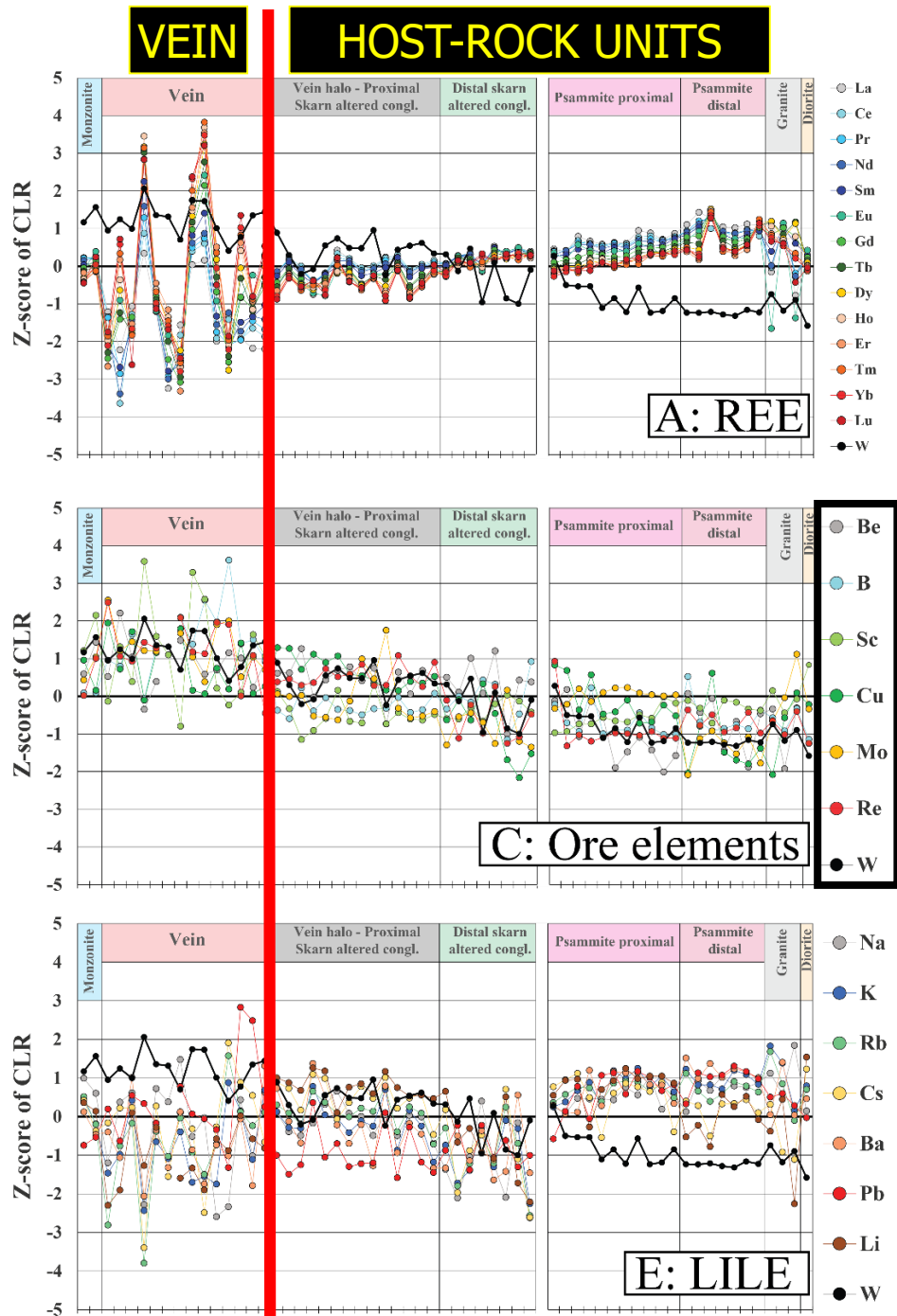
SKARN-ALTERED CONGLOMERATE
N=8

4 cm



PSAMMITE DISTAL N=9
PSAMMITE PROXIMAL N=11

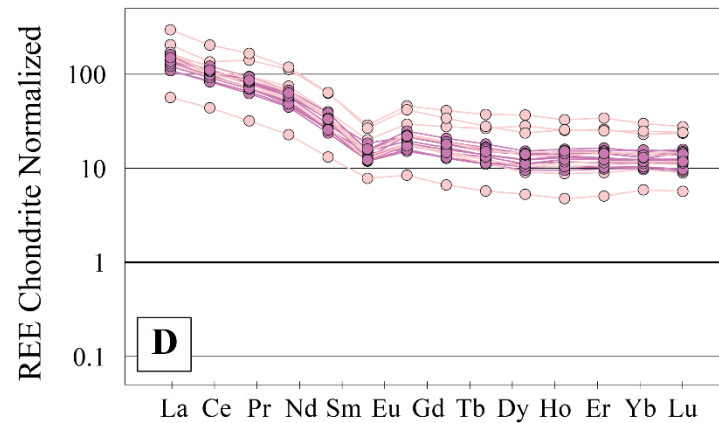
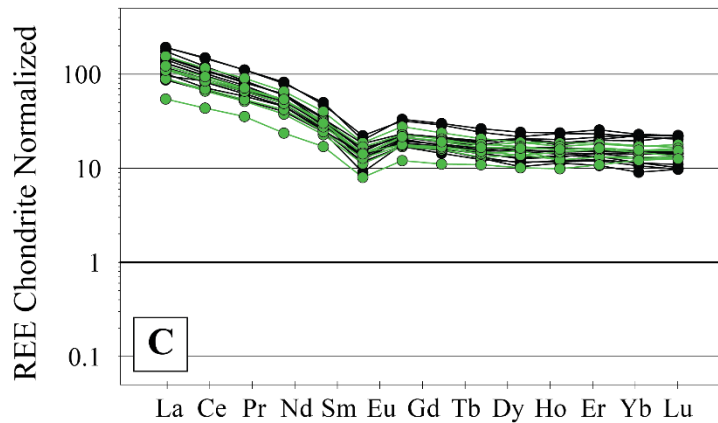
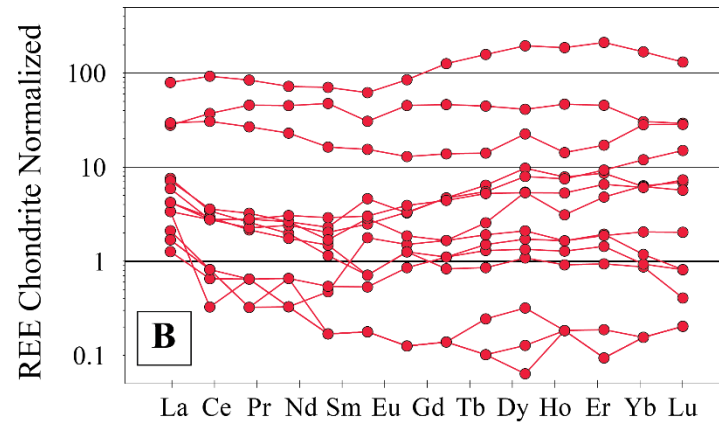
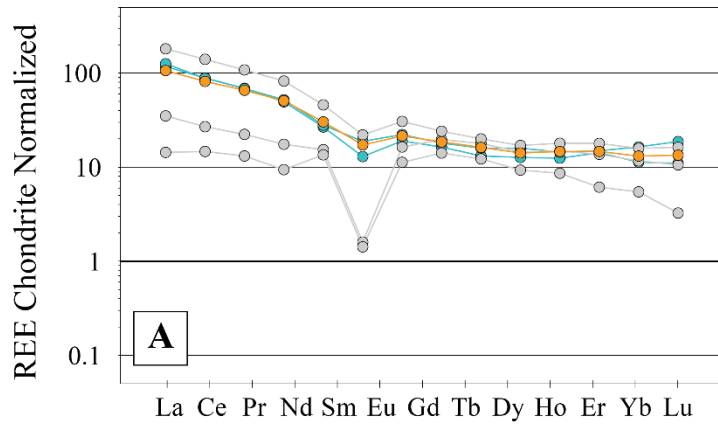




Whole-rock geochemistry

- Z-score of centred log ratio (CLR) (Aitchinson, 1982)
- Elements grouped by similar behaviour among rock types

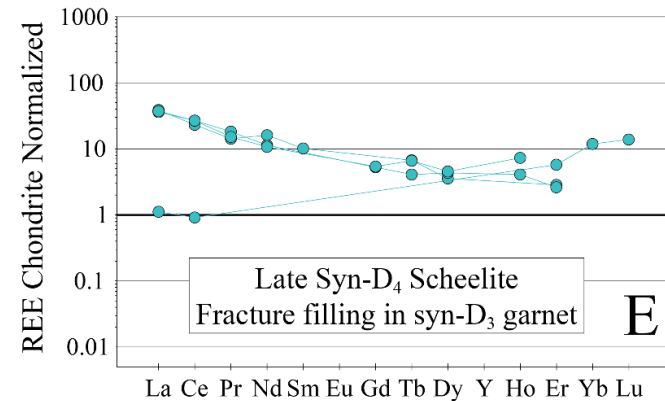
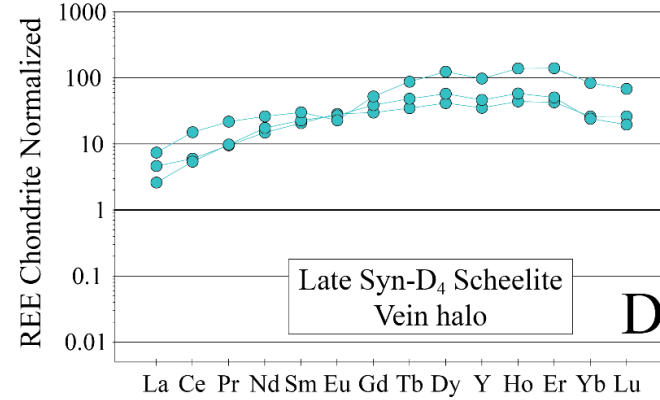
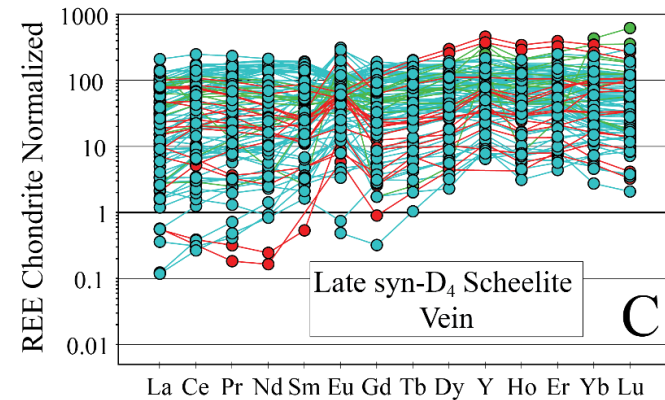
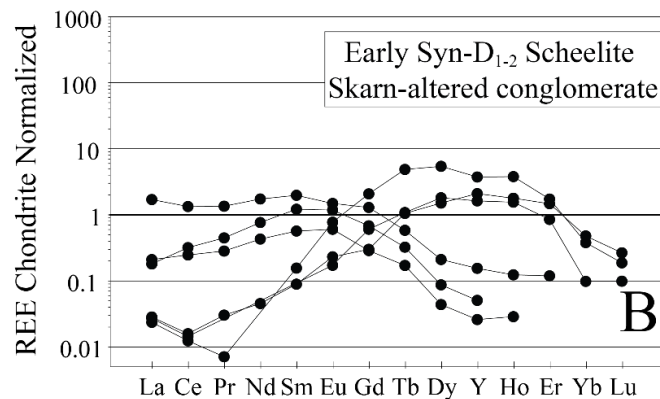
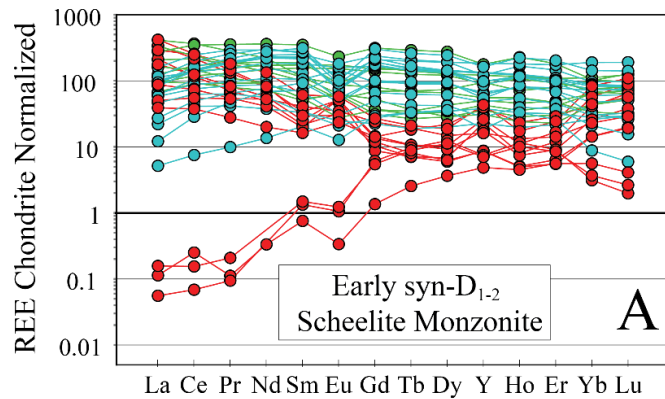
Whole-rock REE spider diagrams



LEGEND

- | | | | |
|---|---|--|--|
| ● Psammite Distal | ● Skarn-altered conglomerate | ● D ₄ Vein | ● D ₄ Diorite |
| ● Psammite Proximal | ● Vein halo (skarn proximal) | ● D ₁₋₂ Monzonite | ● D ₄ Granite |

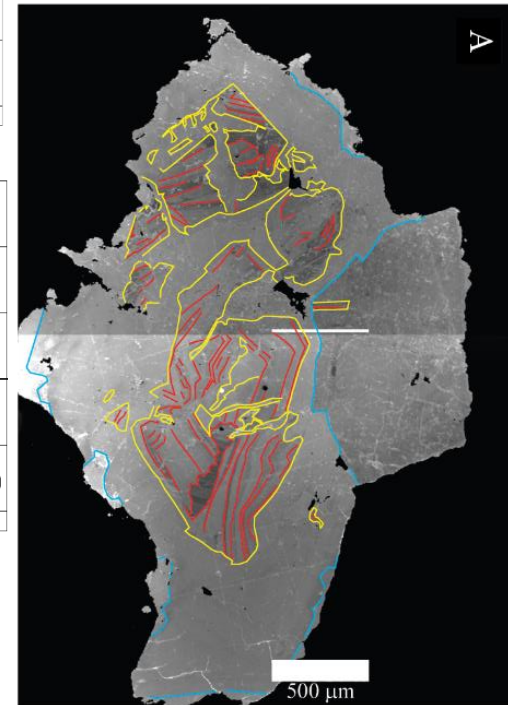
Scheelite REE patterns



LEGEND

Scheelite mineral zone

- Grains with no zoning
- Core of grain
- Grain with growth zoning (overgrowing core)
- Unstructured overgrowth



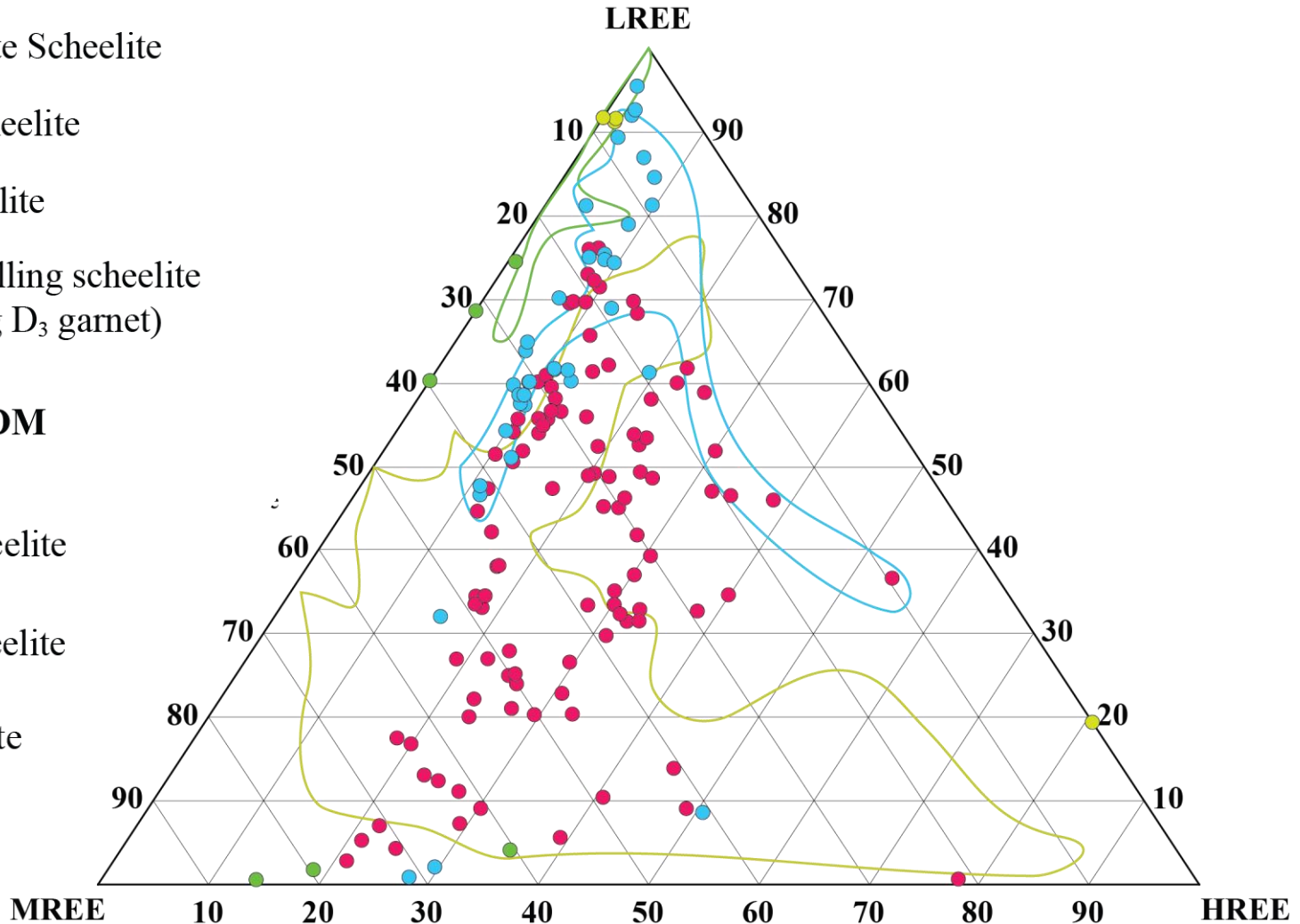
Intrusive vs metamorphic hydrothermal scheelite

WATERSHED SCHEELITE

- D₁₋₂ monzonite Scheelite
- D₁₋₂ skarn scheelite
- D₄ vein scheelite
- D₄ fracture-filling scheelite (cross-cutting D₃ garnet)

SCHEELITE FROM LITERATURE

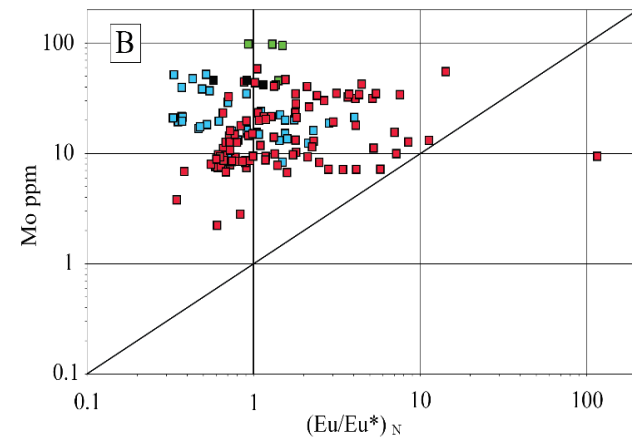
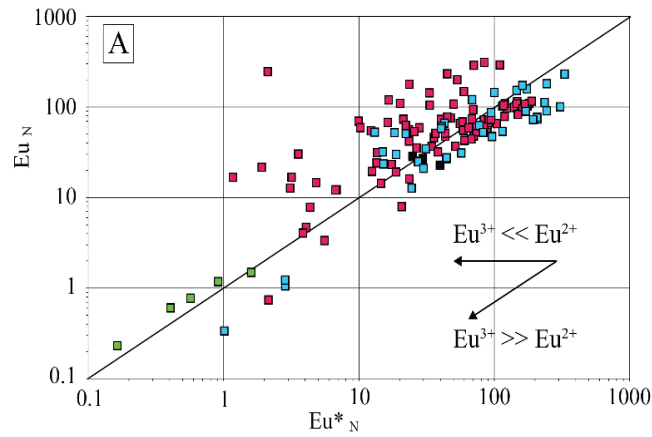
- Intrusive scheelite
- Lode Au scheelite
- Skarn scheelite



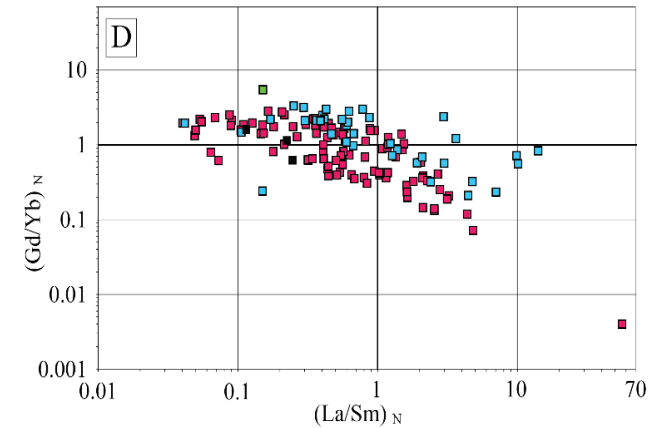
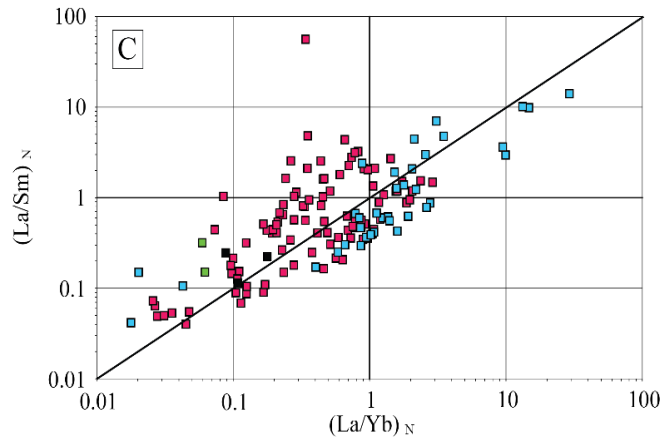
- Granite: Raimbault et al 1993; Sun and Chen, 2017
- Lode gold: Ghaderi et al 1999; Dostal et al 2009; Hazarika et al 2016; Cave et al 2017
- Skarn: Raimbault et al 1993; Song et al 2014; Fu et al 2017

- LREE = La+Ce+Pr+Nd
- MREE = Sm+Eu+Gd+Tb+Dy
- HREE = Ho+Er+Yb+Lu

Redox proxy:



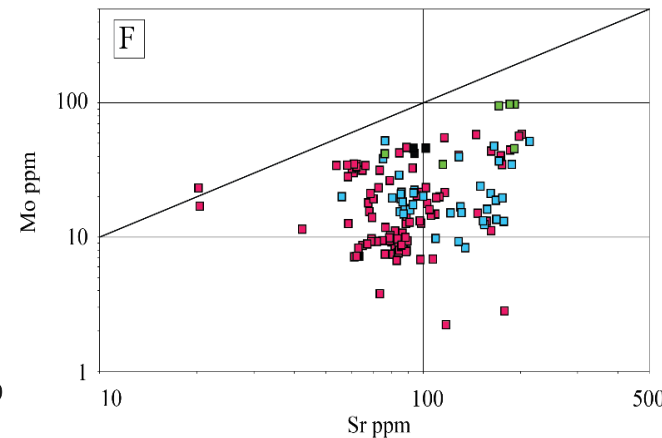
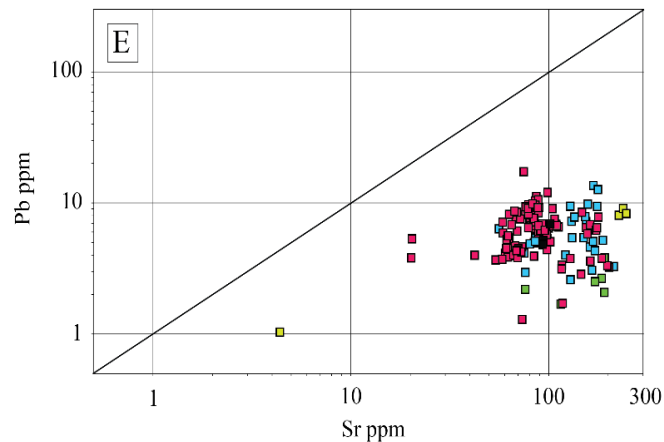
Two types of scheelite:



LEGEND

WATERSHED SCHEELITE

- D_{1-2} monzonite
- D_{1-2} skarn-altered conglomerate
- D_4 vein
- D_4 vein halo
- D_4 fracture-filling (cross-cutting D_3 garnet)



Concluding remarks

- Ternary REE plot for scheelite compositions from Watershed differentiates between the various scheelite types:
 - Carboniferous D₁₋₂ scheelite in monzonite is magmatic-hydrothermal in origin
 - Permian D₄ scheelite in veins consistent with a hydrothermal origin
- **Redox** conditions from **scheelite Eu anomalies and Mo content. Early D₁₋₂ scheelite** from relatively **oxidized fluids**, while **late D₄ scheelite** in veins **shift to more reduced conditions** → interaction of mineralizing fluids with reduced host-rock.
- Hydrothermal fluids that introduced **W**, also introduced **Be, B, Sc, Cu, Mo and Re (fingerprint)**. These fluids leached REE+Y, Nb, Ca, F, P, Fe and Sr from skarn-altered conglomerate
- **Regional footprint** (i.e., 100 m scale) preserved in psammite include **W, Cu, Mo, Ca, Fe, Mn and Li on approaching Watershed**



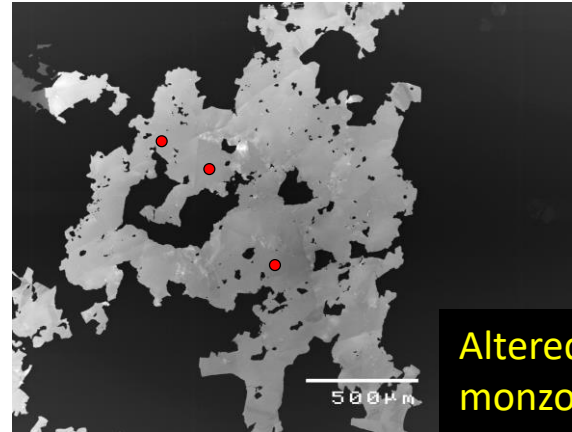
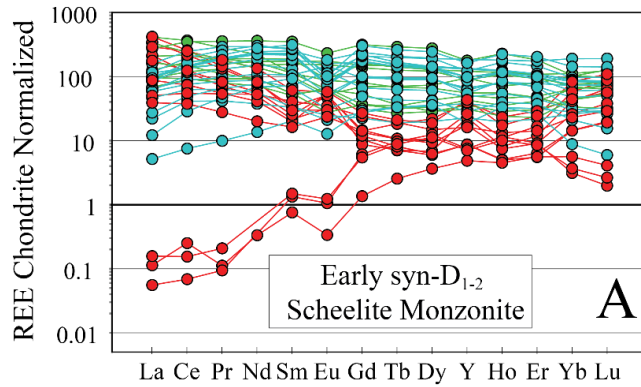
THANK YOU!



From Watershed – Looking NNW



D₁₋₂ mineral trace element analysis

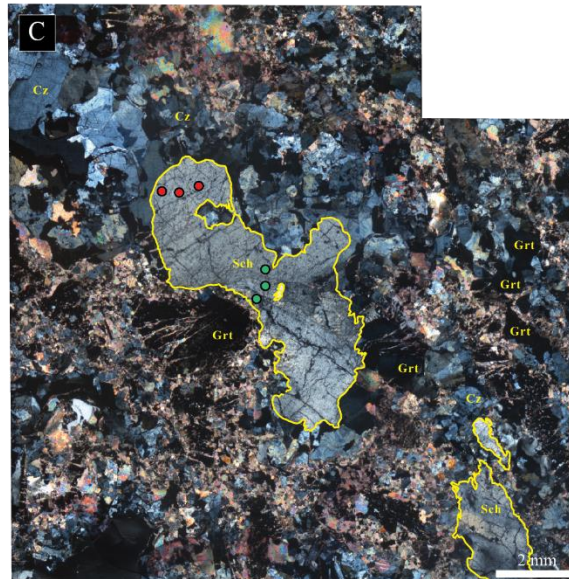
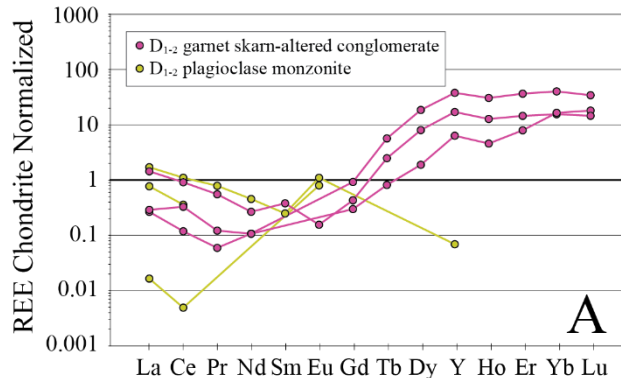
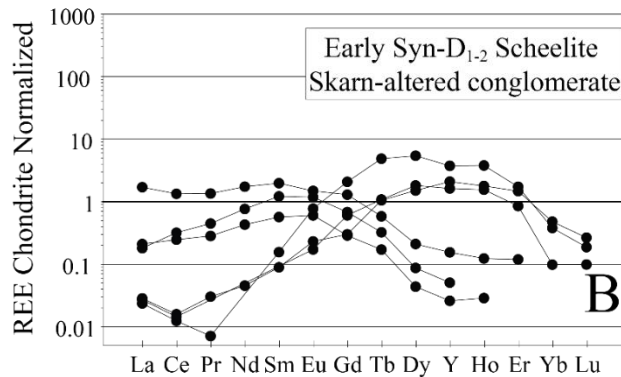


LEGEND

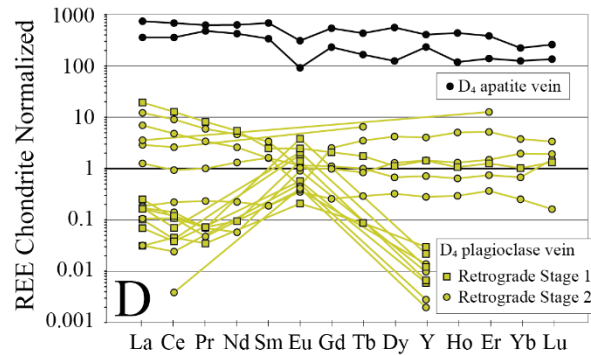
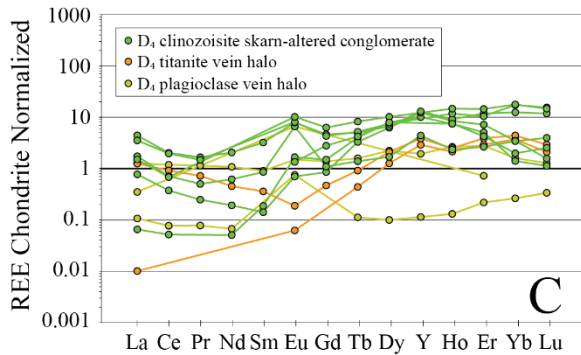
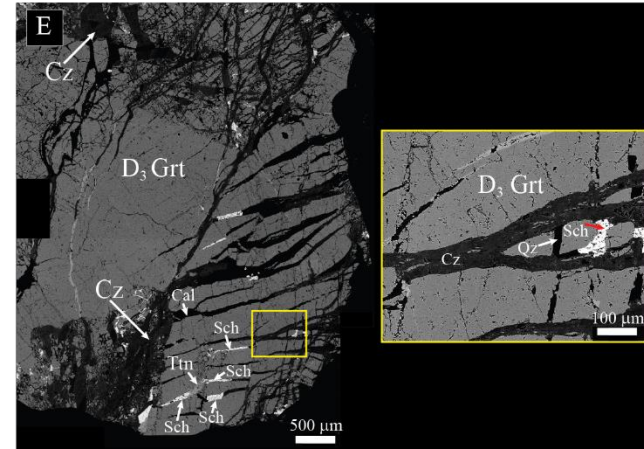
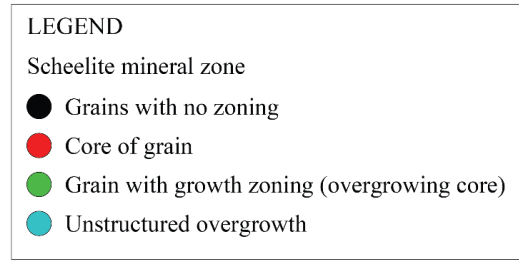
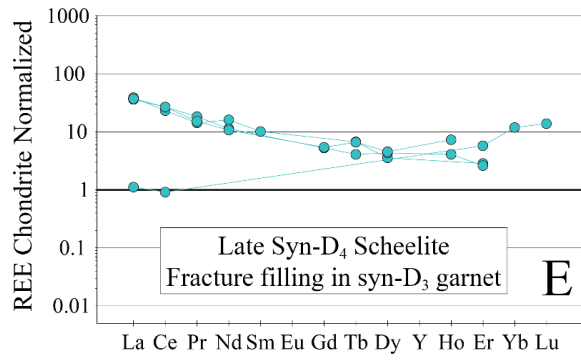
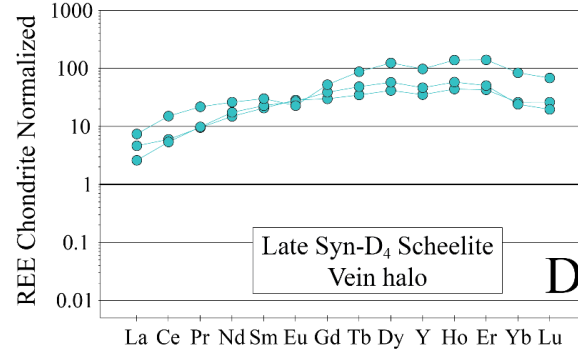
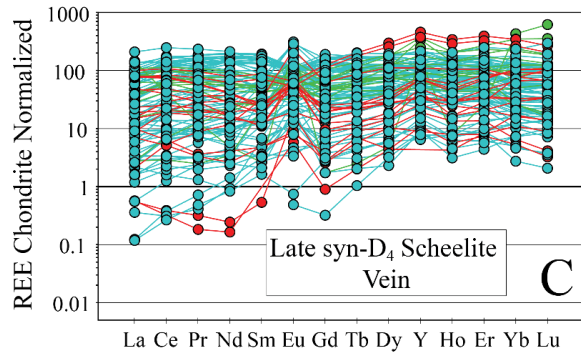
Scheelite mineral zone

- Grains with no zoning
- Core of grain
- Grain with growth zoning (overgrowing core)
- Unstructured overgrowth

Altered scheelite in monzonitic dyke



Mineral trace element analysis



Host-rock: Hodgkinson Fm



➤ Slate / Slate breccia



➤ Quartzite / Grit



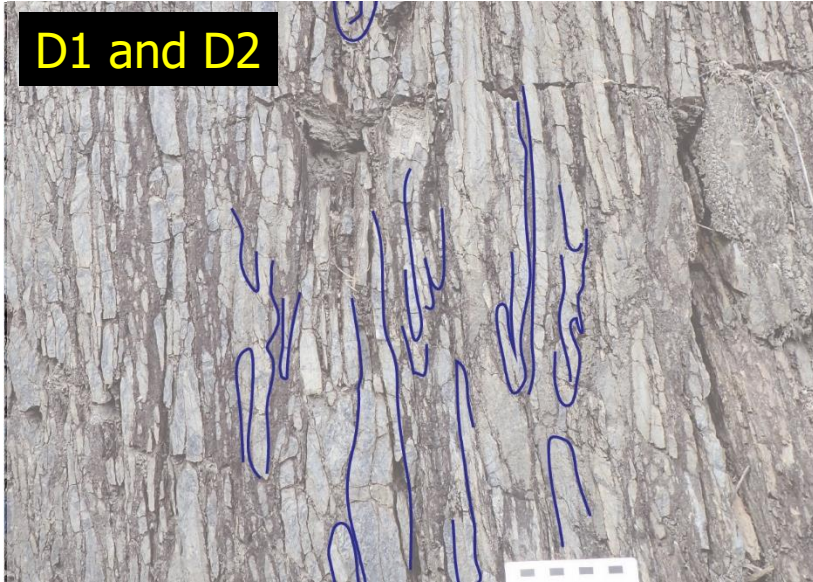
➤ Psammite



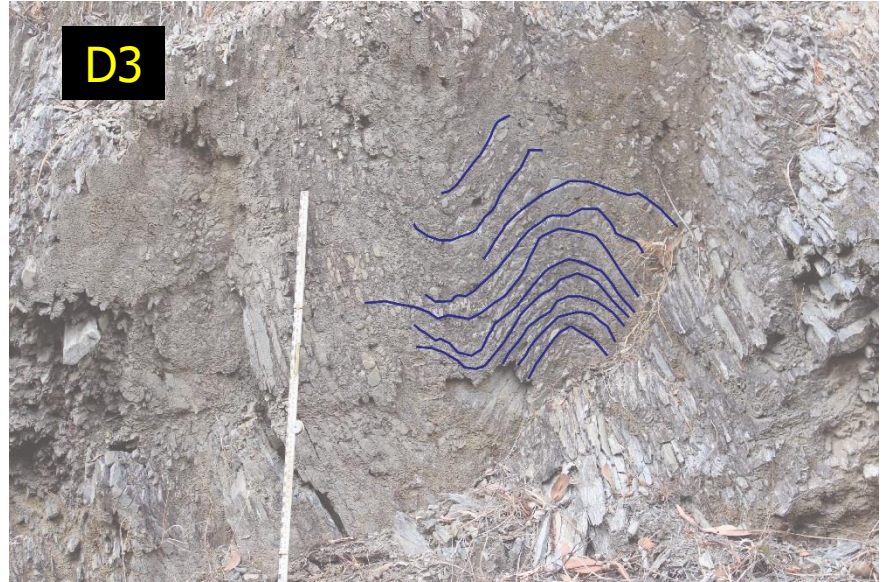
➤ Conglomerate

Deformation Events

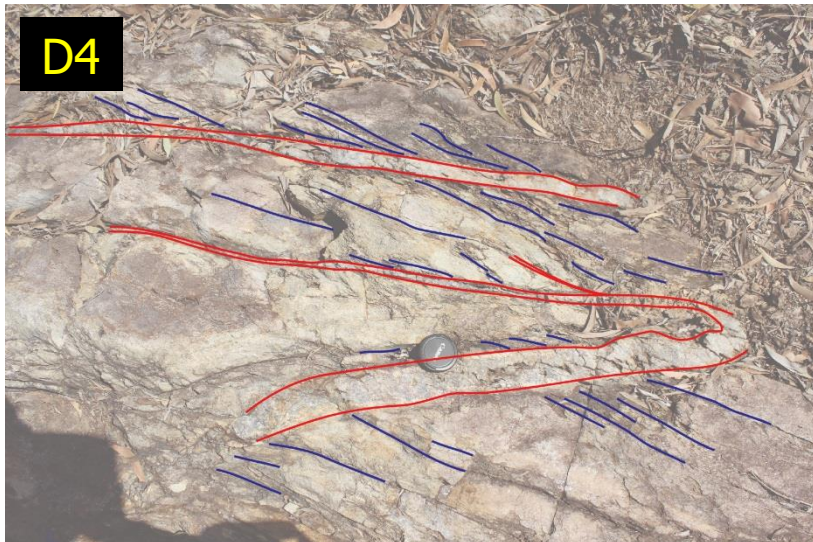
D1 and D2



D3

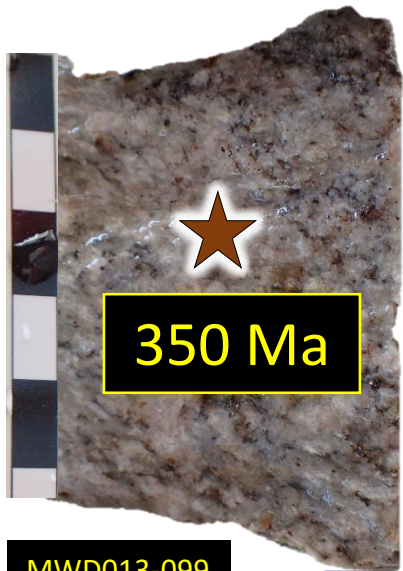


D4

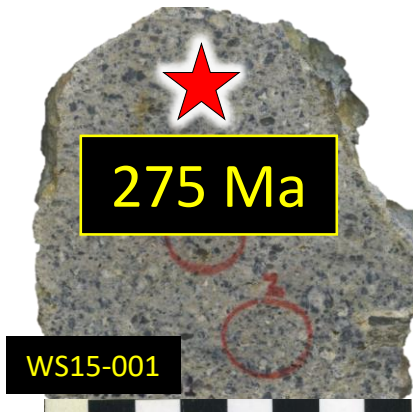
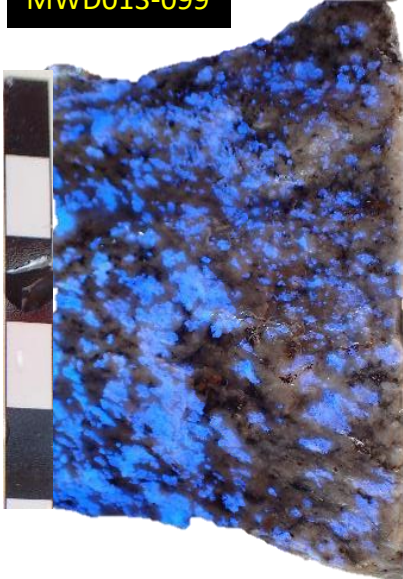


- D1 and D2, isoclinal, transposition
- D3 open folds, crenulation
- D4 shear
- COLINEARITY

INTRUSIVE ROCKS



MWD013-099



WS15-001



WS16-002



WS15-017



WS15-005






➤ Monzonitic dyke

➤ Dioritic body

➤ Granitic dyke

➤ Koobaba Granite

Summary of Geochron

-  $^{40}\text{Ar}-^{39}\text{Ar}$ Muscovite
-  U/Pb Titanite
-  U/Pb Granites
-  U/Pb Diorite
-  U/Pb Monzonite

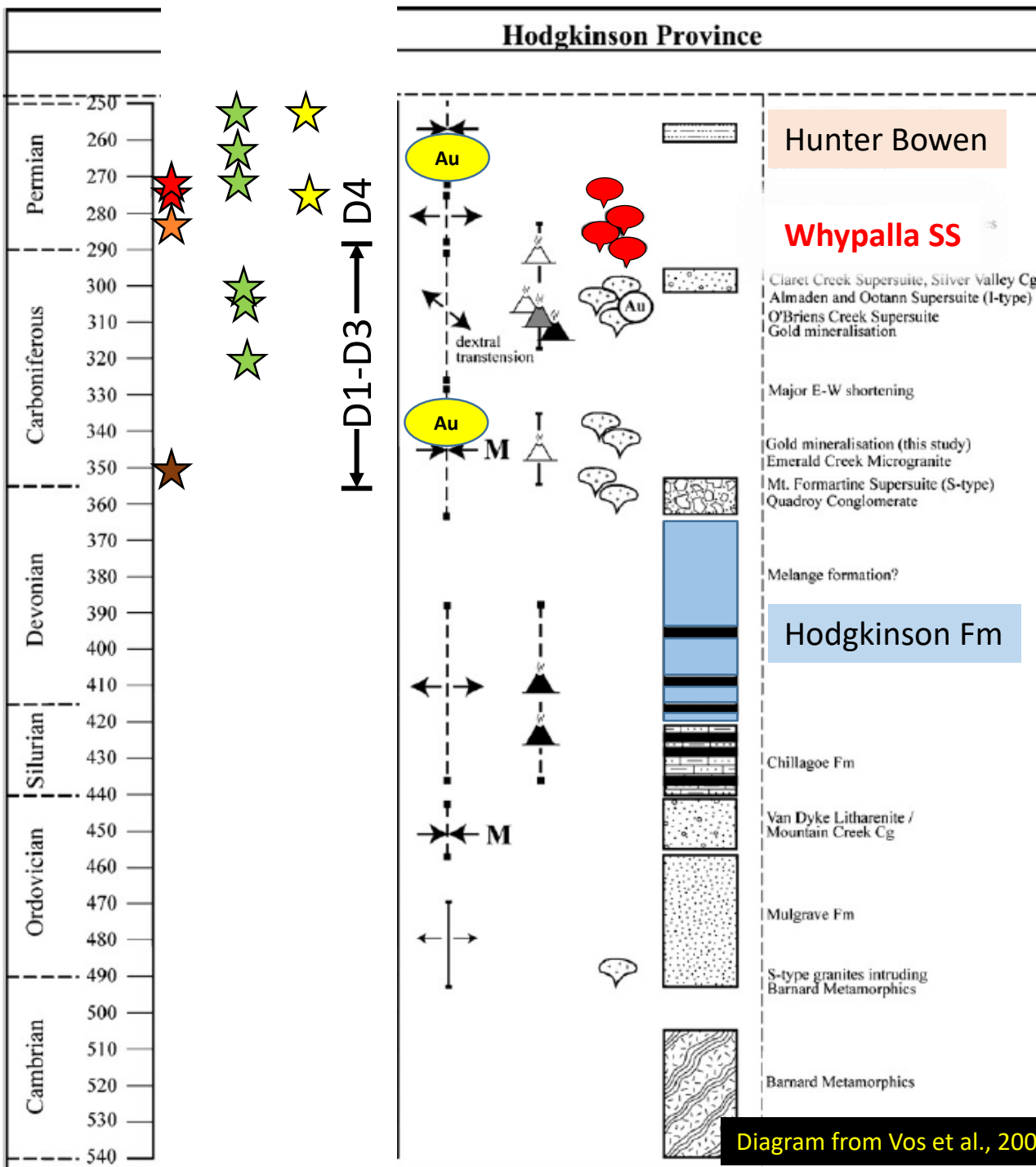














Diagram from Vos et al., 2007

LEGEND	
	Compression
	Extension
	Magmatism
	Felsic volcanism
	Intermediate volcanism
	Mafic volcanism
	Gold deposition
	Metamorphism
	Metamorphic rocks
	Basalts interspersed with sediments and volcanoclastics
	Mixed shallow-marine sediments
	Deep-marine sediments