Future Potential for metal Resources From Black Shales: Ni, Mo, Zn, Cu, U, V, Ag, Au, PGE

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University of Tasmania

Oxidized Vs Reduced Basins

- OXIDIZED Basins produce stratiform Cu-Co, Zn-Pb and U
- REDUCED Basins produce Au-As, P, Ba and metalliferous black shales (Ni, Mo, Zn, Cu, U, PGE)

Pyritic Black Shales are King!

Sources of Ni, Mo, As, Zn, Cu, Co, U, V, Ag, Au, PGE

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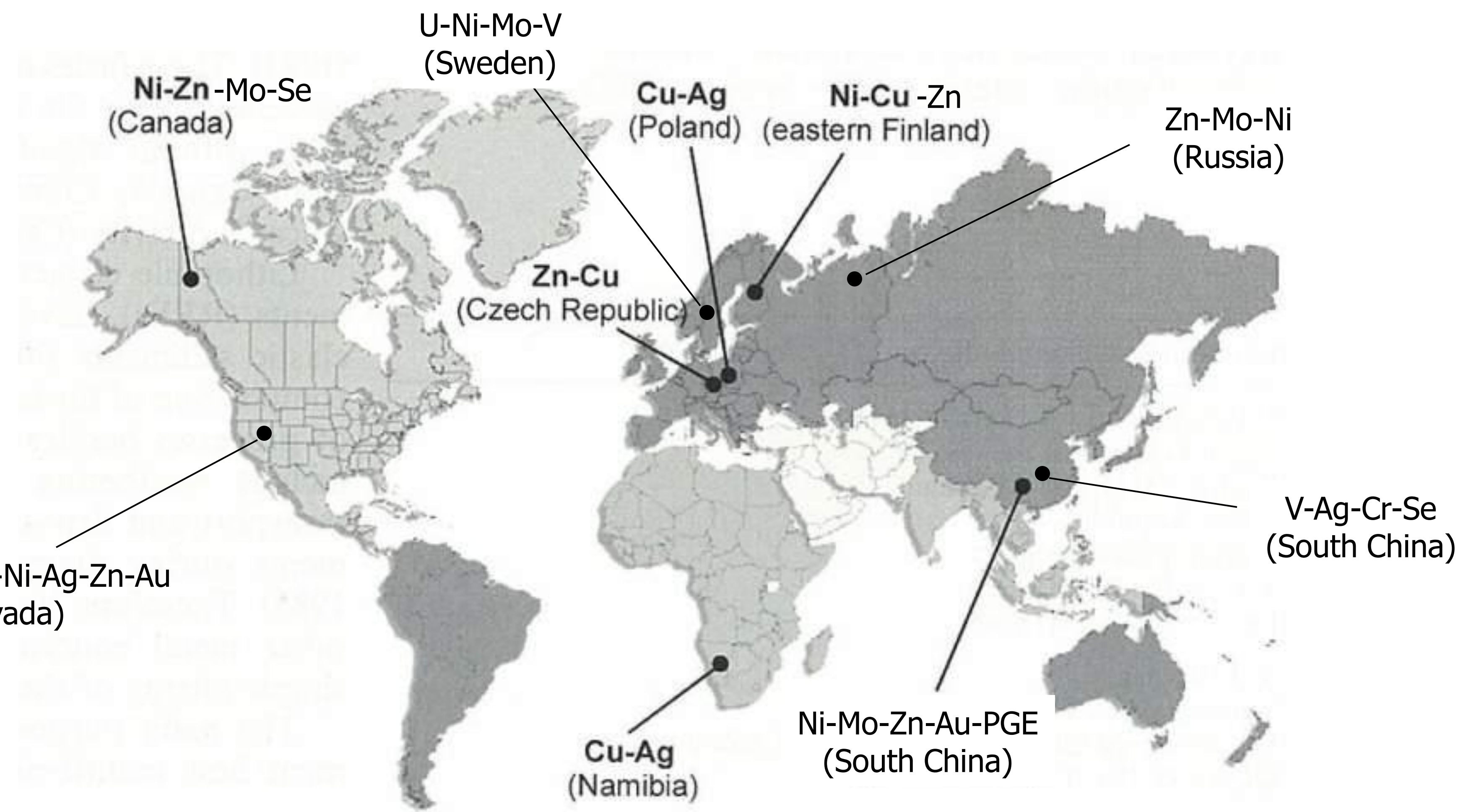
Some Significant Metalliferous Black Shales



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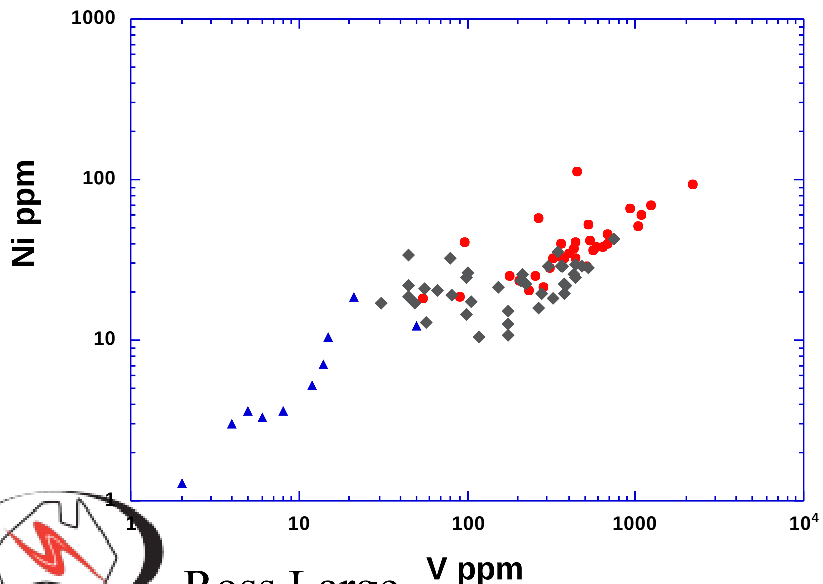
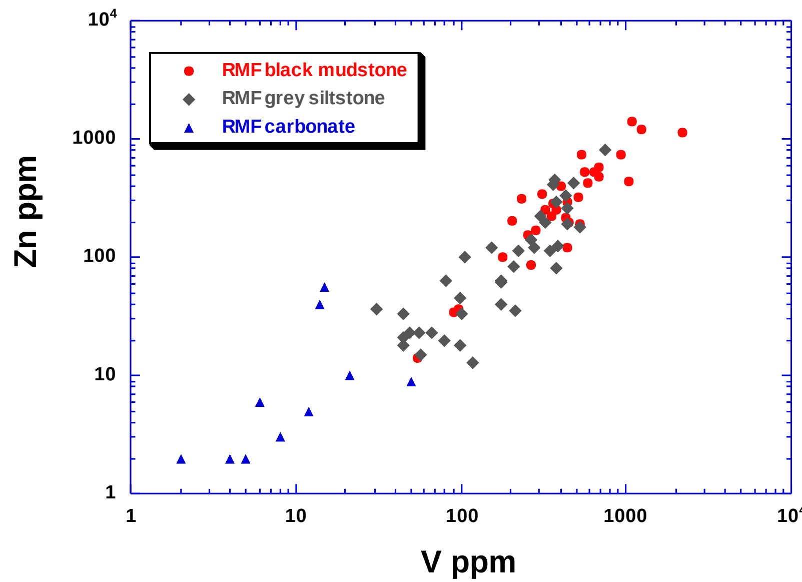
Some Approximate Grades

	size	ppm	ppm	ppm	Comment
Talvivaara Finland	1.1 billion t	1300 Cu	4900 Zn	2200 Ni	3% of world Ni resource
Alum Shale Sweden	>1.0 billion t	160 U	300 Mo	2500 V	Approx figures
Mo-Ni South China	1600km X 2-15 cm	1-4% Ni	2-7% Mo	600 V	Plus Se, U, As Au, Pt
Nevada NCT	70km^3 X 2-15 m	235 Ni	120 Mo	2200 V	2000 Zn, plus Se, Au, Ag, As
Nick Deposit Canada	~ 400 km^3 X 10-40 cm	5% Ni	0.7% Zn	3000 V	Plus Au, PGE, Se, As, Mo, Re

Organic Carbon Content

- Varies from 0.2 to 25% organic carbon
- Low metamorphic grade examples are “oil shales”
- Metal content is commonly related to organic carbon content
- V and Mo are good proxies for organic carbon





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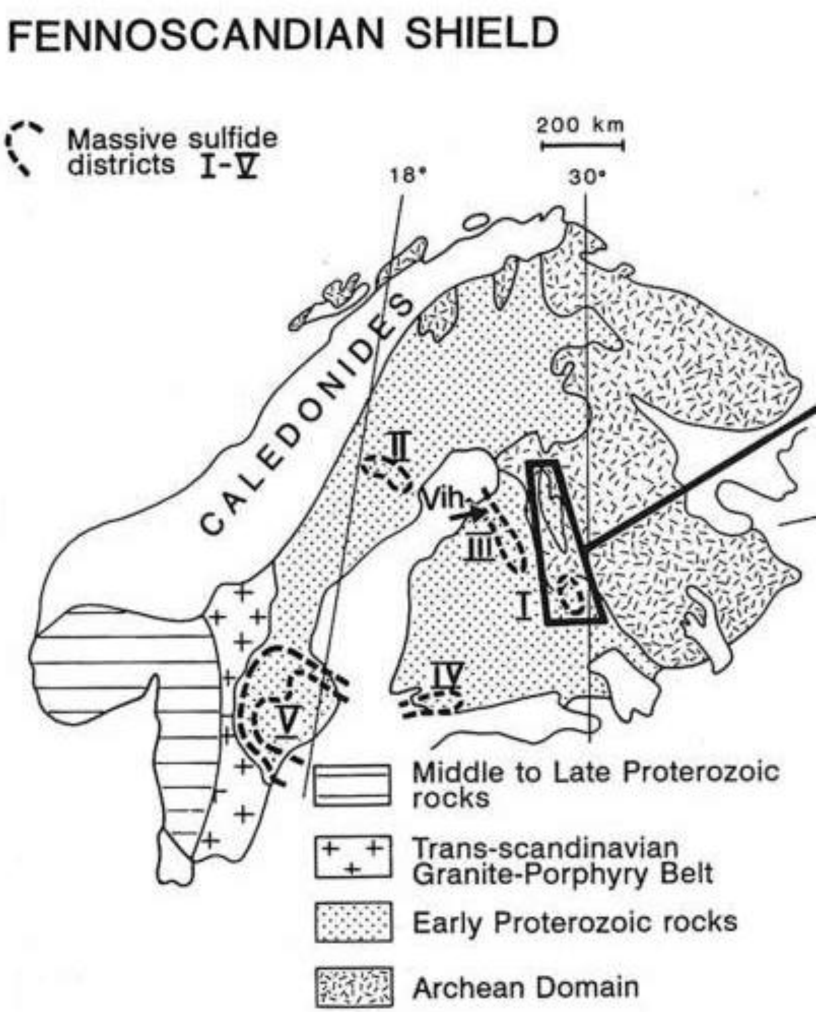
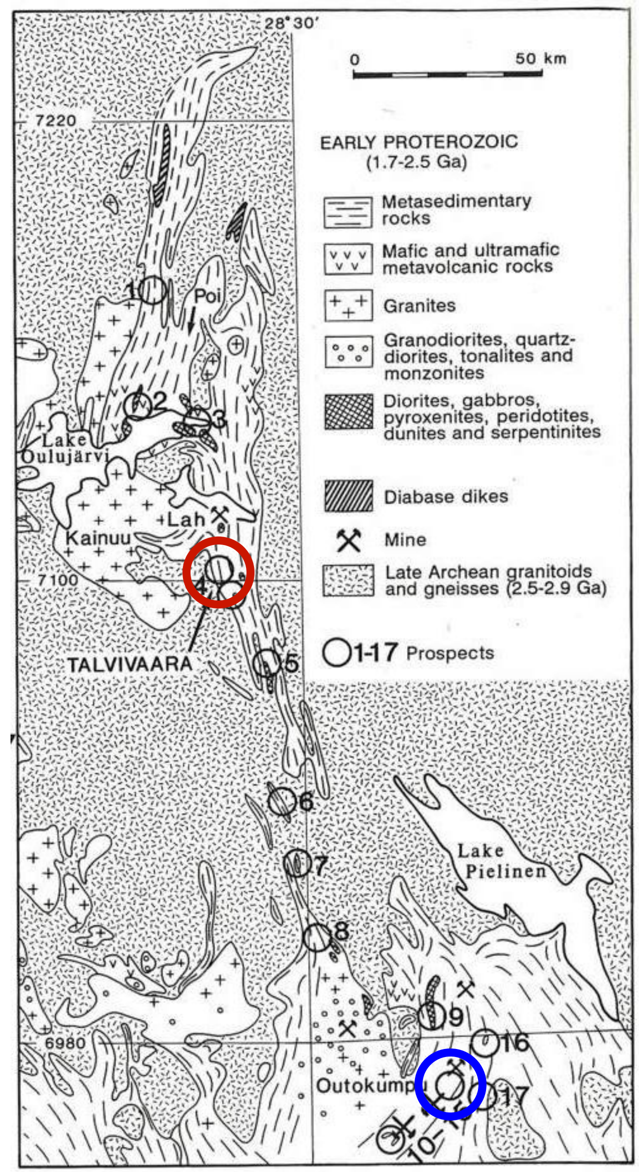
Talvivaara: Finland





KAINUU SCHIST BELT
AND
OUTOKUMPU DISTRICT

Palaeo Proterozoic

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Talvivaara - Finland

- Discover in 1982 by Geol. Survey of Finland
- Palaeoproterozoic black shales (schists) in Archean gneiss terrain
- 20 - 100m thick pyrite-pyrrhotite carbonaceous schist
- Identified over strike length of >200km
- Resource grade of 0.13% Cu, 0.49% Zn, 0. 22% Ni, 102 ppm Mo, 630 ppm V and 7% organic C
- Mining commenced in 2008
- Metals extracted by bioheapleach methods

Alum Shale Sweden

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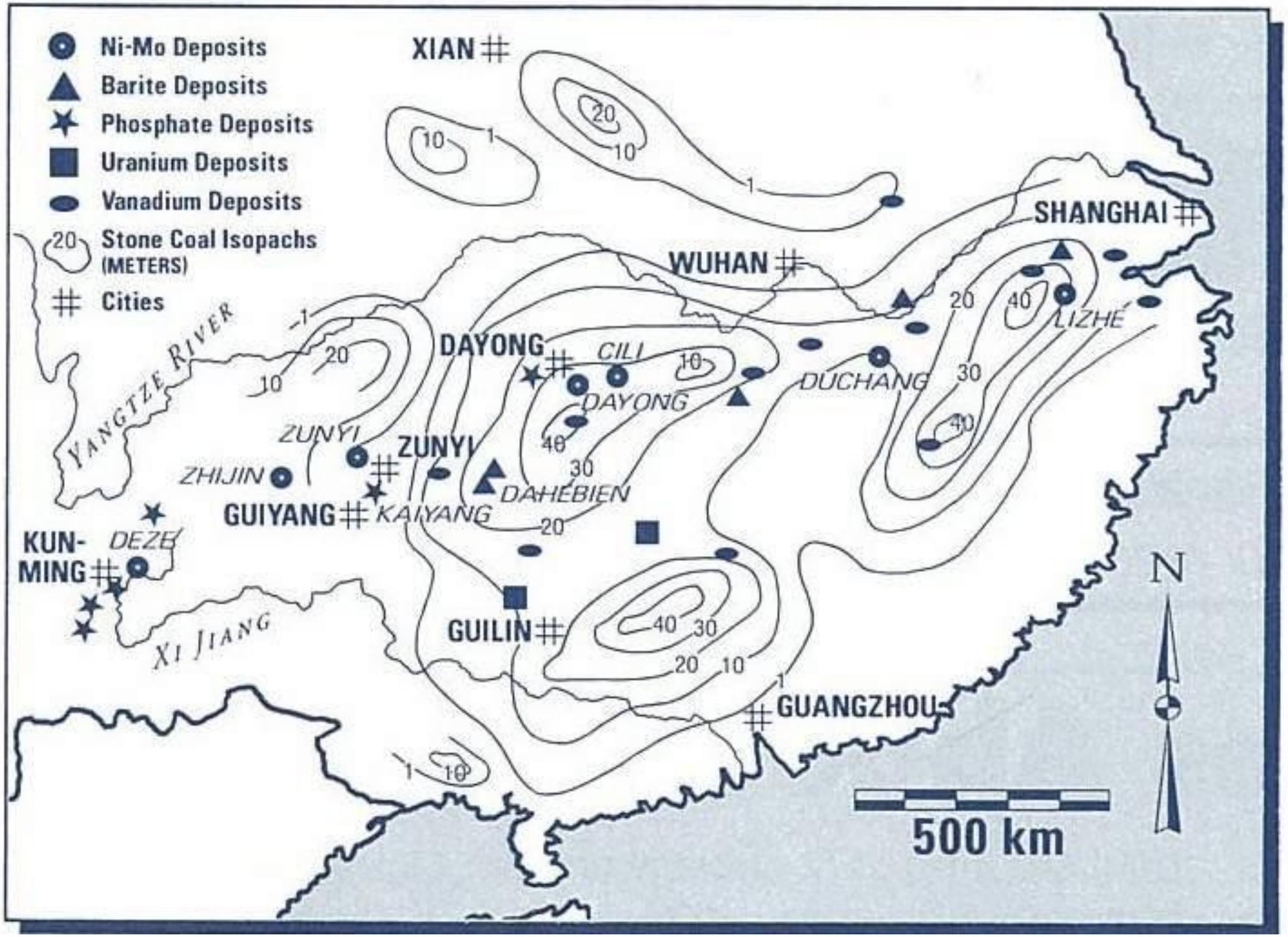
Alum Shale - Sweden

- Cambrian to Lower Ordovician
- Organic-rich pyritic shale unit 20 to 60 m thick within black shales over 200m thick
- Previously mined for alum, oil and uranium
- One of world largest resources of uranium
- 1.05 billion pounds of U_3O_8 defined at the Viken Project, grading 170 ppm U
- Other metal contents are around 300 ppm Mo, 2500 ppm V, 380 ppm Ni

Southern China
Lower Cambrian Black Shale Series



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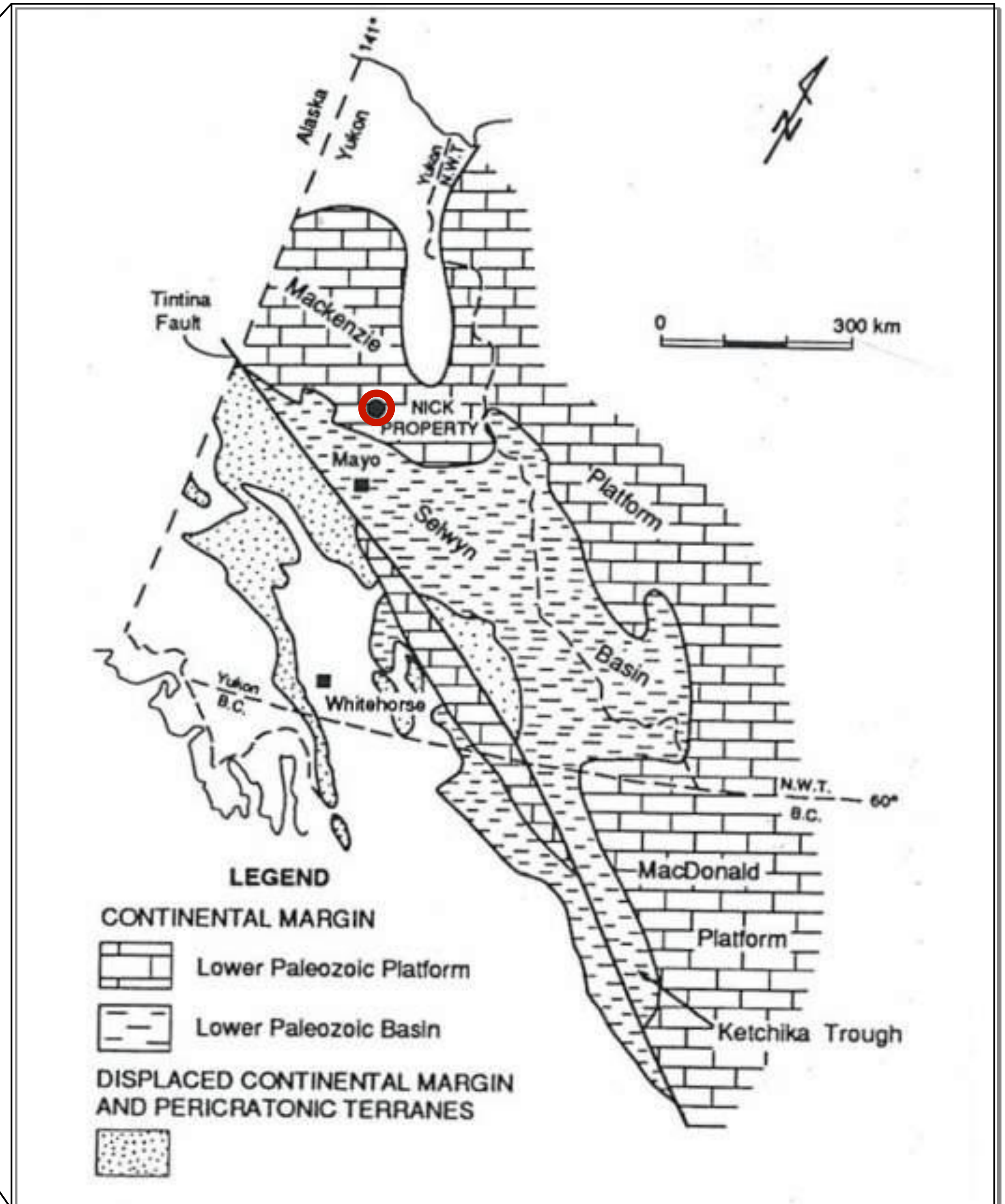
Southern China

- Lower Cambrian black shales and oil shales
- Various stratabound deposits of Ni-Mo, barite, phosphate, uranium and vanadium within the black shale series
- Thin massive sulfide Ni-Mo ores average ~4% Mo and ~2% Ni
- Other metals: ~2% Zn, ~800 ppm V, 2400 ppm Se, 250 ppm U plus minor PGE
- Intermittent occurences over 1600km strike length

Yukon - Nick

Ni-Zn
(Canada)



141°
Alaska
Yukon
Yukon
N.W.T.
Mackenzie
Tintina
Fault
0
300 km
NICK
PROPERTY
Mayo
Selwyn
Platform
Basin
Yukon
B.C.
Whitehorse
N.W.T.
B.C.
60°
MacDonald
Platform
Ketchika Trough
LEGEND
CONTINENTAL MARGIN
Lower Paleozoic Platform
Lower Paleozoic Basin
DISPLACED CONTINENTAL MARGIN
AND PERICRATONIC TERRANES

Stratigraphic Column

Hulbert et al. (1992)

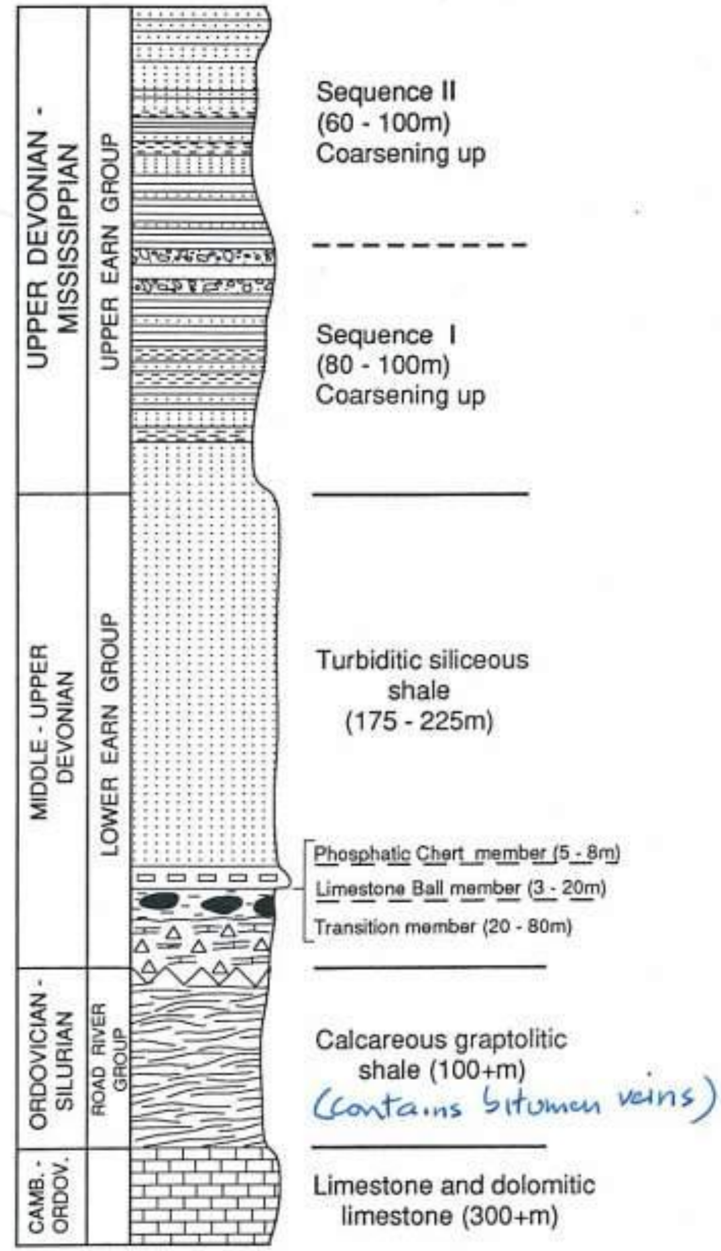


Fig. 3 Stratigraphic column of the Nick basin. The Ni-Zn-PGE mineralization occurs at the base of the Phosphatic Chert Member.

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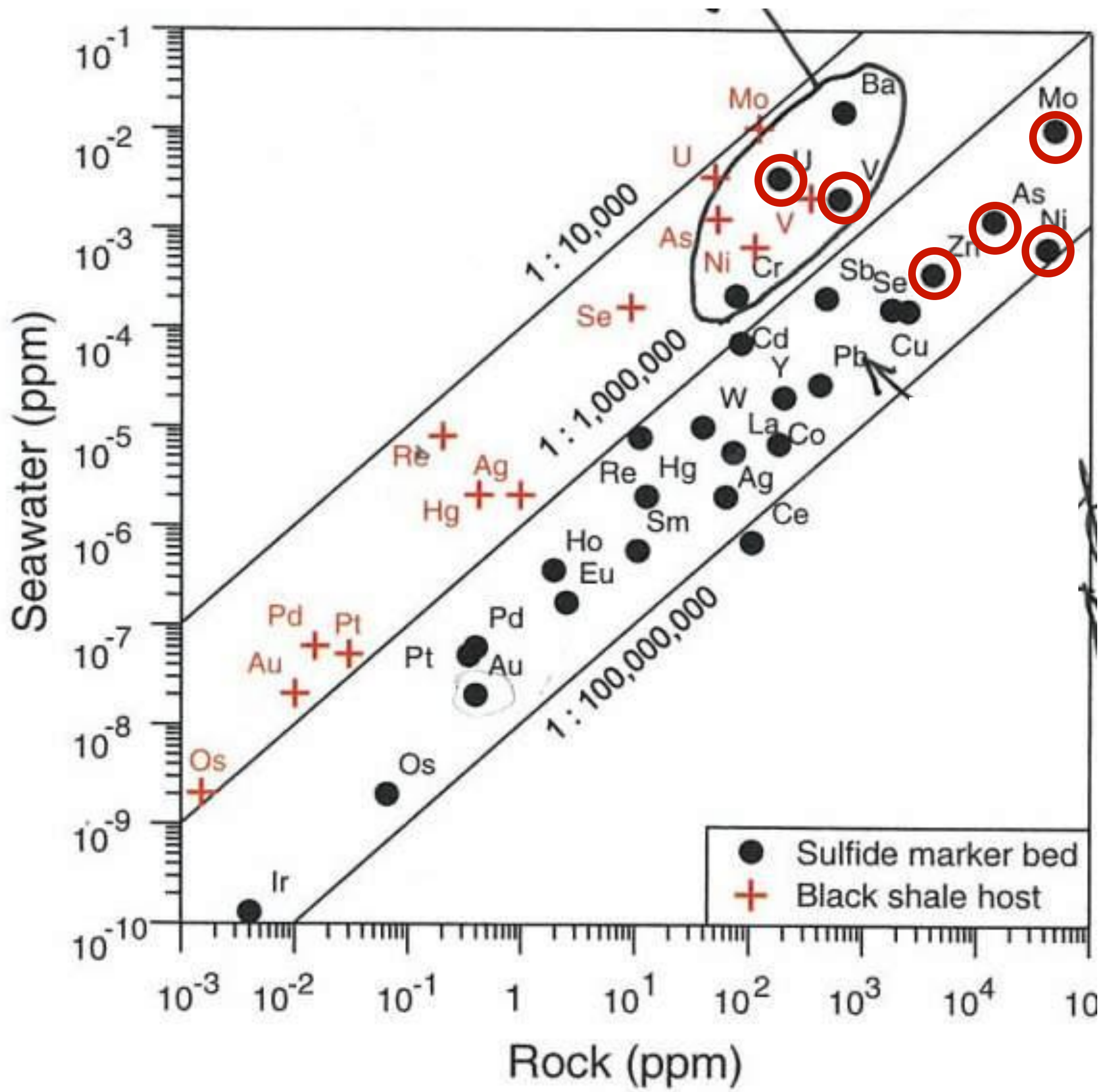
Richardson-Ogilvie Mts: Yukon

- Nick deposit discovered in 1981
- Devonian black shale basin
- 10 - 40 cm thick massive sulfide layer
- Identified over strike length of 400km
- Best grades of 7% Ni, 2.3% Zn, 0.33% Mo, 0.57% Se, 2400 ppm V and minor PGE

Genetic Theories

- Meteorite impact ejector (Goodfellow, 2009)
- Metal Exhalation along basin margin faults (Coveney et al., 1992)
- Absorption from seawater onto organic matter under extreme euxinic conditions (Lehmann et al., 2007)

Absorption from Seawater



Lehmann et al., (2007)

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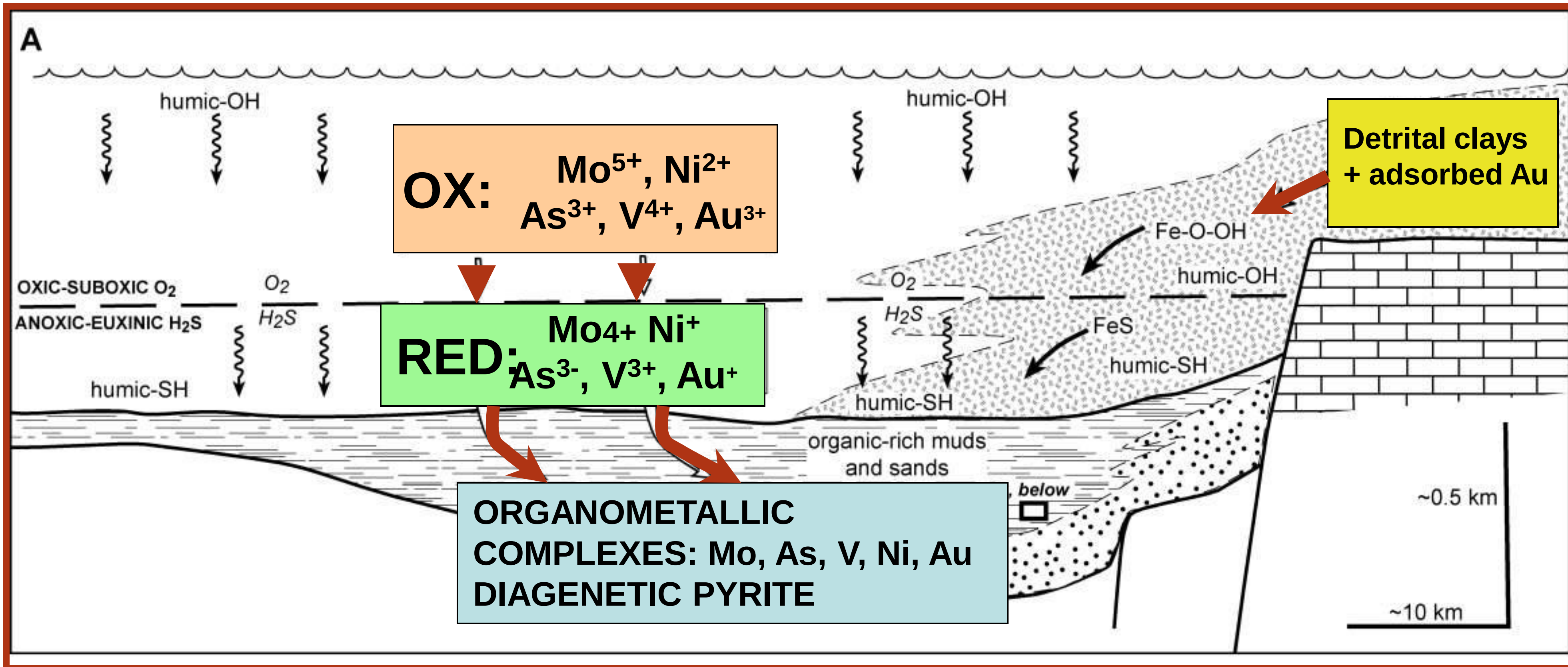
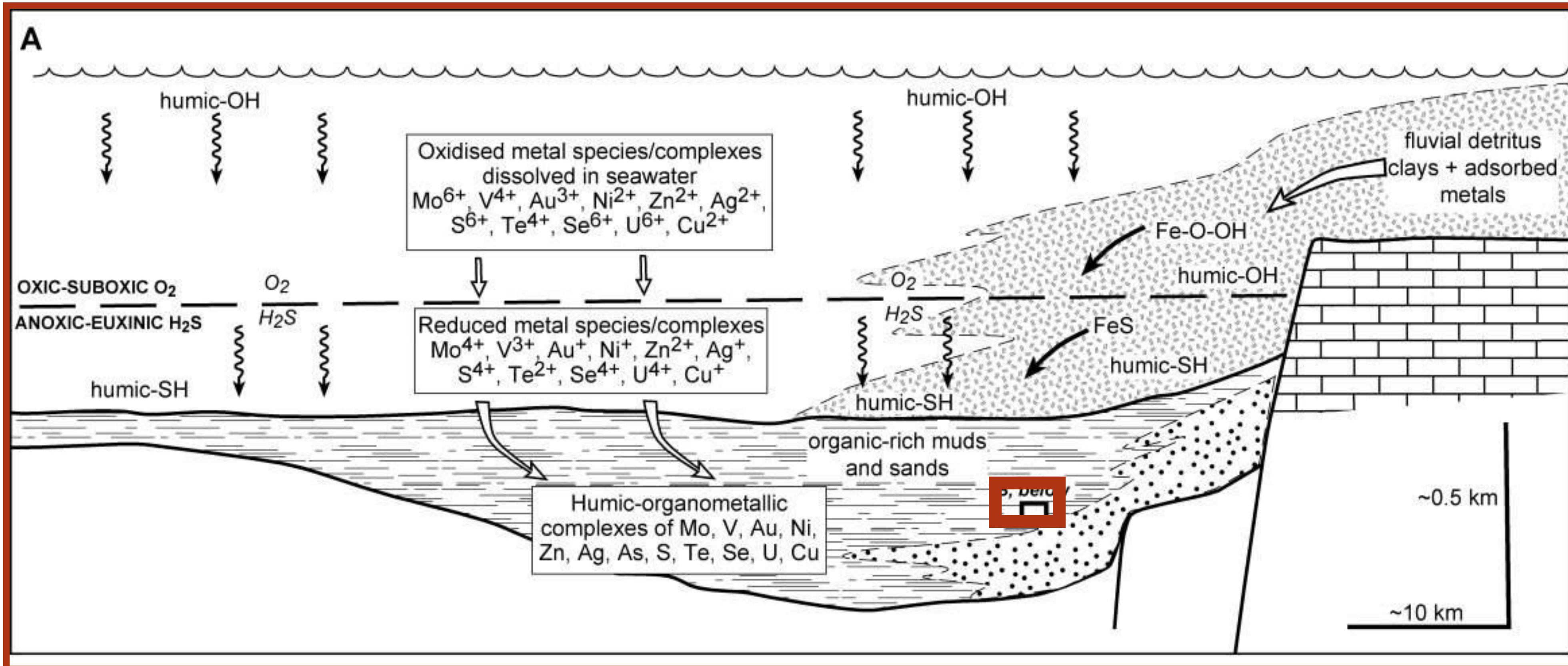
Continental Margin Anoxic-Euxinic Basin

metal input: fluvial detritus

Redox sensitive trace elements trapped in organic muds



Stage 1: During Diagenesis



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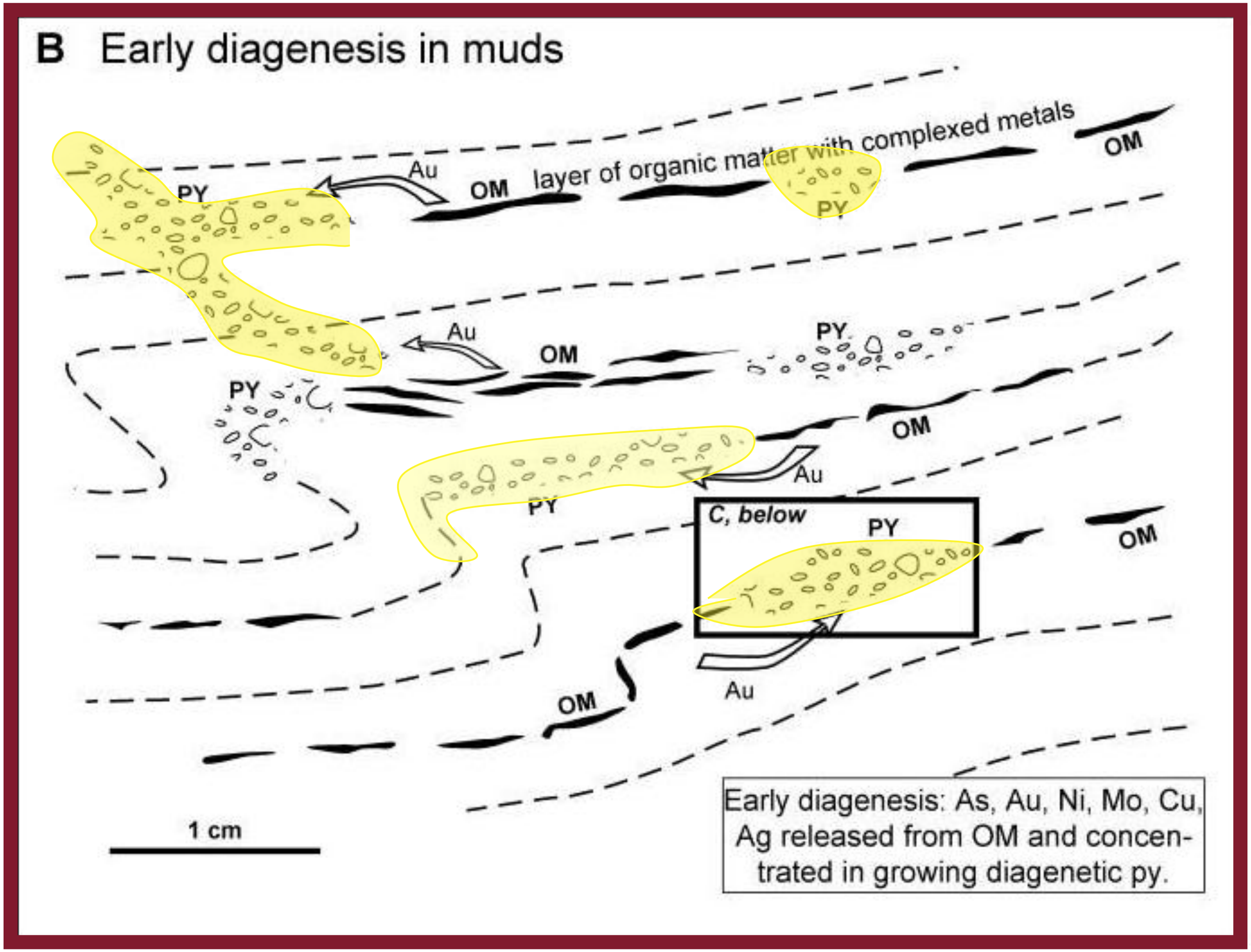
Metals Move from OM into Diagenetic Pyrite



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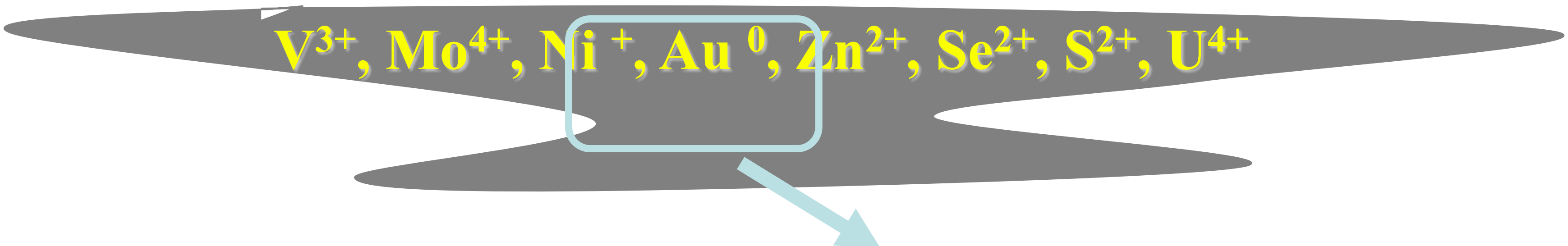
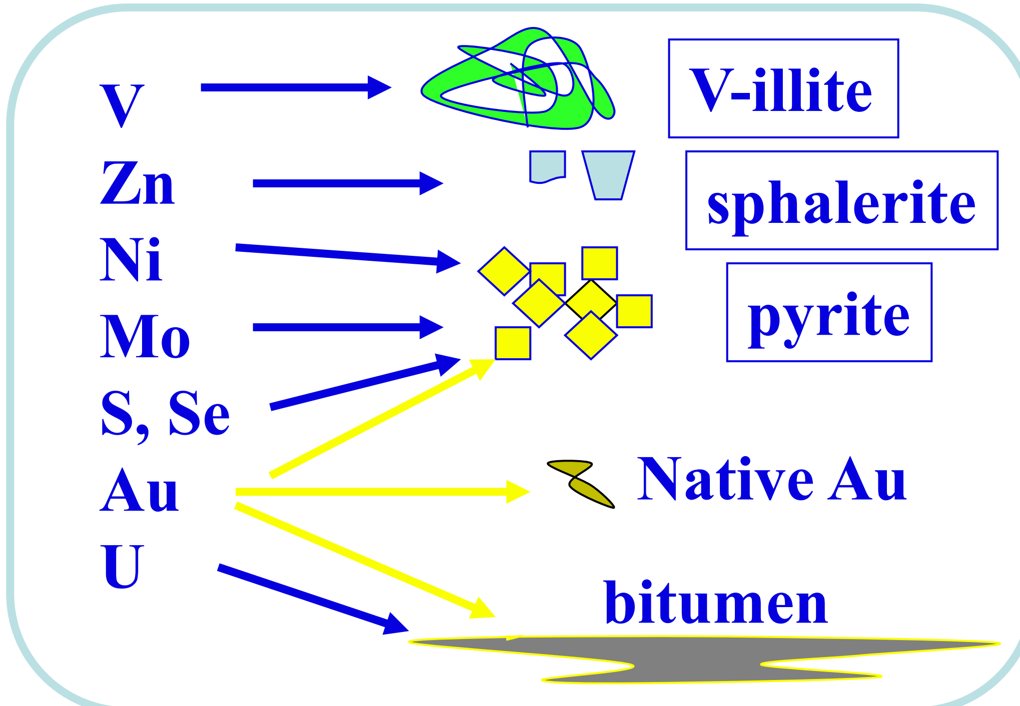
Metals Re-organise During Diagenesis



Metals are partially to completely released from organic matter into new diagenetic mineral phases



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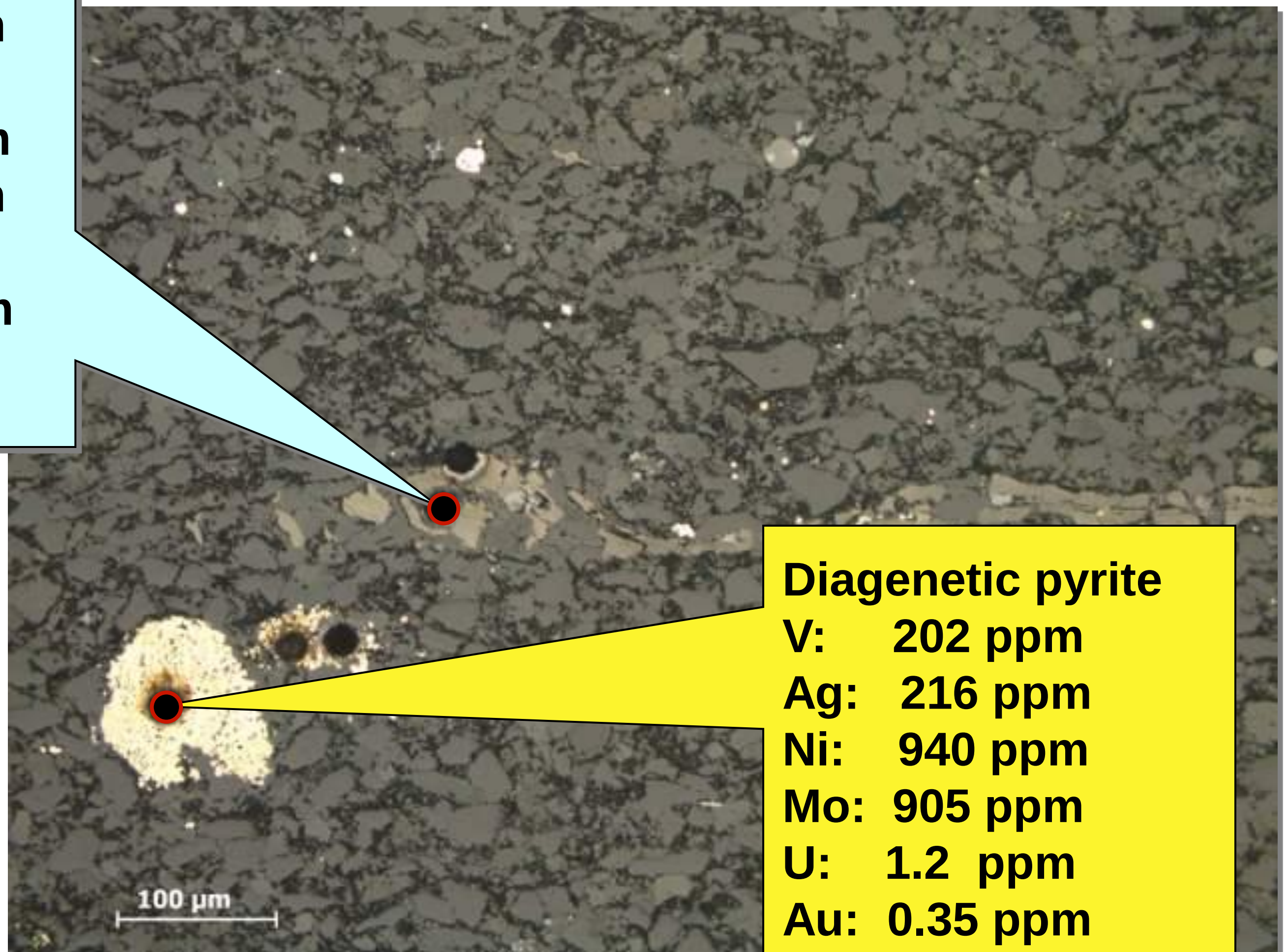
Metalliferous Carbonaceous Mudstone/Siltstone

Pyrobitumen
V: 1,740 ppm
Ag: 2.4 ppm
Ni: 290 ppm
Mo: 690 ppm
U: 425 ppm
Au: 4.6 ppm



Diagenetic pyrite
V: 202 ppm
Ag: 216 ppm
Ni: 940 ppm
Mo: 905 ppm
U: 1.2 ppm
Au: 0.35 ppm

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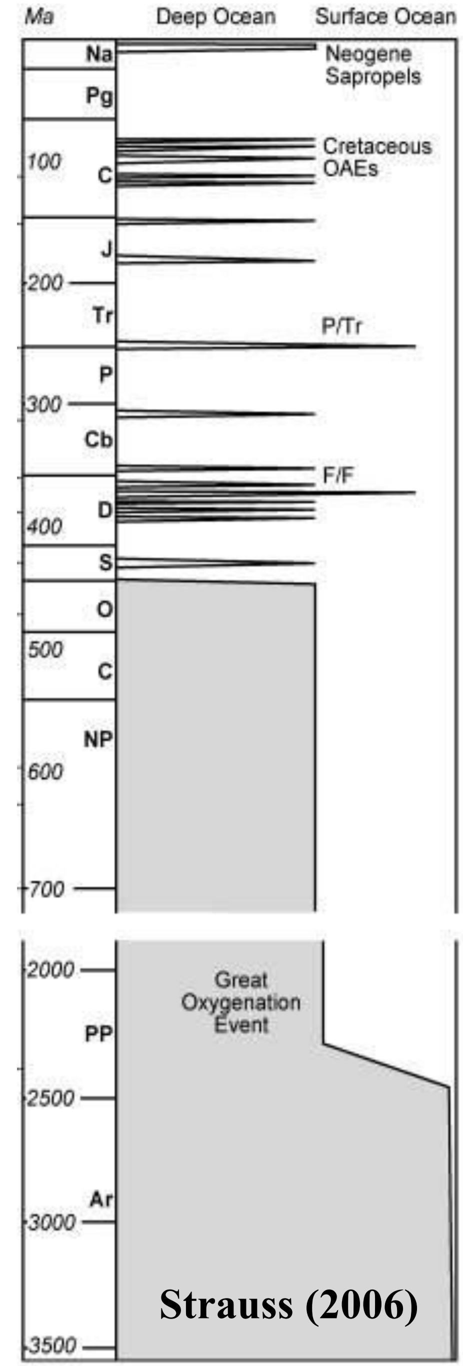
Marine black shales are concentrated during Ocean Anoxic Events (OAEs)



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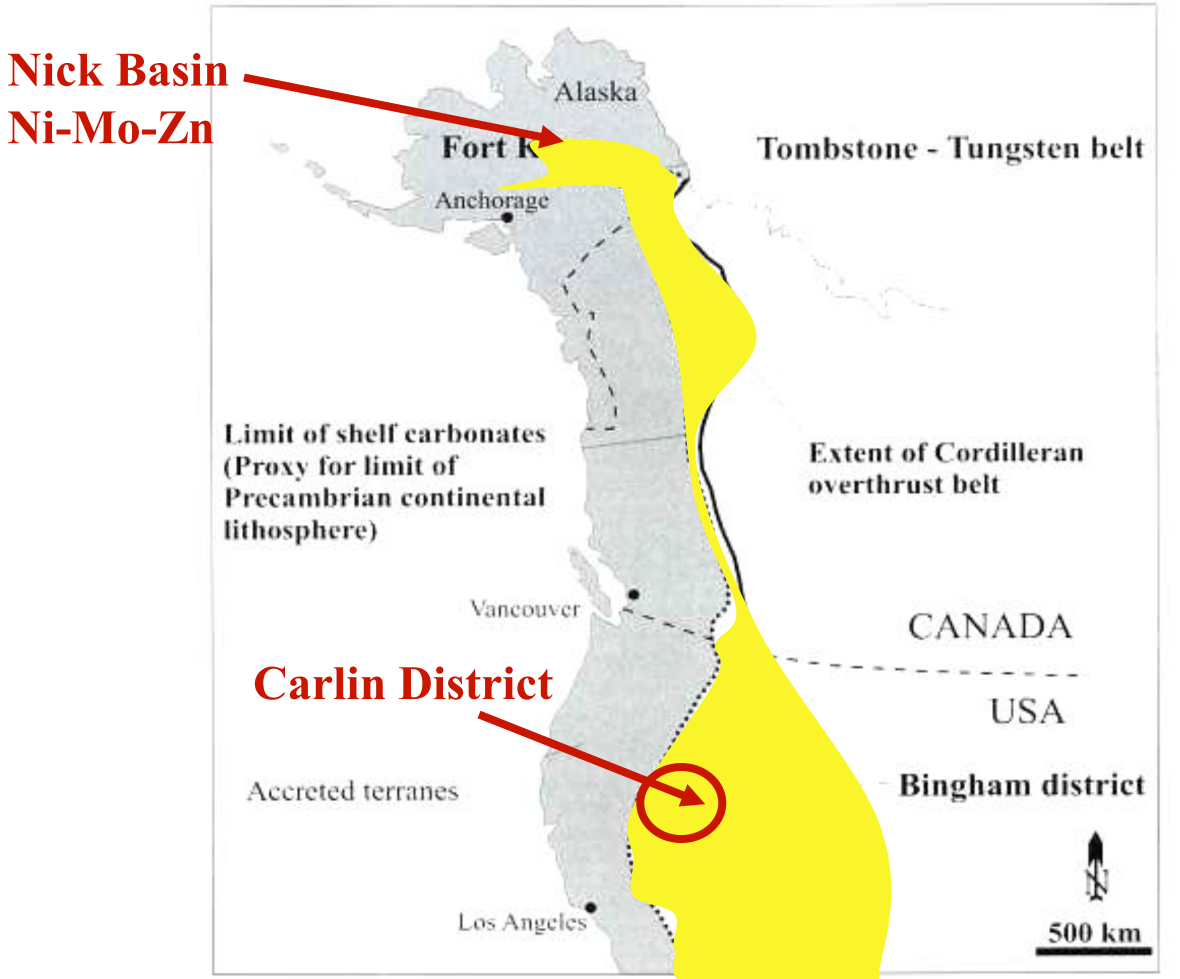
North American Margin: Cambrian to Devonian



Groves et al (2005)

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Slope and Basin Facies

(after Cook et al., 2005)

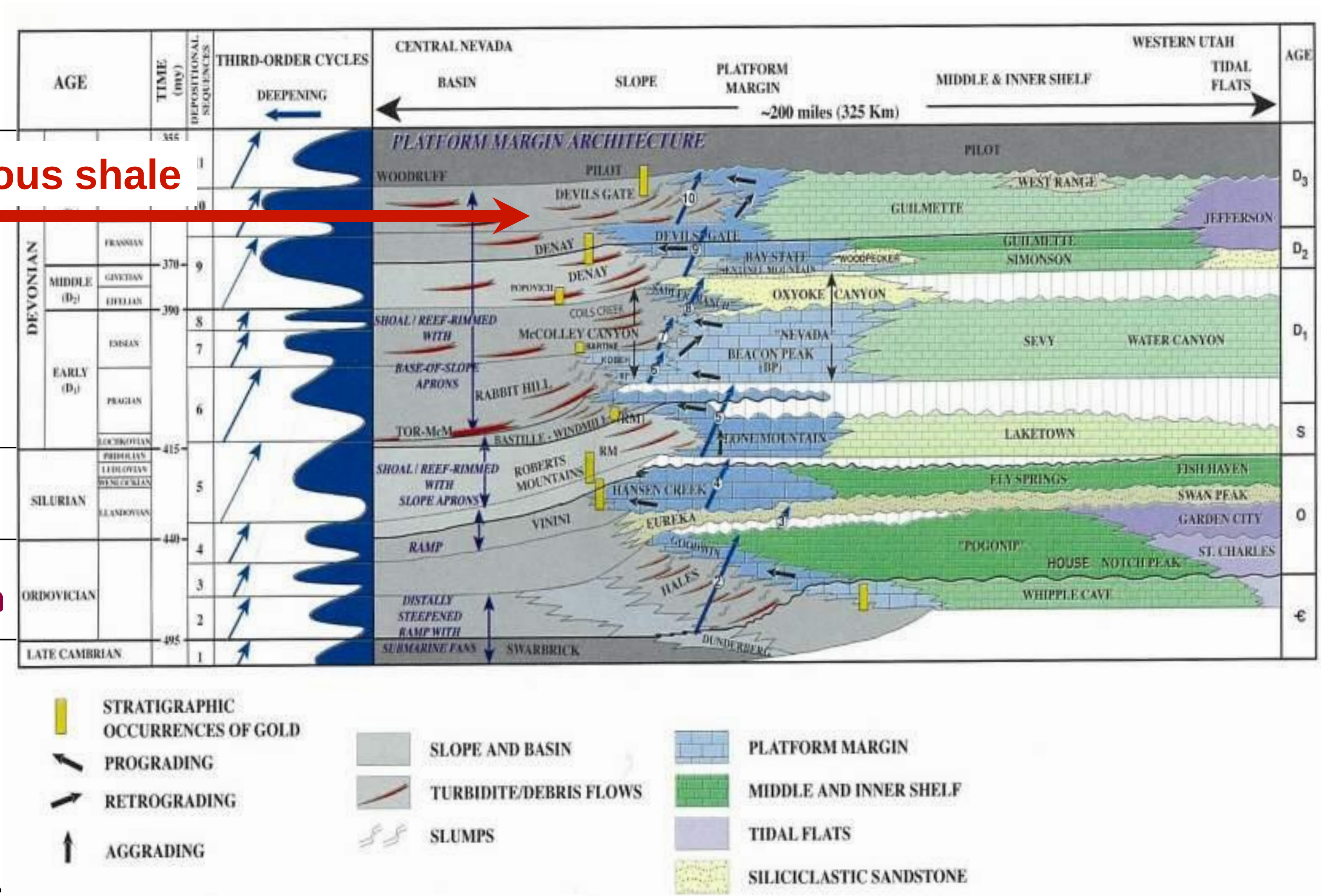
Metalliferous shale

Devonian

Silurian

Ordovician

Cambrian



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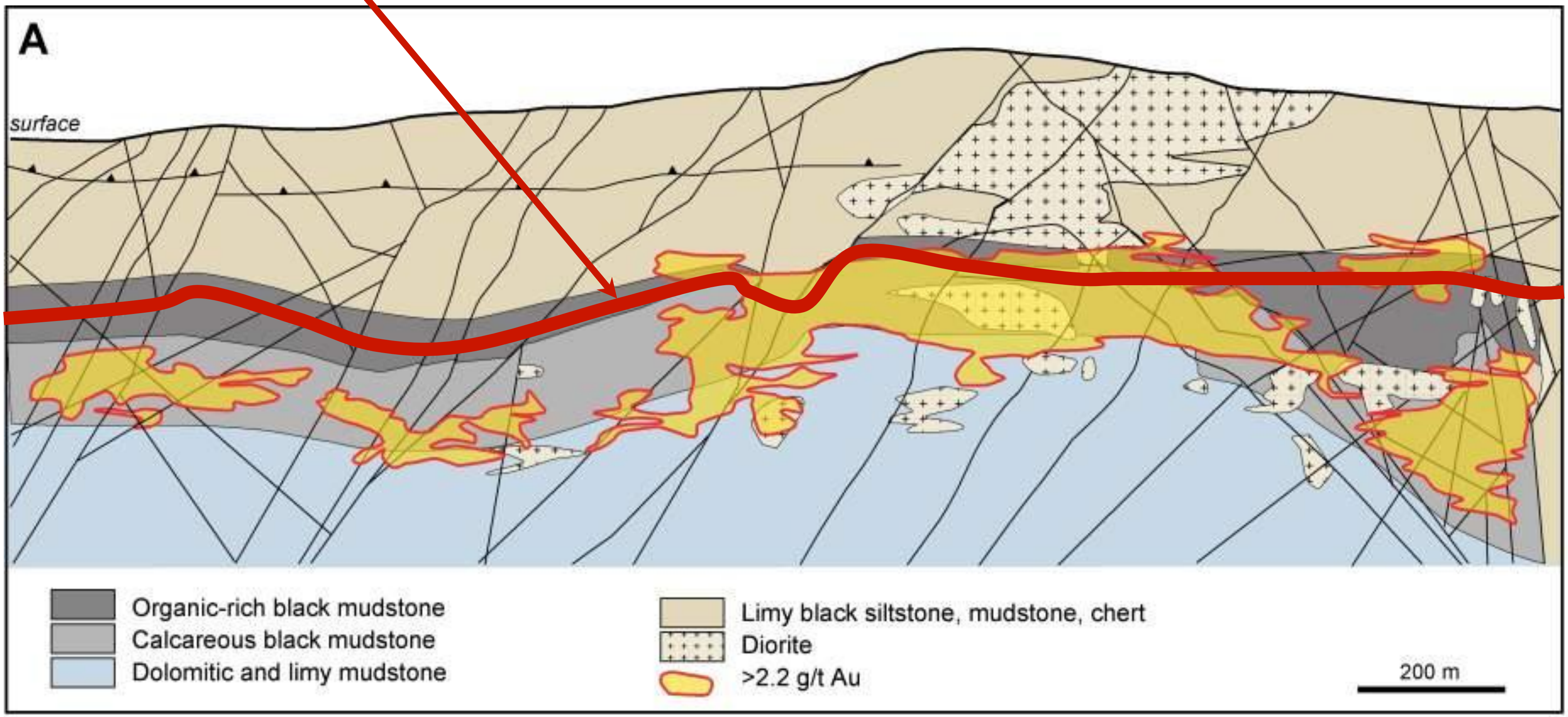
North Carlin Trend

Upper Mud Member: metalliferous black shale



Same age as the Nick Ni-Mo-Zn horizon in Yukon

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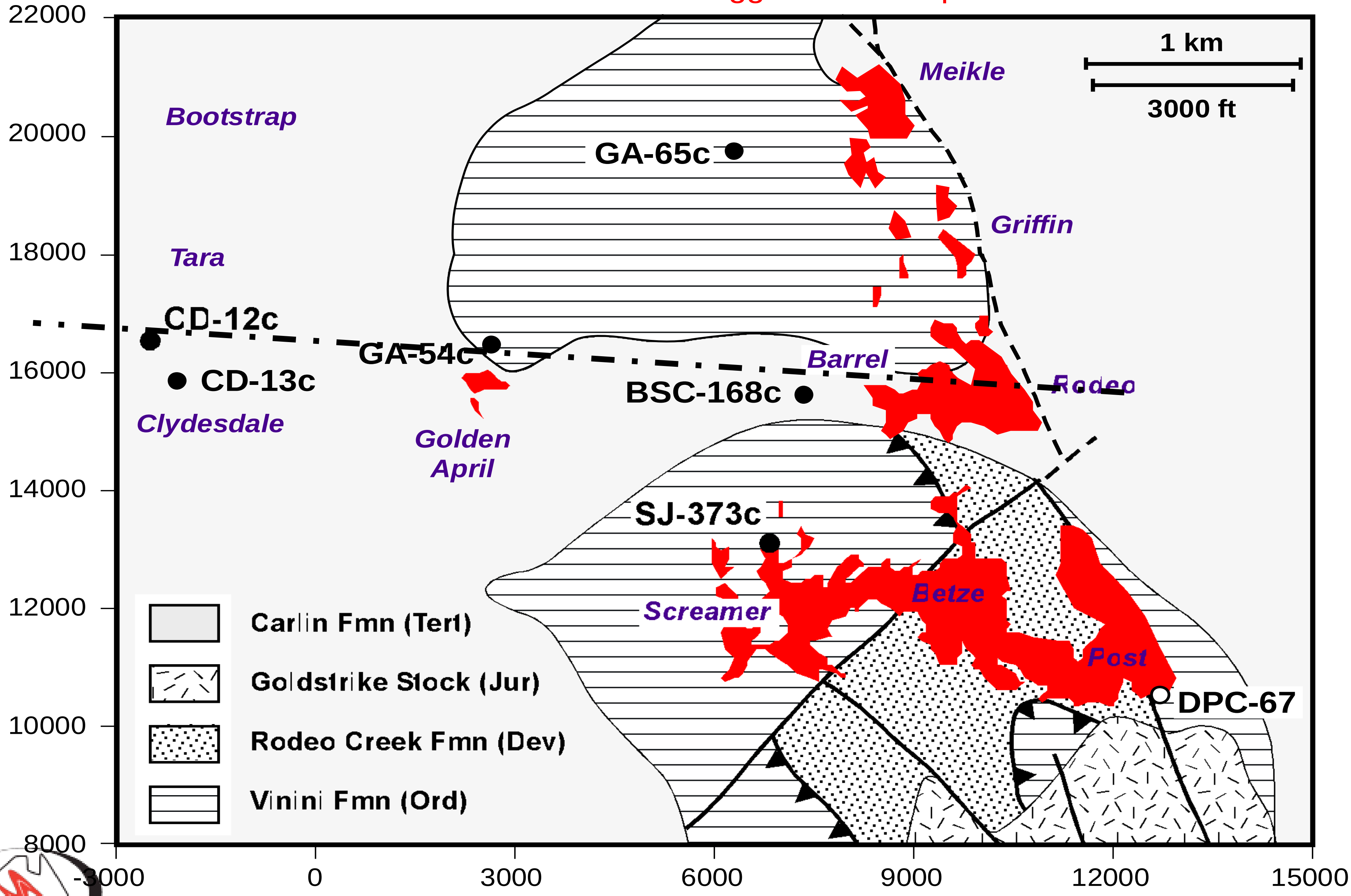
CODES / AMIRA P923: Drill holes logged and sampled at Goldstrike



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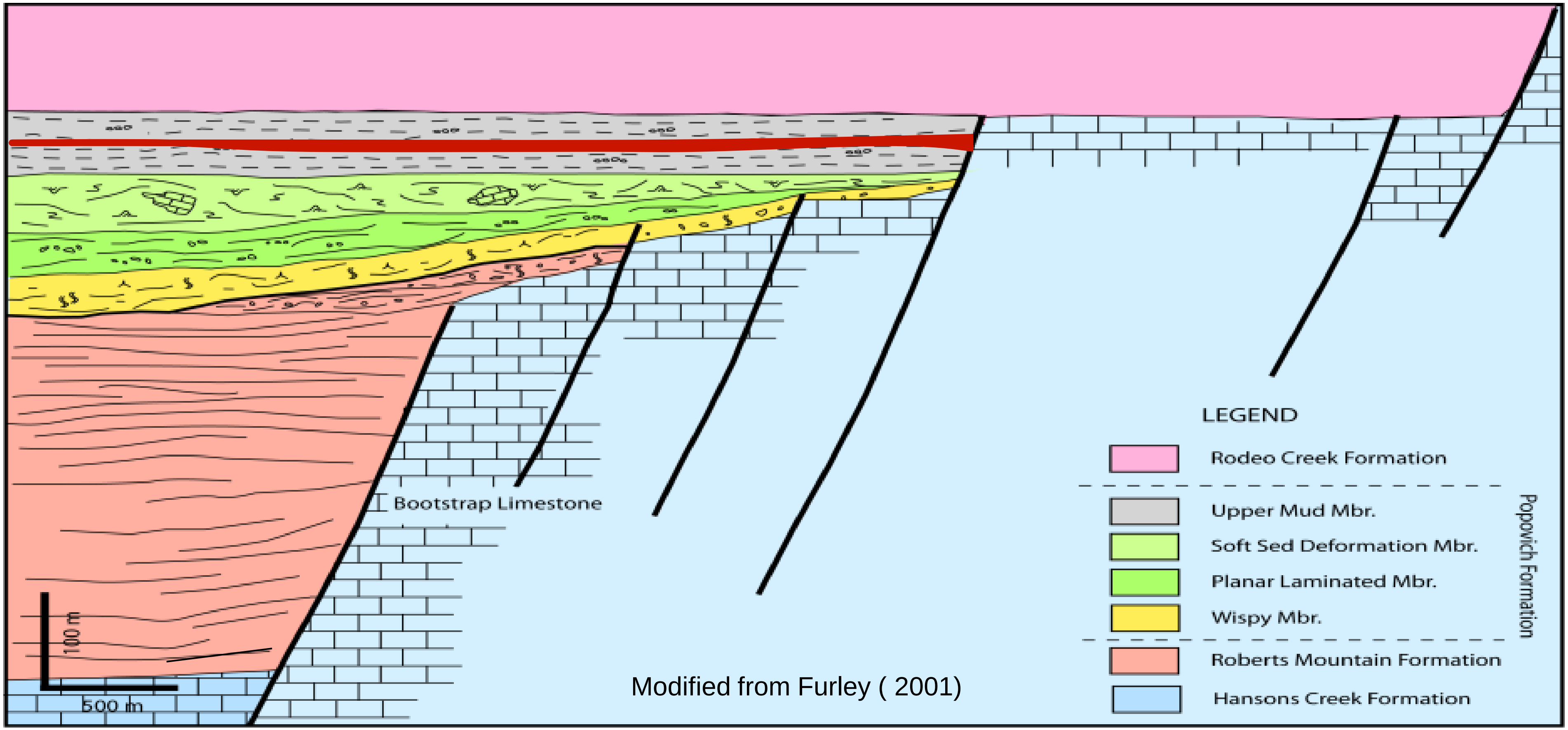
Metalliferous Organic-Rich Unit in Upper Mud

Enriched in V, Ag, Mo, Se, Ni, As, Zn, Au

first recognised by Emsbo et al (1999)



Upper Mud Member

Enriched in V, Ag, Mo, Se, Ni, As, Zn, Au

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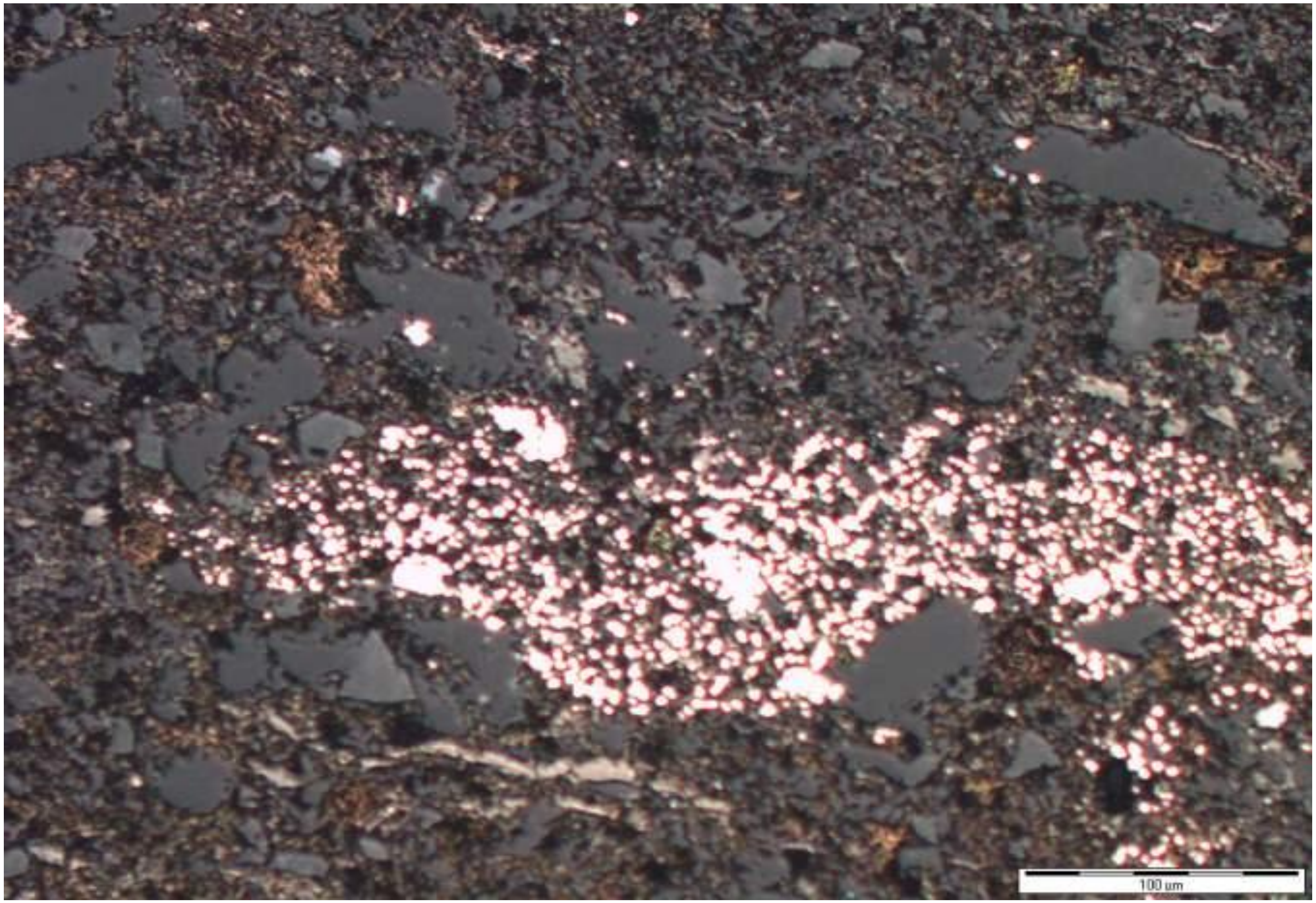
Sample 224 - Upper Mud Member



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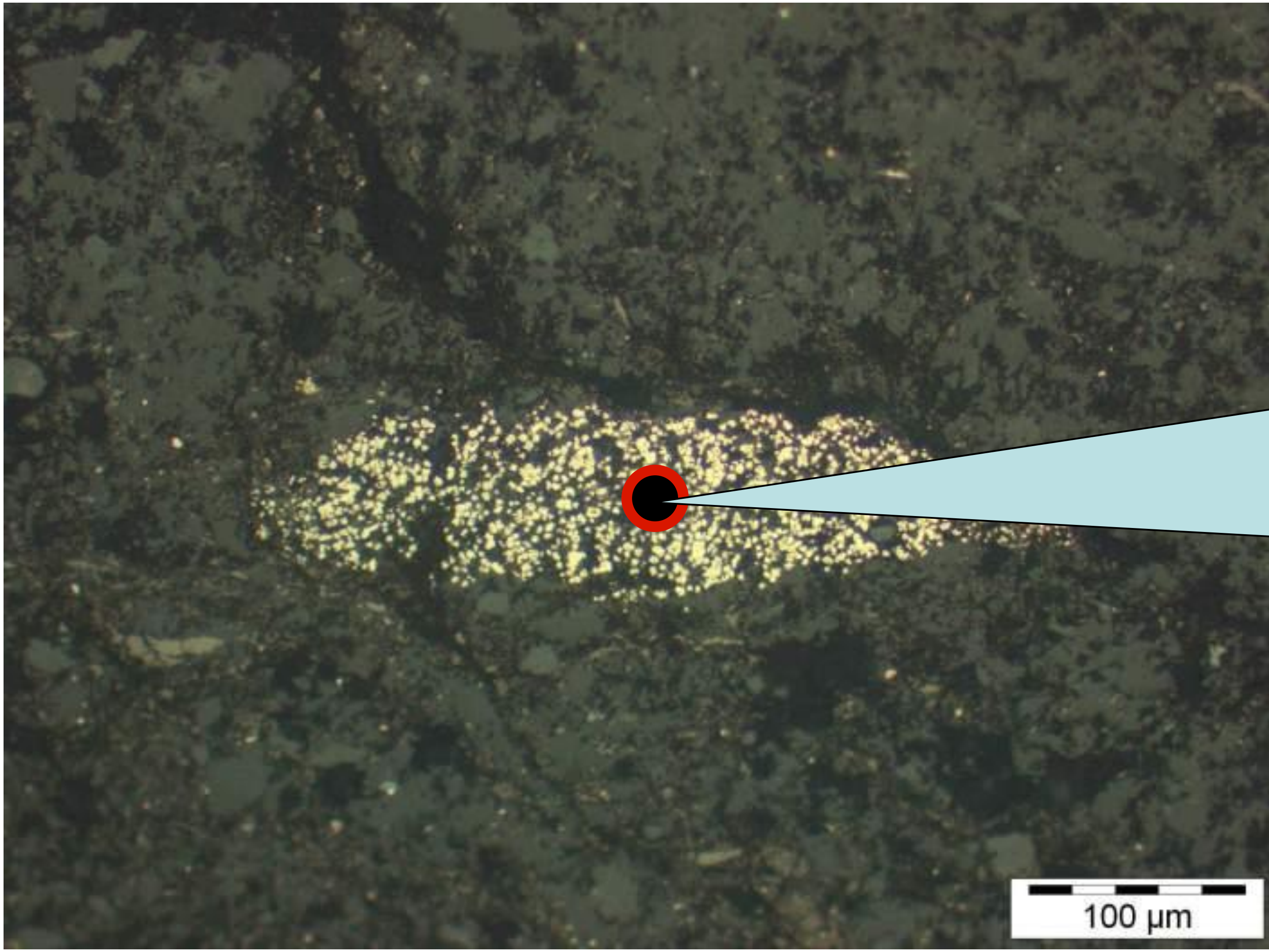
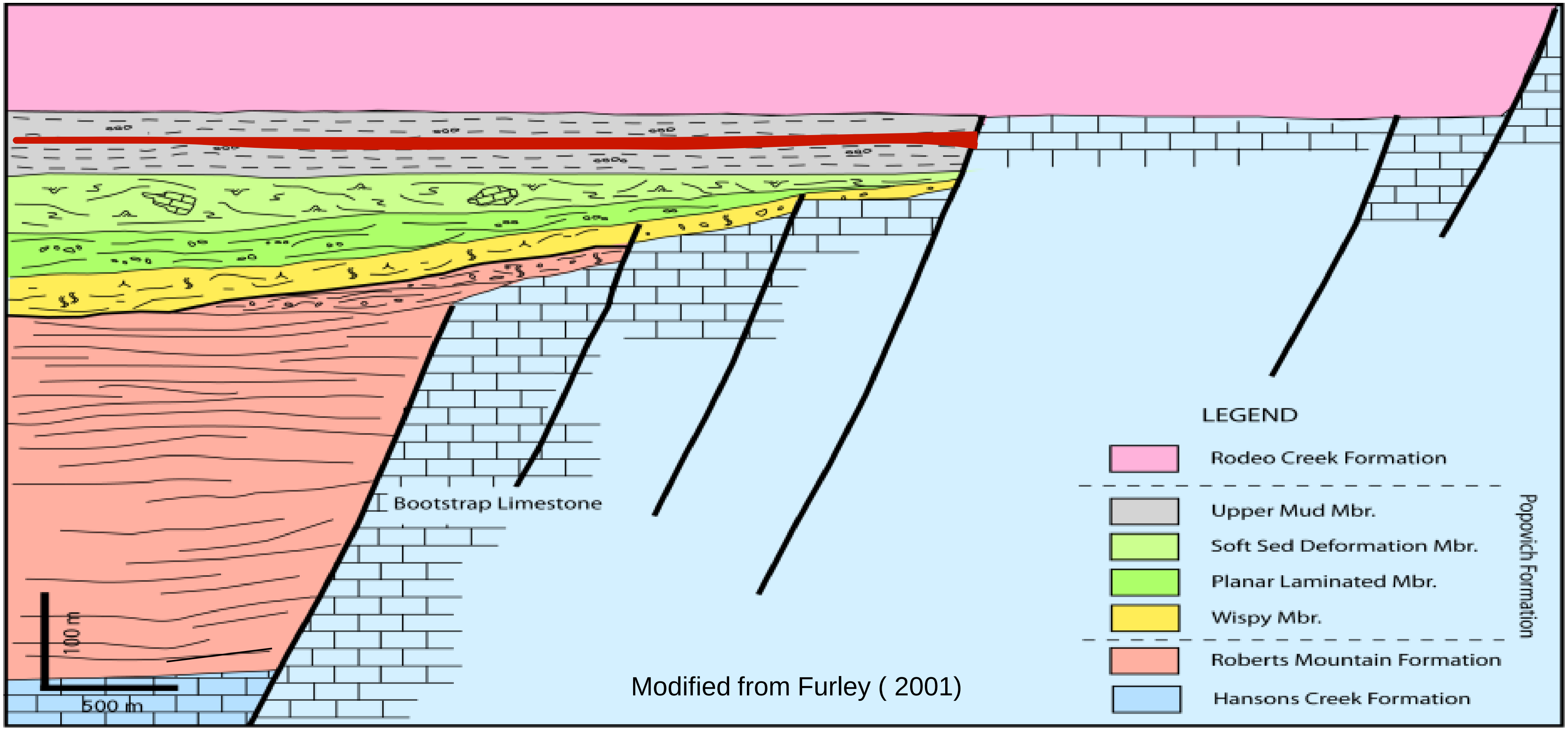
Diagenetic Pyrite Analysis



Diagenetic
Pyrite
ppm
V: 2170
Ni: 8950
Cu: 12,590
Mo: 2670
Se: 3990
Au: 72.4
As: 3900

Stratiform Au-Ni-Mo-Se-V in Upper Mud



Modified from Furley (2001)

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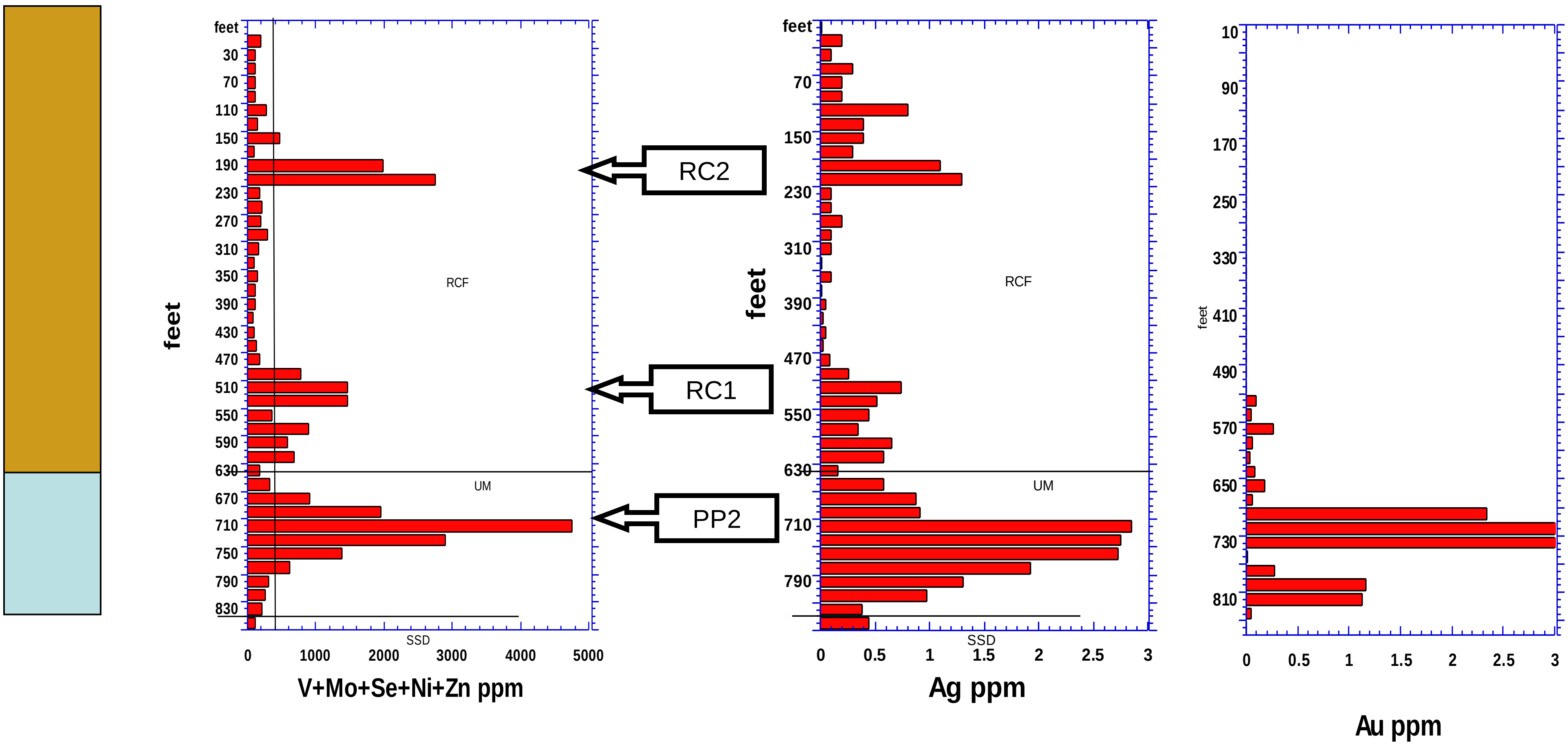
BSC 168c - west of Screamer
V score = V+Mo+Se+Ni+Zn



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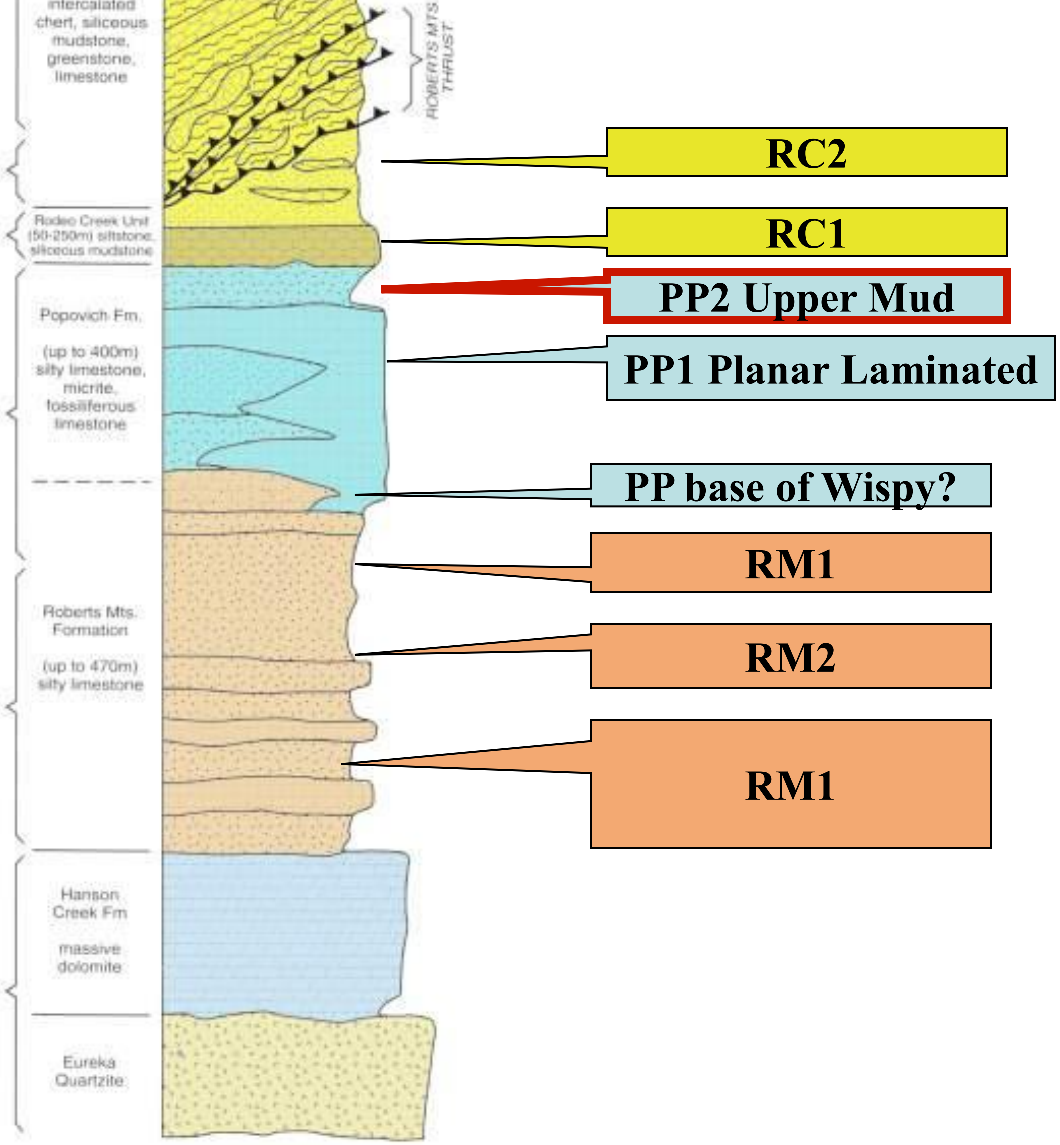
Organic-rich diagenetic pyrite Horizons; enriched in Se, Zn, Ni, Mo, V, Ag +/- Au related to sedimentary cycles



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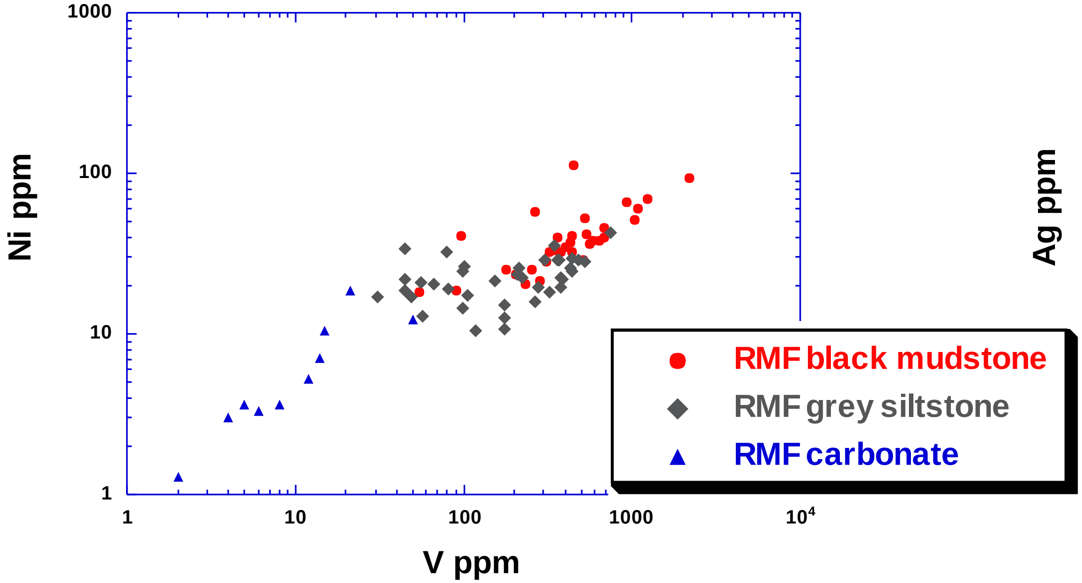
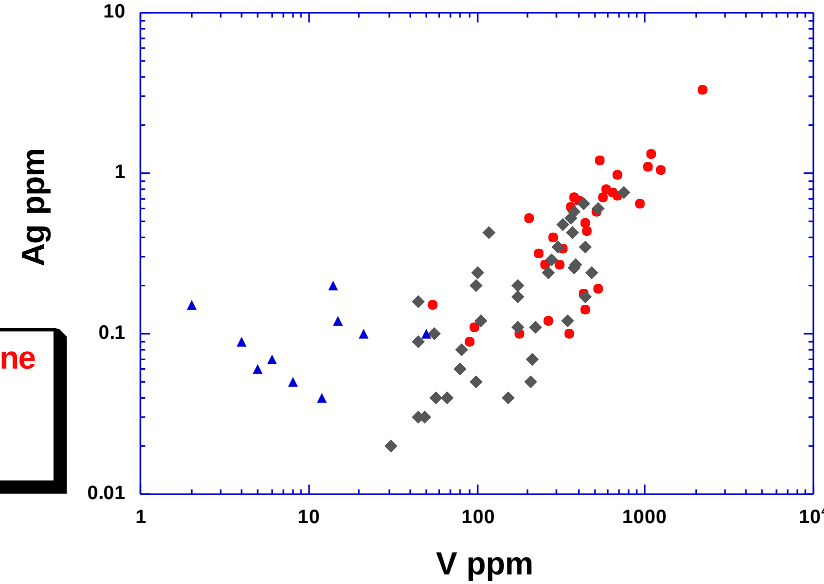
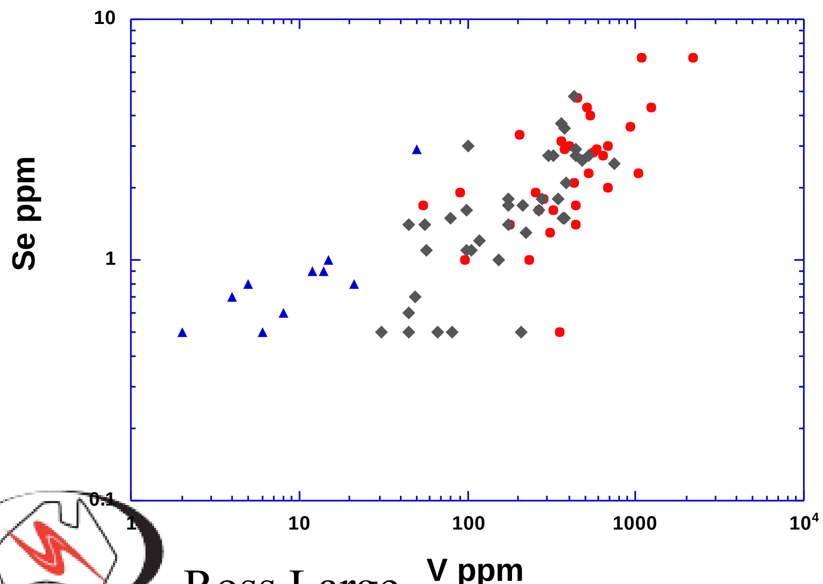
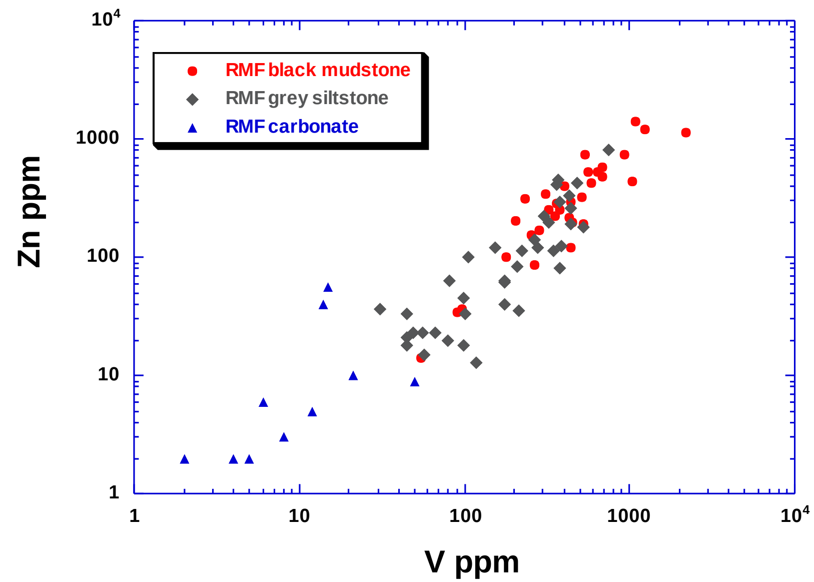
VAMSNAZ Relations in WR









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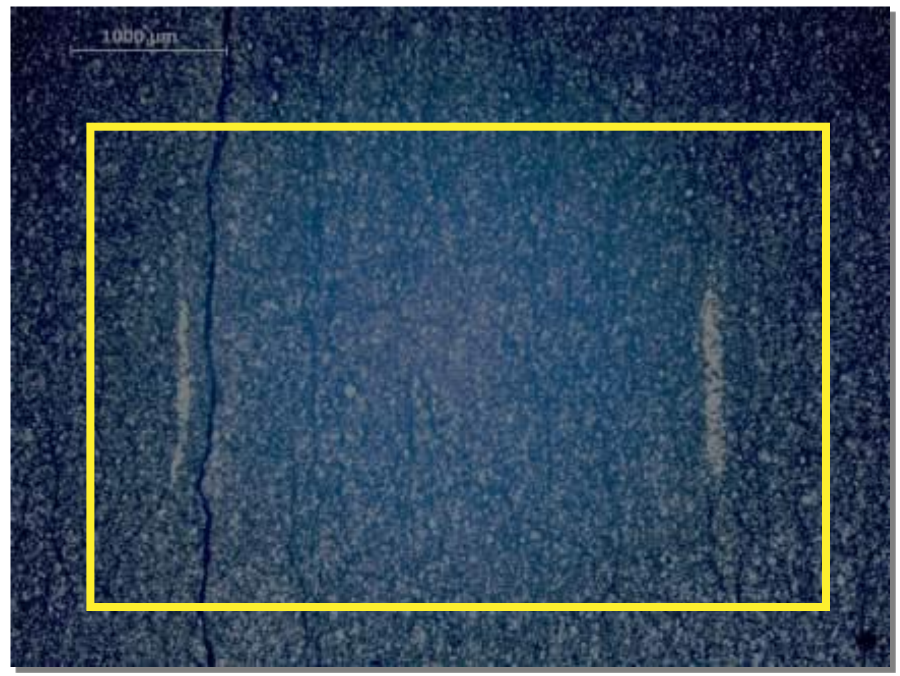
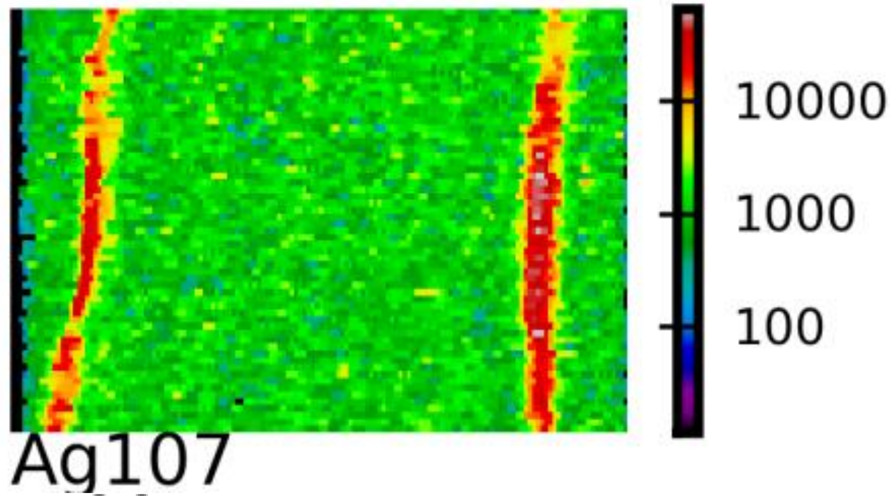
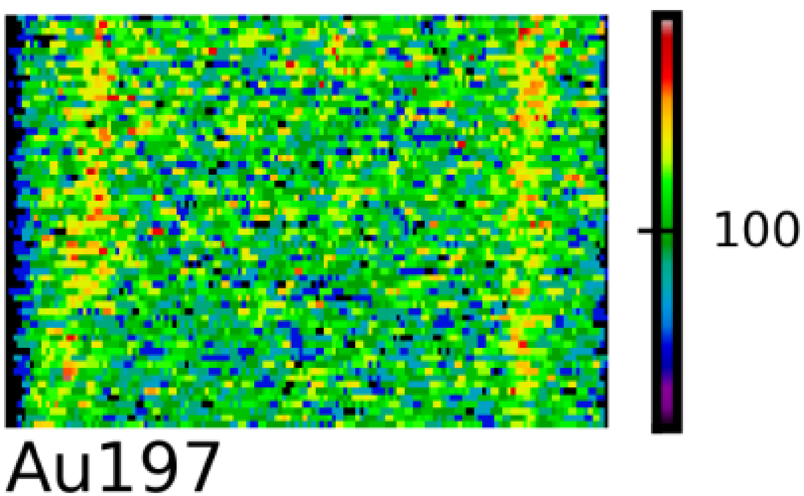
RMF VAMSNAZ

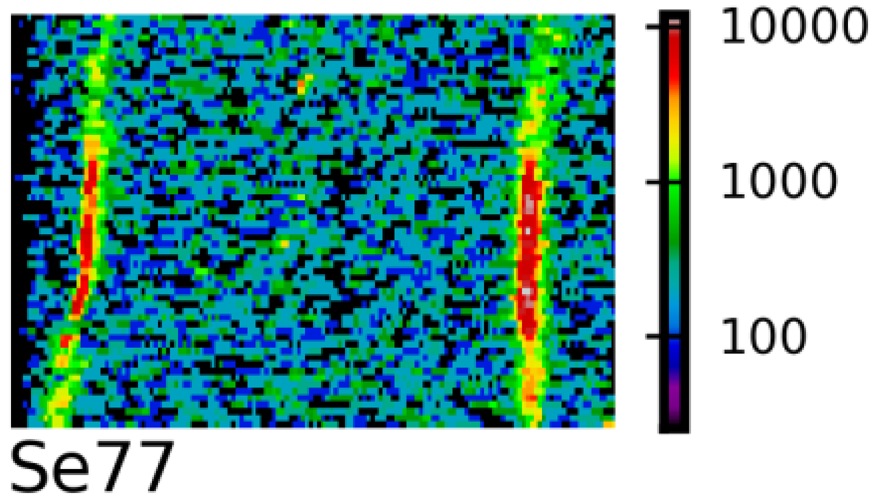
LA-ICPMS Map



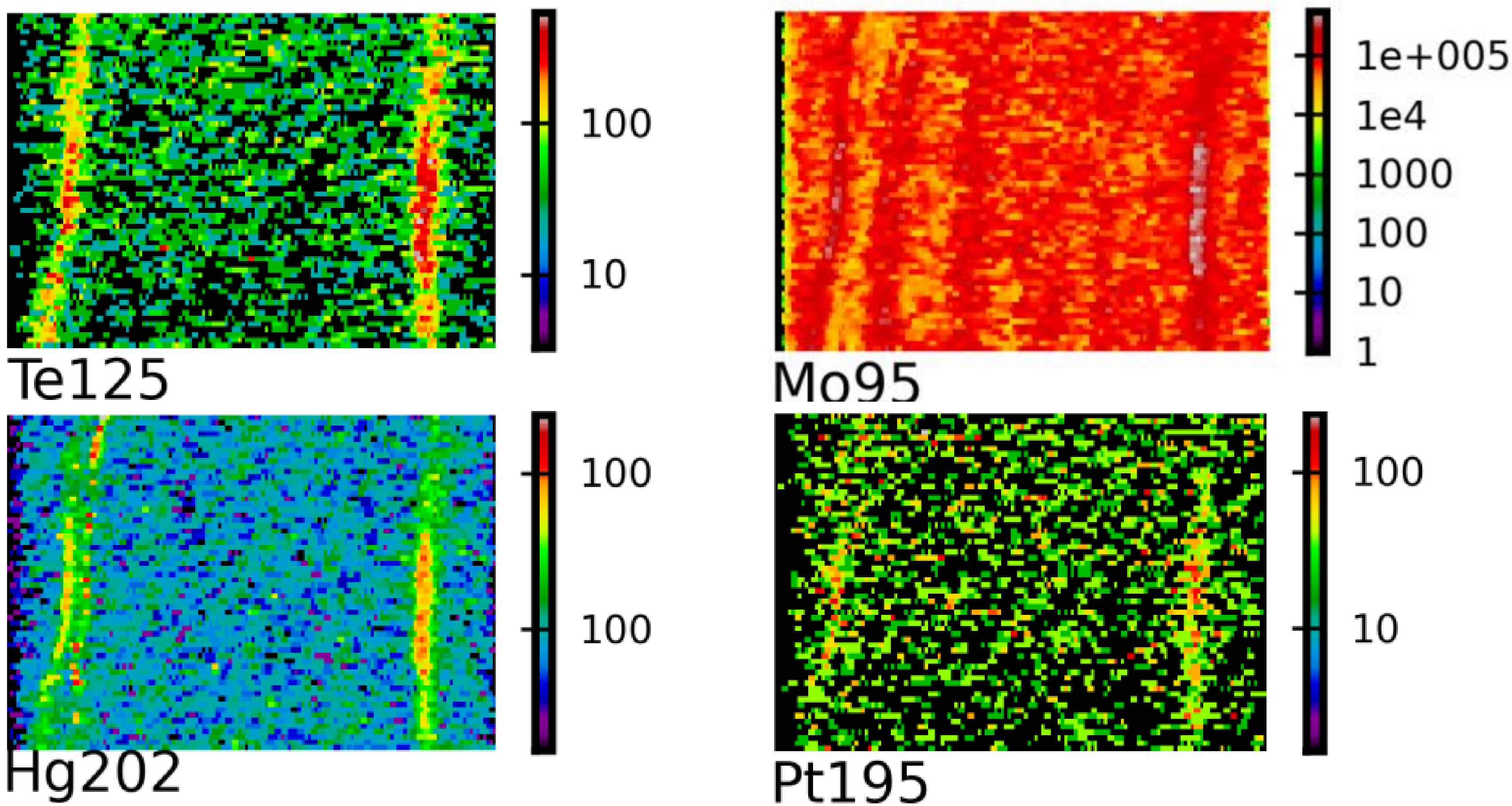
Diagenetic Pyrite Layers;
Enriched in Ag, Au, Se and Ni



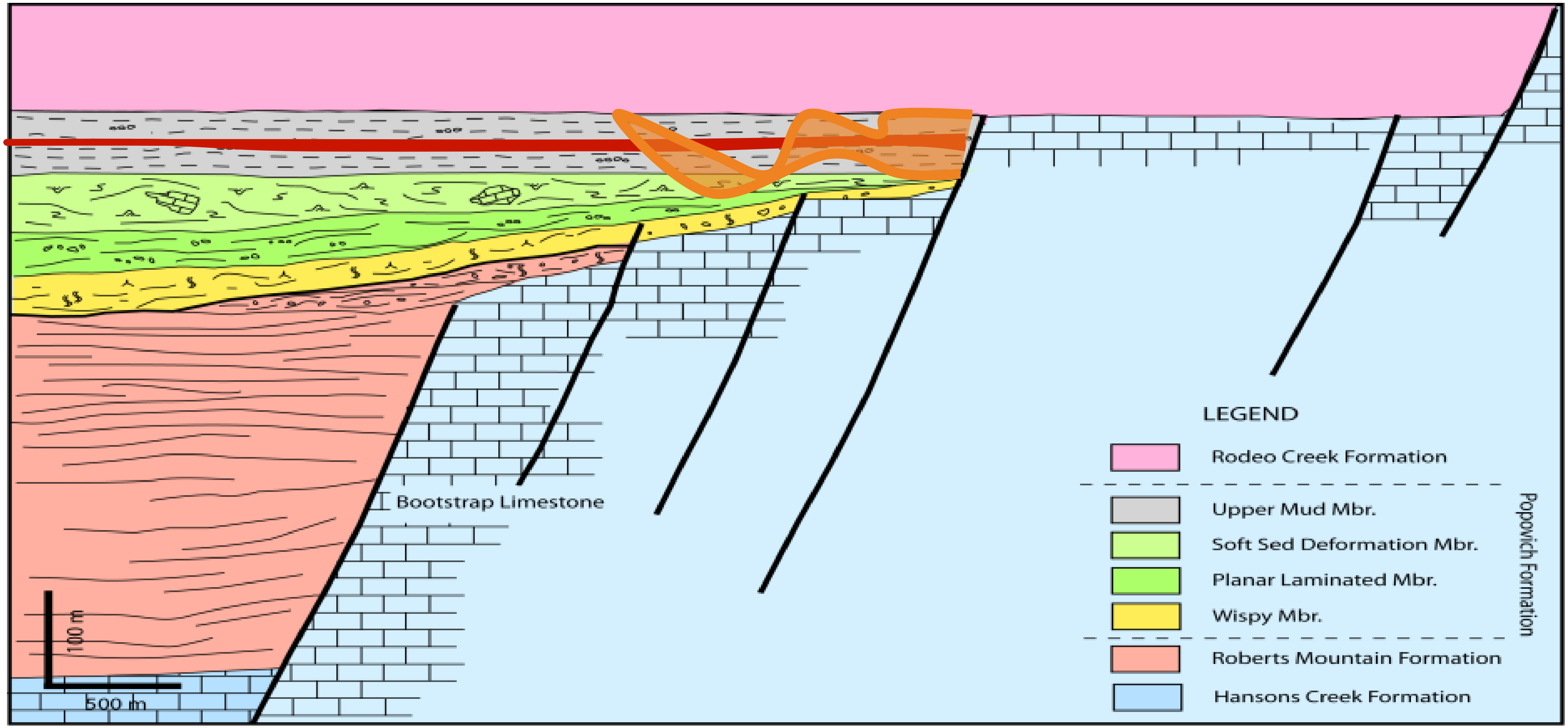




Also Contain Te, Mo, Hg, Pt



Epigenetic Carlin Gold Overprints Metalliferous Shale



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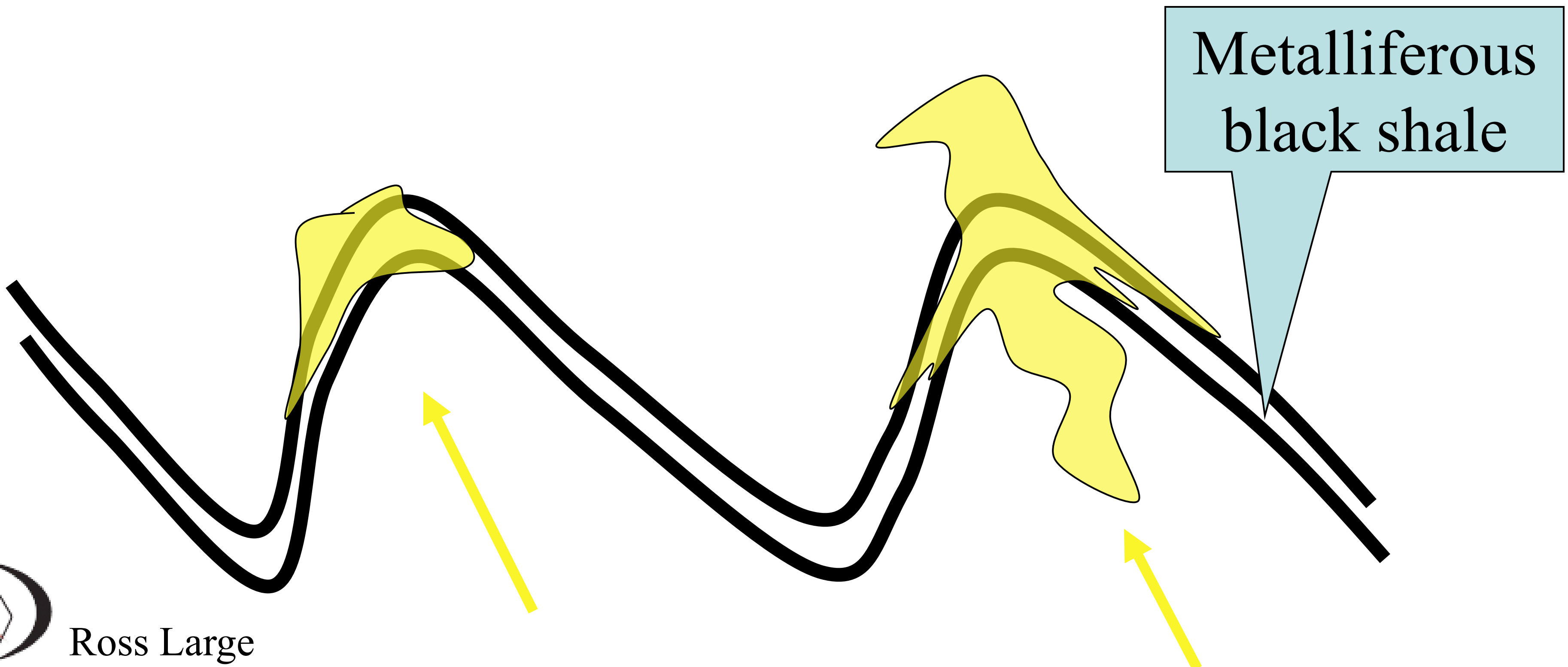
This is a Very Common Feature of Carlin and Orogenic Au Deposits



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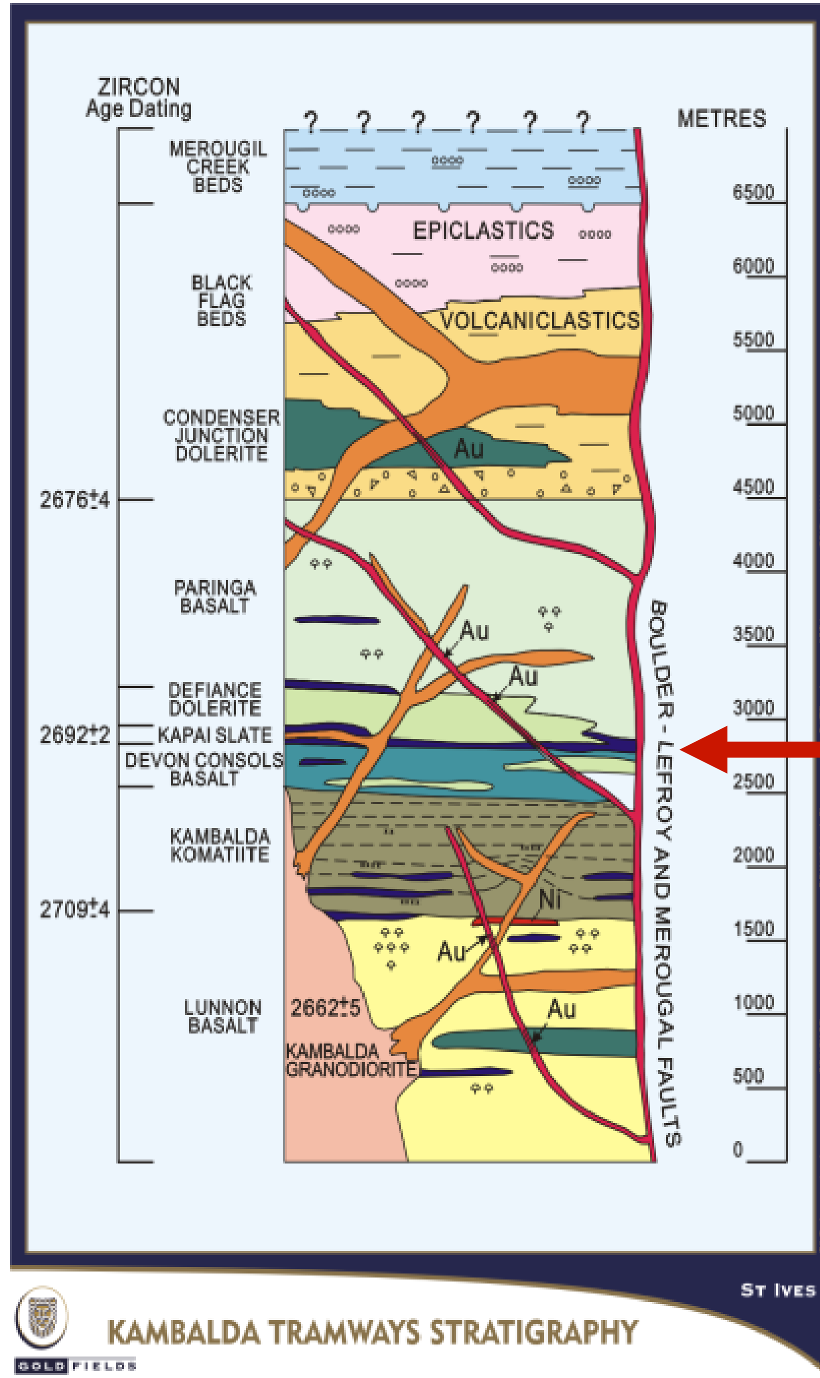
Kapai Slate is a metalliferous black shale which may play a similar role in the Goldfields

(The green leader?)



Kapai Slate

Take Home Message(s)

- **Metalliferous black shales are developed from Archean to Jurassic**
- **Related to periods of widespread ocean anoxia**
- **Potential economic metals are Ni, Zn, Cu, Mo, U, Au and PGEs**
- **Stratifom or stratabound ores can be regionally extensive, low grade but billions of tonnes**
- **These thin metalliferous shale horizons can be the focus for later hydrothermal gold overprinting and concentration (e.g. North Carlin Trend)**

Where to Explore in Australia for Metalliferous Shales

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