WOLD-CLASS CARLIN-TYPE GOLD DEPOSITS AT THE GOLDSTRIKE PROPERTY, NEVADA, USA

Prof. Gema Ribeiro Olivo

SIMEXMIN 2010

Queen's UNIVERSITY

OS DEPÓSITOS DE OURO DE CLASSE MUNDIAL DO TIPO CARLIN DE GOLDSTRIKE, NEVADA, ESTADOS UNIDOS

Prof. Gema Ribeiro Olivo

SIMEXMIN 2010

Queen's UNIVERSITY

AGRADECIMENTOS/ ACKNOWLEDGMENTS

- PROF. ONILDO J. MARINI, CHICO AZEVEDO, JEFFREY HEDENQUIST, ADIMB, SEG, AND SIMEXMIN/SEG 2010 ORGANIZING COMMITTEE
- Collaborators: CAROLINA ALMEIDA, ANNICK CHOUINARD & CHARLES WEAKLY

PREA

OUTLINE

- LOCATION AND TECTONIC SETTING
- ECONOMIC IMPORTANCE, RESOURCES, PRODUCTION & EXPLORATION
- GEOLOGY OF THE GOLDSTRIKE PROPERTY
  - STRUCTURAL AND LITHOLOGICAL CONTROLS
- PARAGENESIS AND TYPES OF GOLD ORE
- SOURCE OF ORE-RELATED ELEMENTS
- GENETIC MODEL
- GUIDELINES FOR EXPLORATION

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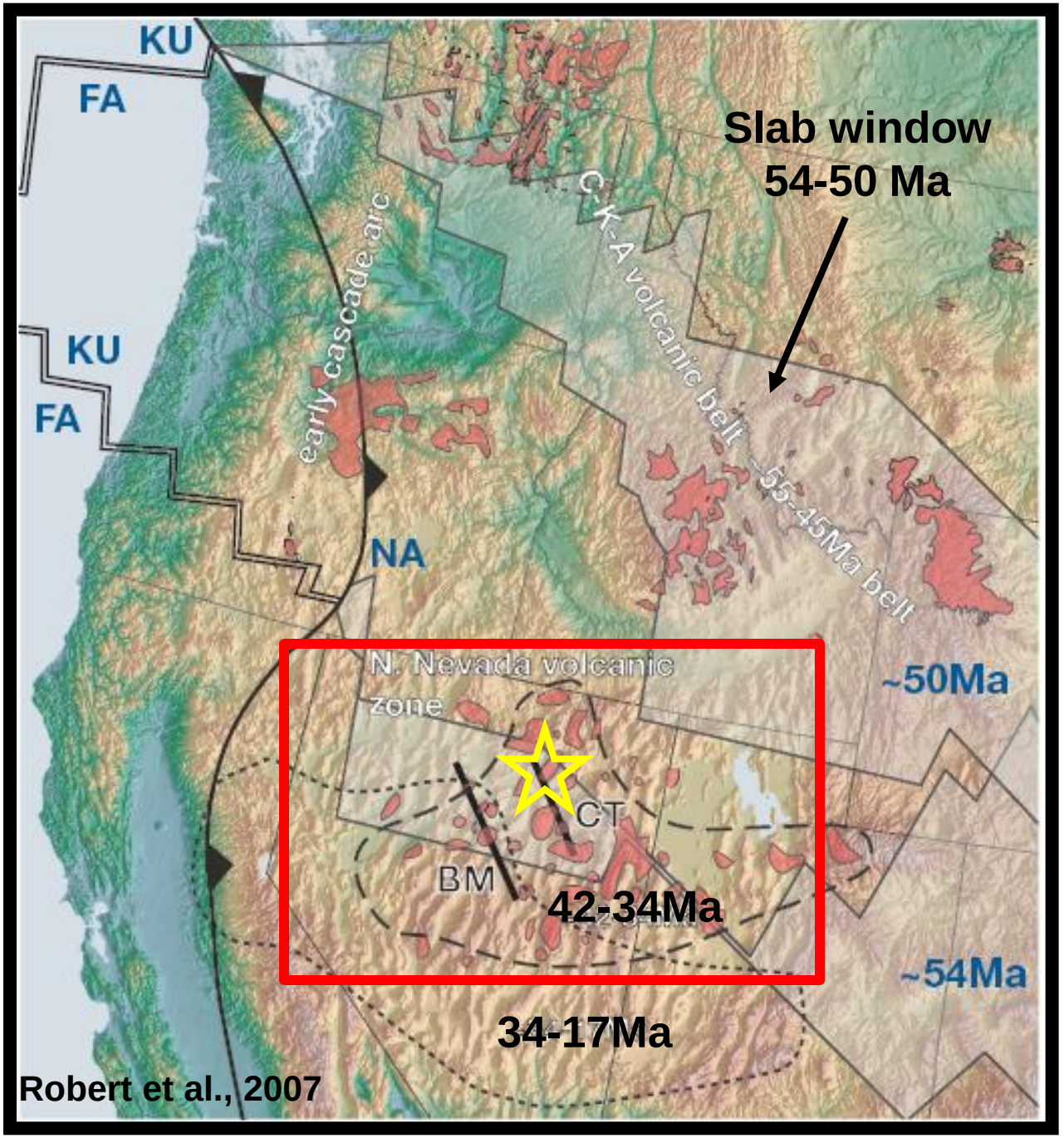
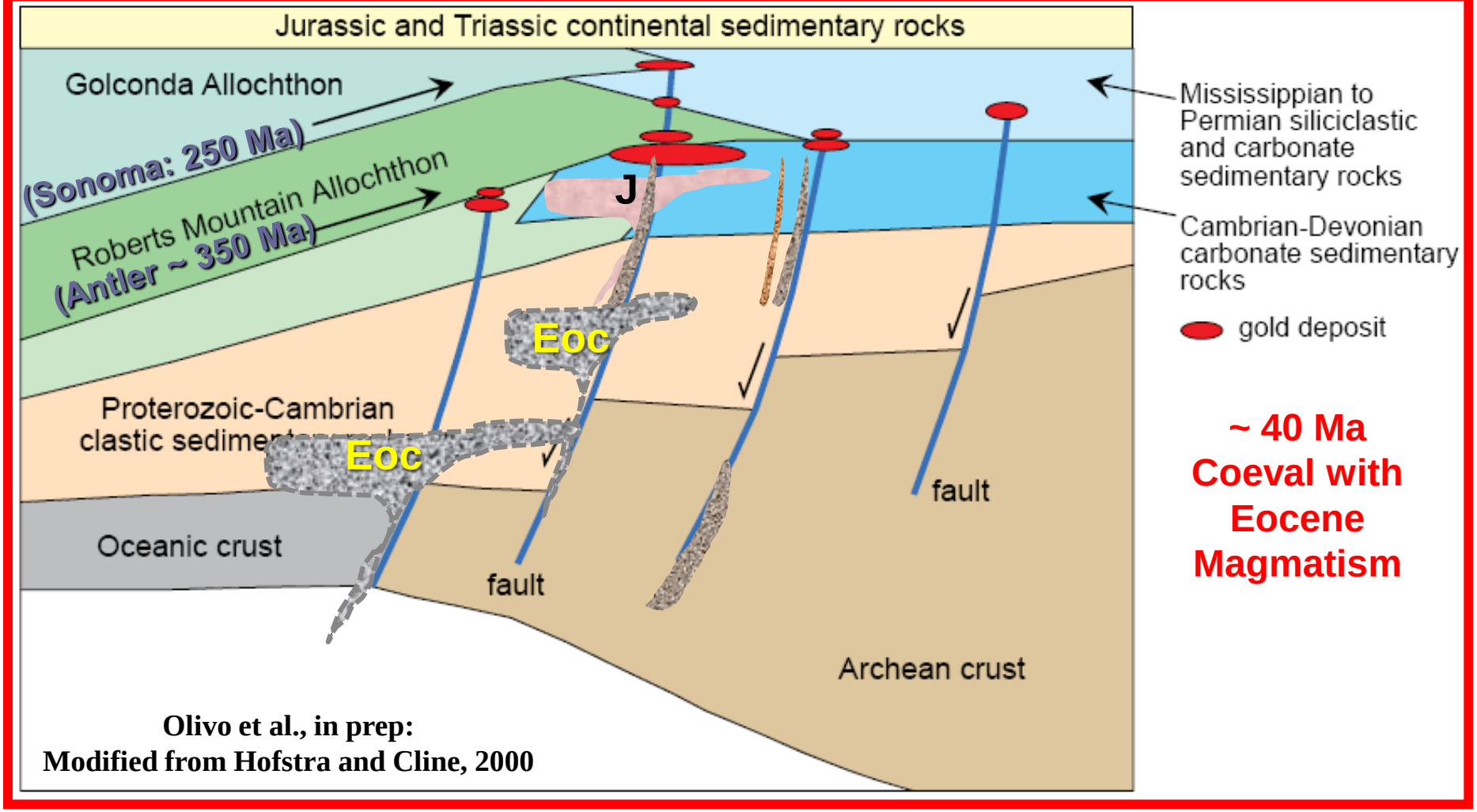
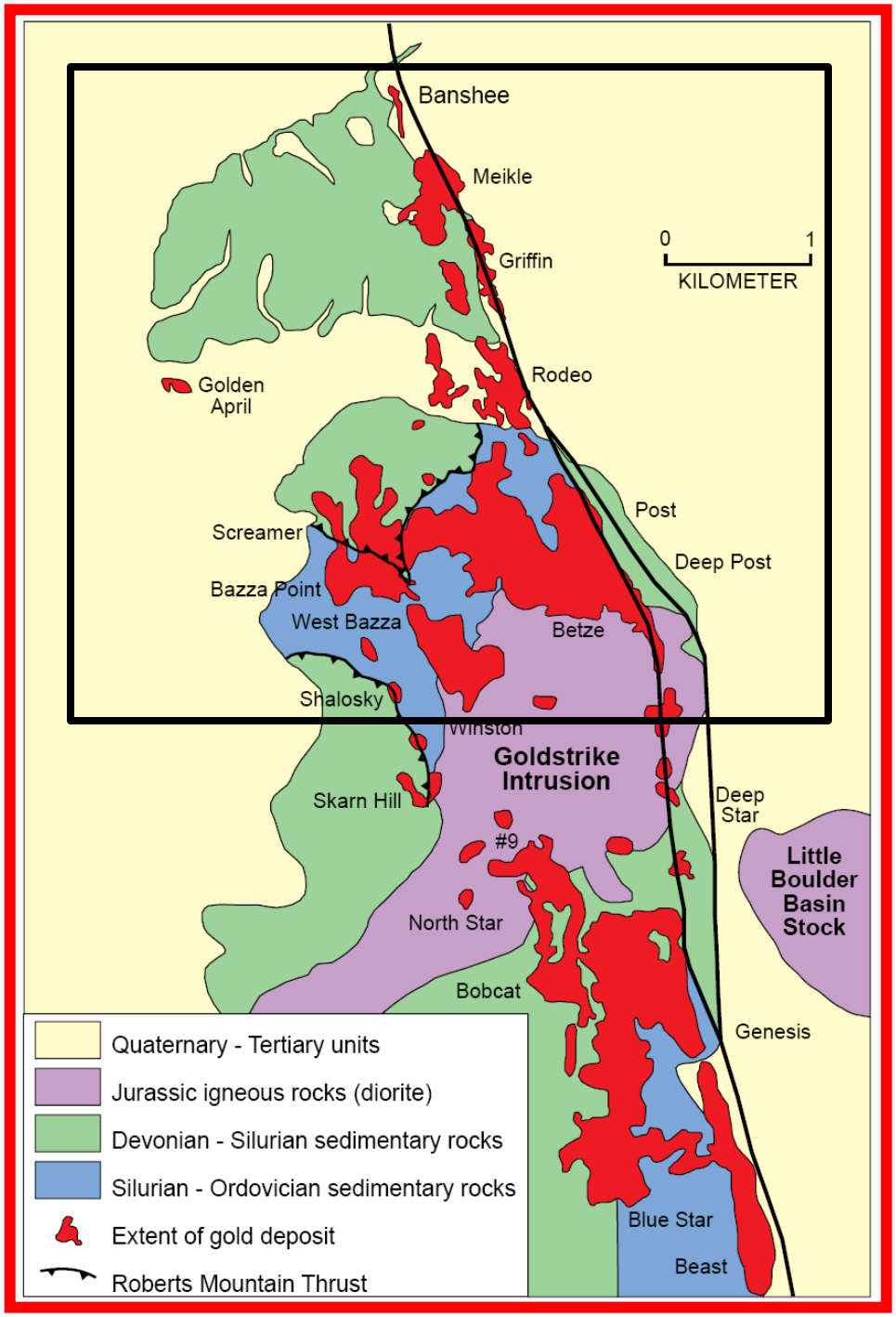


Tectonic Setting

- Basin and Range-Nevada USA
- Coeval with 42-39 Ma magmatism
- In major structural trends: CARLIN TREND

CARLIN-TYPE DEPOSITS: GEOLOGICAL SETTING





Goldstrike: North Carlin Trend

- Ore bodies project to the surface
- Structural controls of the intrusions and gold mineralization

(Modified from Bettles, 2002)

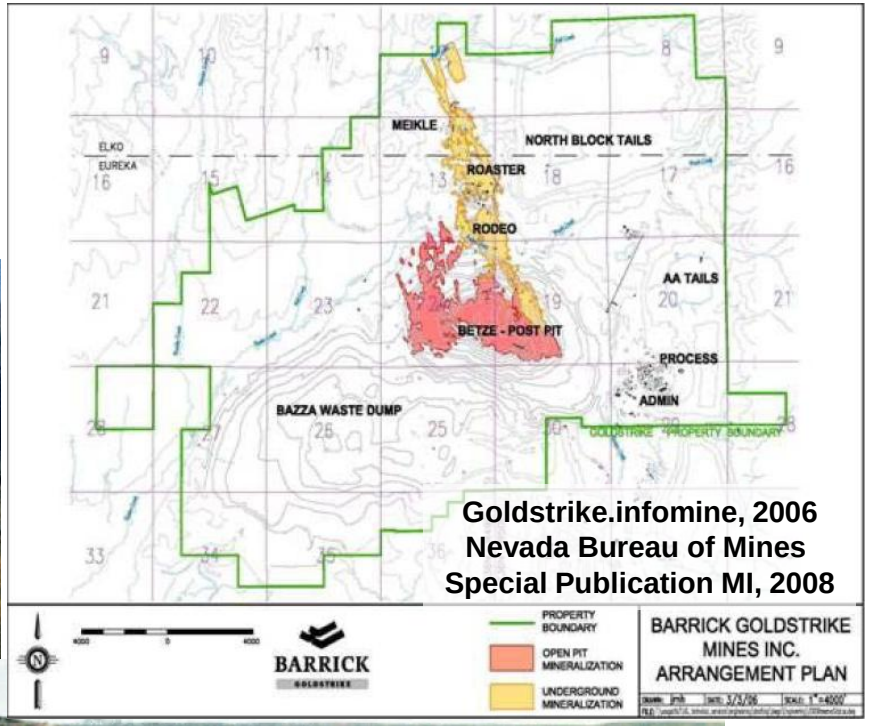
Goldstrike History

- **1962: First drill hole**
- **1976: PanCanada Minerals Ltd production**
- **1986/87: Barrick acquired 100% interest: $62 million**
  - **Post surface oxide deposit- heap leach (0.5 million ounces of Au)**
- **1988: Discovery of Rodeo deposit**
- **1989: Betze Development Plan: larger open pit and expansion of milling facilities**
- **1989: Discovery of Meikle deposit**
- **1996: Meike production- underground mine**
- **2001: Rodeo production - underground mine**

Goldstrike History

- **Goldstrike complex (30% of the Carlin trend gold production):**
  - **Betz-Post ore zones: open pit**
  - **underground operations: Meikle and Rodeo**
- **2008 total production: 1,706 thousand ounces Au @ US$ 452/ounce (grade: 0.175 ounces/ton)**
- **2009 total production: 1,355 thousand ounces Au @ US$ 464/ounce (grade: 0.172 ounces/ton)**
- **Expected remaining mine life: 11 years for underground mining, 14 years open pit and 26 years processing operations**

GOLDSTRIKE:
pit and underground



Goldstrike.infomine, 2006
Nevada Bureau of Mines Special Publication MI, 2008

BETZE-POST ORES ZONES

1,828 m extension

183-244 m width

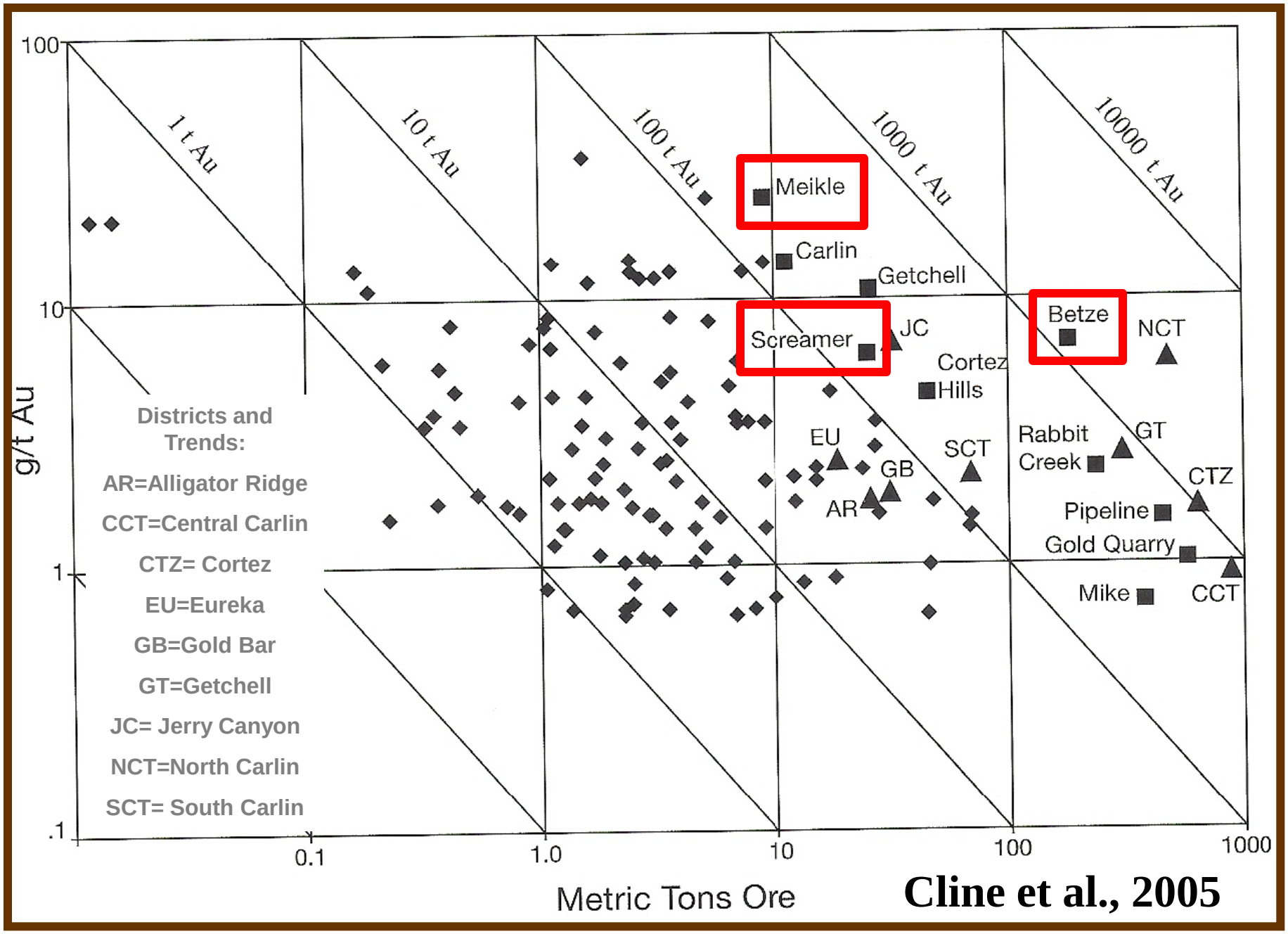
122-183 m thickness

GOLDSTRIKE

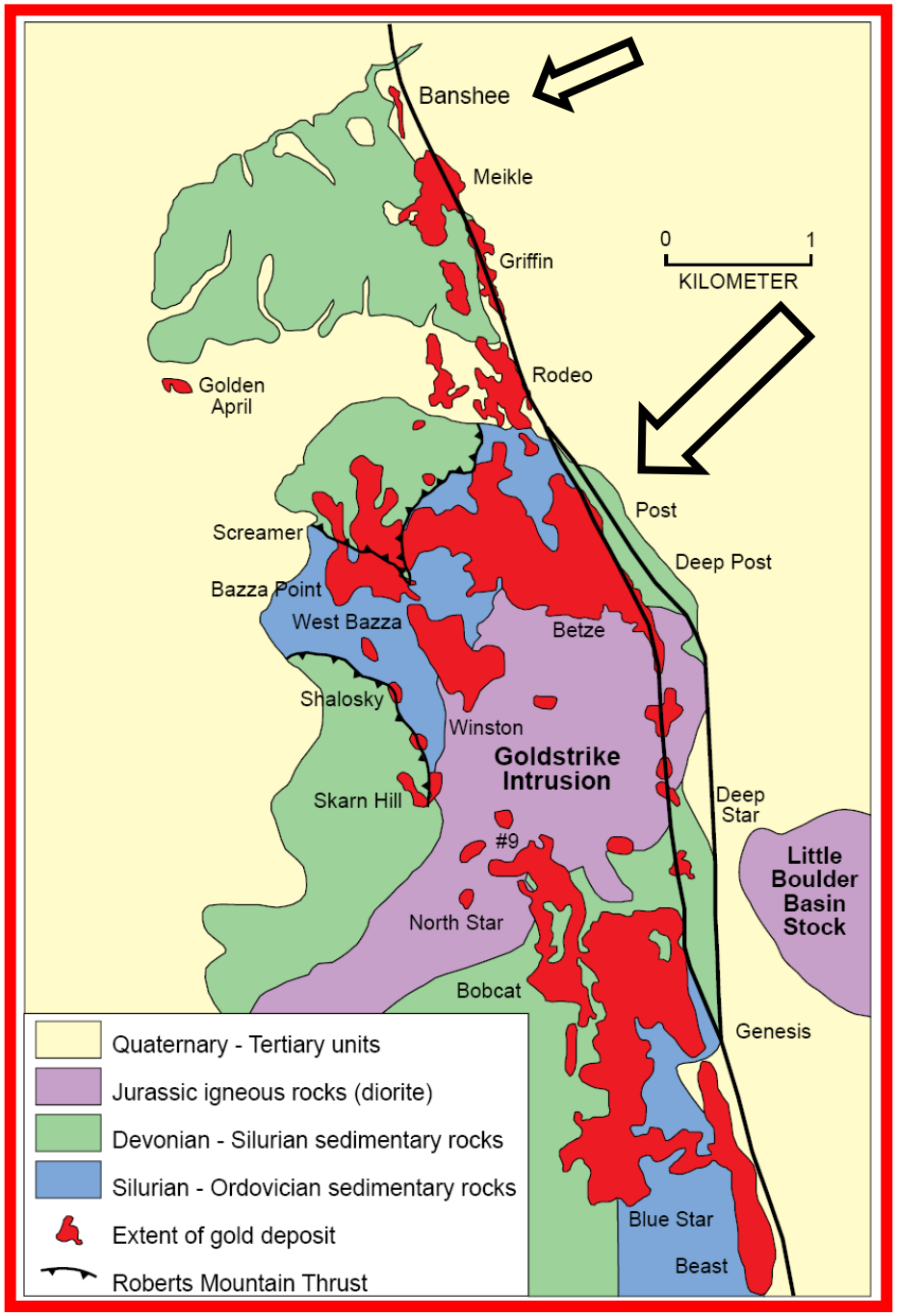
RESOURCE AND PRODUCTION

2008	BETZ-POST	MEIKLE
PROBABLE AND PROVEN RESERVES	86,254,000 tons @ 0.110 opt Au	6,923 million tons @ 0.368 opt Au
MEASURE AND INDICATE RESOURCE	15,751,000 tons @ 0.055 opt Au	4,467 million tons @ 0.333 opt Au
INFERRED RESOURCE	479,000 tons @ 0.092 opt Au	3.344 million tons @ 0.393 opt Au
PRODUCTION	1,281,450 oz Au 152,886 oz Ag	424,687 oz Au 51,434 oz Ag

Nevada Bureau of Mines Special Publication MI 2008



Cline et al., 2005



Goldstrike: 2009/2010 Exploration

- 2009: drifting and resource delineation at Deep North Post underground & drilling in Banshee
- 2010 Deep North Post and Corona (NNW of Meikle) drilling
- Up to 2009: 6,500 drill holes in Betze-Post deposit (69% RC and rotary); drilling spacing: 53 m (Betze-Screamer), 46 m (Post), 30 m (North Screamer and Barrel)

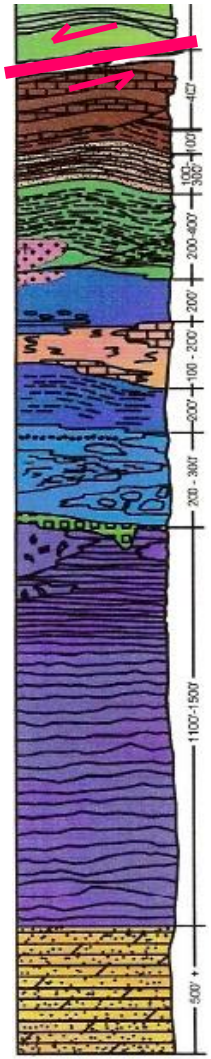
Barrick (2009: SEC)

GOLDSTRIKE HOST ROCKS

EOCENE
(37-40 Ma)
Bt-Pl porphyry dacite, rhyolite, minor mafic dikes

JURASSIC
(158-163 Ma)
Diorite-granodiorite
Lamprophyre dikes

GOLD



Roberts Mtns Thrust

Devonian Rodeo Creek Fm (RC)

Devonian POPOVICH Fm
UM= muddy limestone
SD= laminated limestone
PL= laminated muddy limestone
WS= silty limestone with wispy laminations

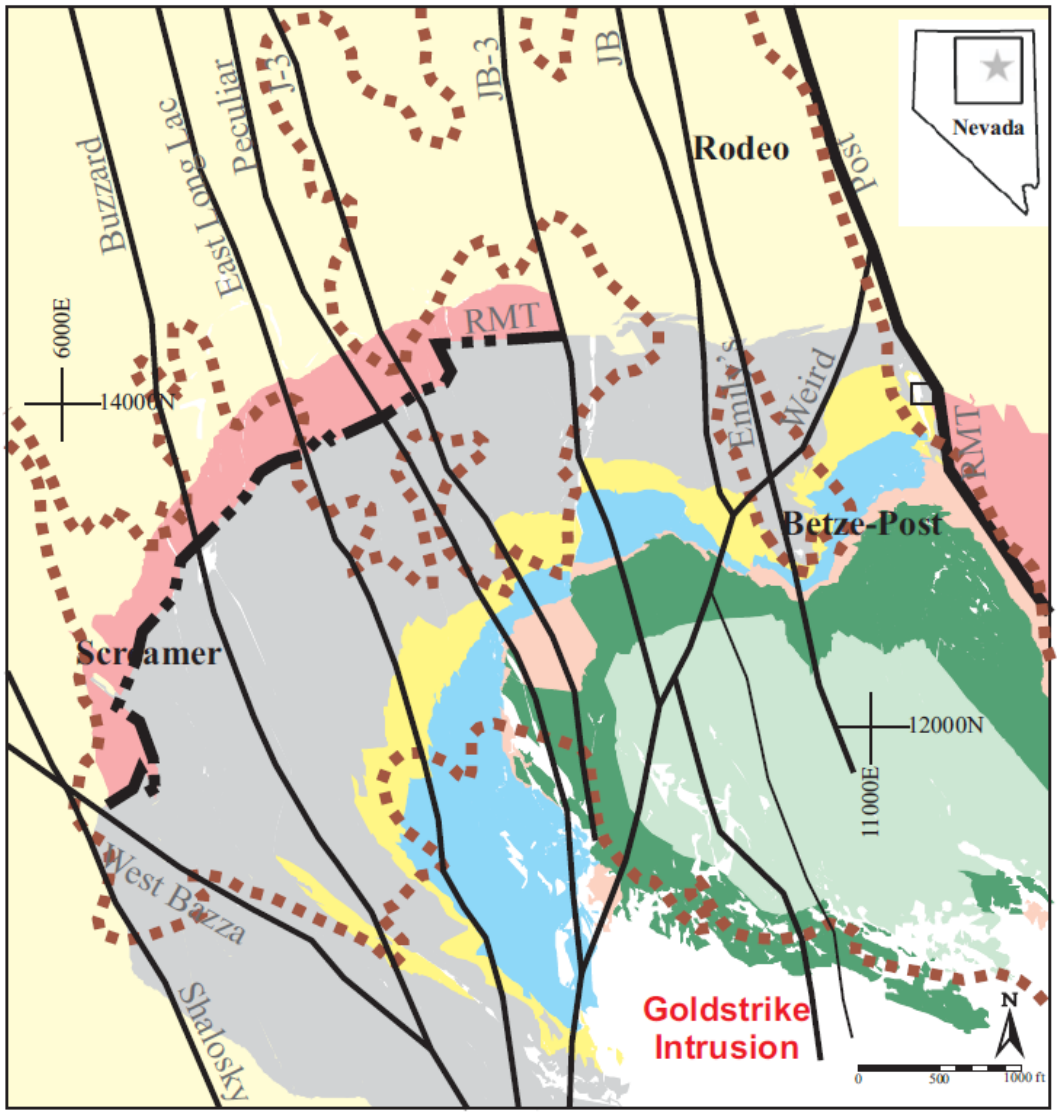
Sillurian-Devonian ROBERTS MTNS. Fm
Upper LL= limestone to dolomitic limestone

Lower LL: sandy limestone to calcareous siltstone

Ordovician Hanson Creek Fm: Sandy Dolomite

(Modified from Volk et al., 2001, Olivo etl al., 2009)

Goldstrike Host-Rocks



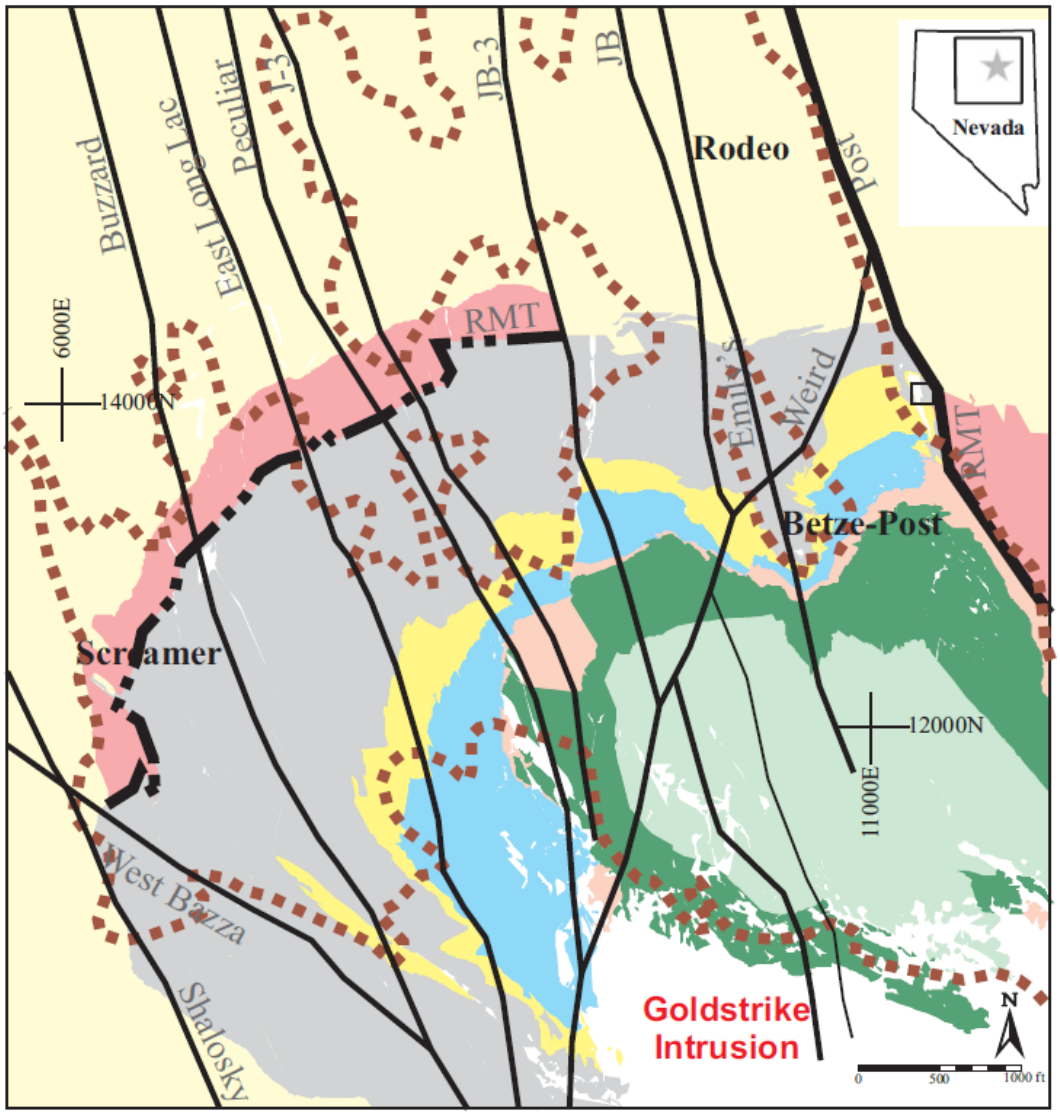
Lithological Units

Popovich Formation

- Carlin Formation and Alluvium
- Goldstrike intrusion and associated dikes
- Rodeo Creek Formation
- Upper Mud Unit
- Soft Sediment Deformation Unit
- Planar Unit
- Wispy Unit
- Roberts Mountains Formation
- Undifferentiated Upper Plate sedimentary rock

(Almeida et al., 2010 in press) Geological contacts and ore grade envelop- 2.02 g/t- compiled from Barrick Gold

Goldstrike: Structural Controls



- Lower-plate units
- Proximity of Jurassic Goldstrike intrusion
- NNW, NE and NW faults
- Anticlinal structures

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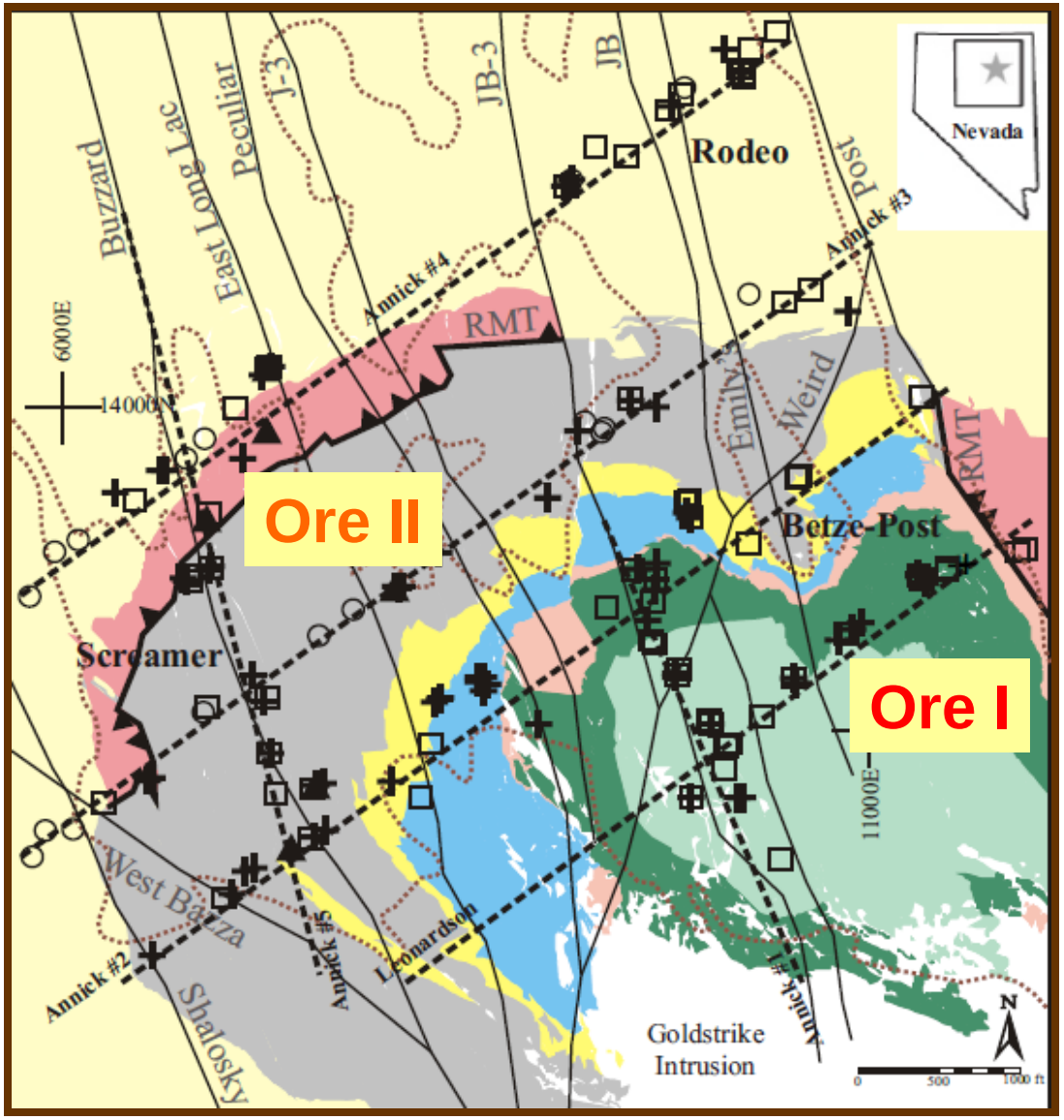
Goldstrike: ORE I AND ORE II



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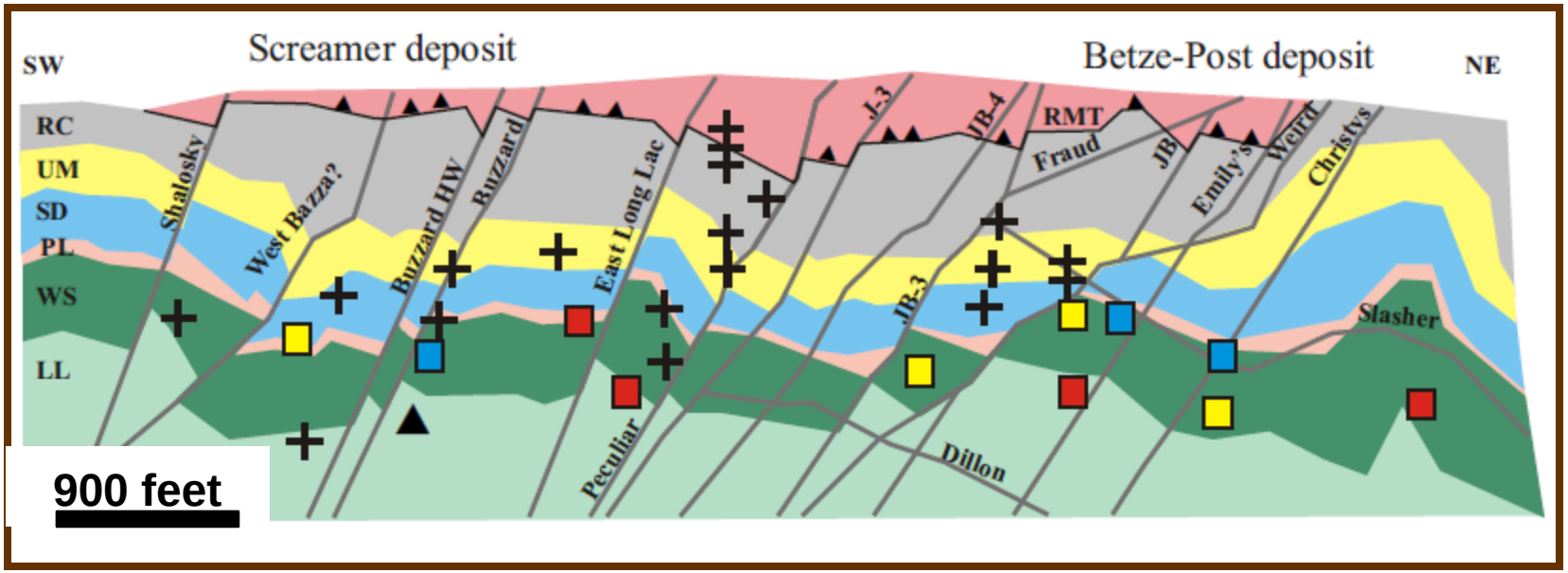
Whole-rock analyses

- Least altered
- Altered and barren (< 1 g/t Au)
- Ore-I
- Ore-II

- Faults
- Sampling cross-section
- Ore-grade contour (2.02 g/t Au)

Olivo et al. (2009), Almeida et al. (2010 in press)

Screamer – Betze-Post Section



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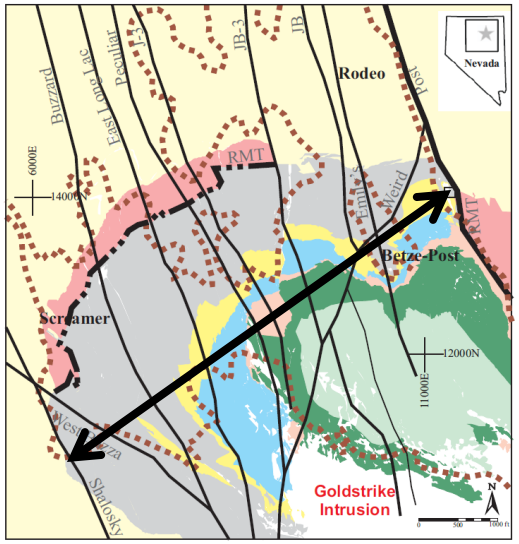
- □ Ore I
- ○ Ore II

Au (g/t)

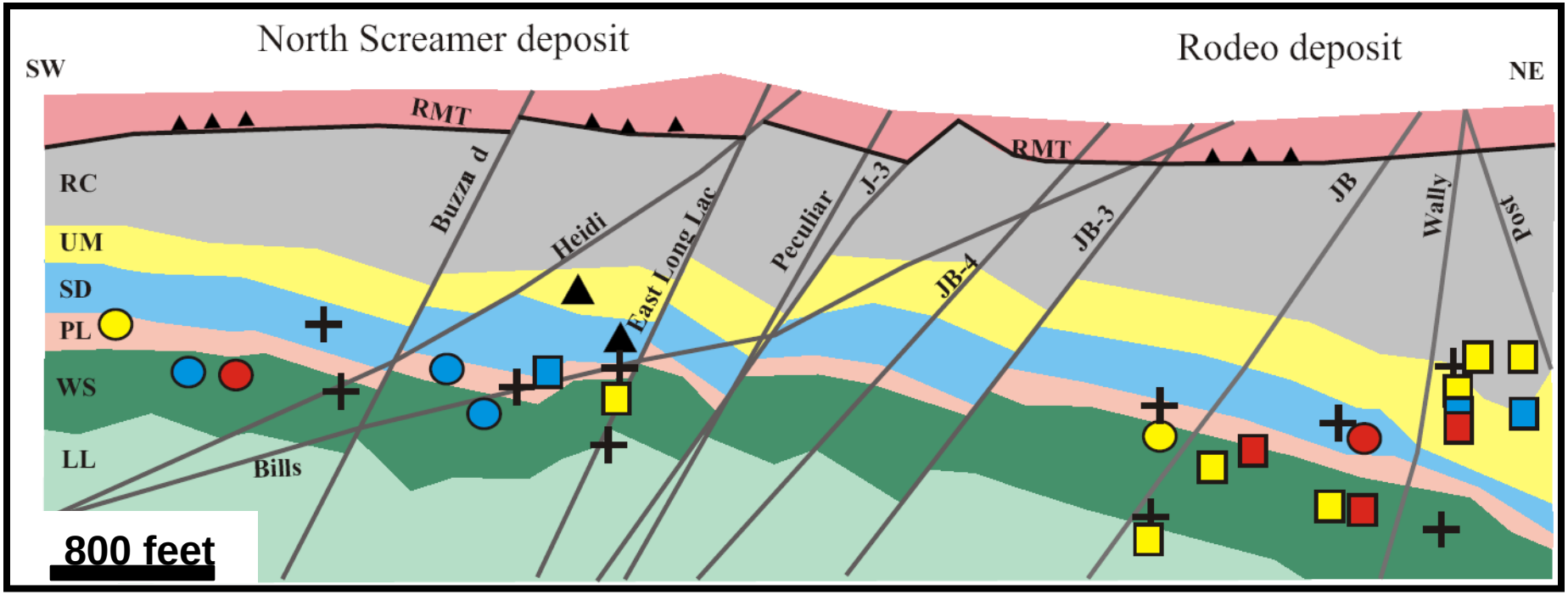
- + <1.00
- 1.01-5.00
- 5.01-10.00
- >10.00

/ Faults



(Almeida et al., 2010 in press)

North Screamer- Rodeo Section



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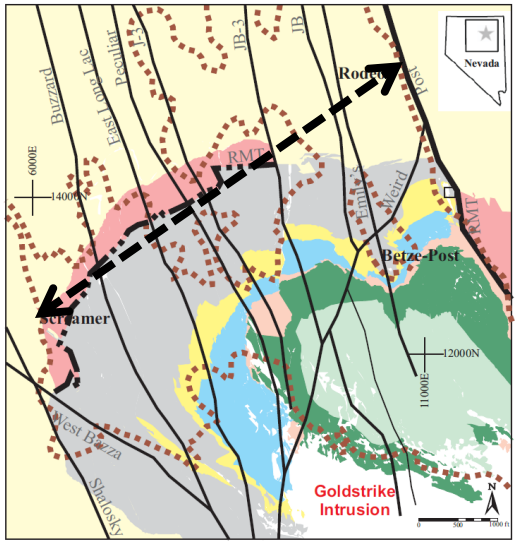


Goldstrike Paragenesis

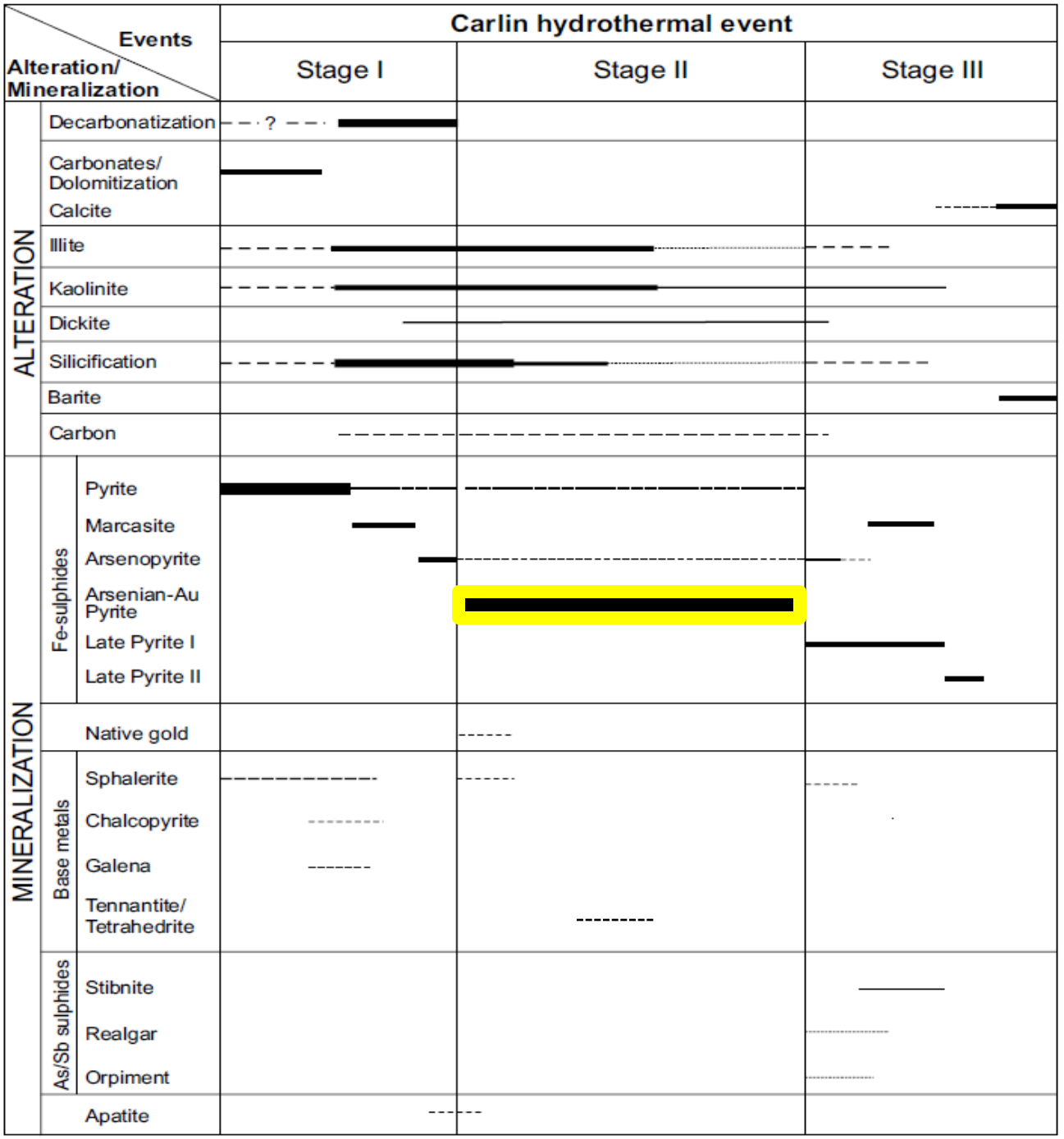
PRE-CARLIN EVENTS:

- PALEOZOIC: Dolomitization, pyrite and sphalerite
- JURASSIC: Calcisilicate alteration

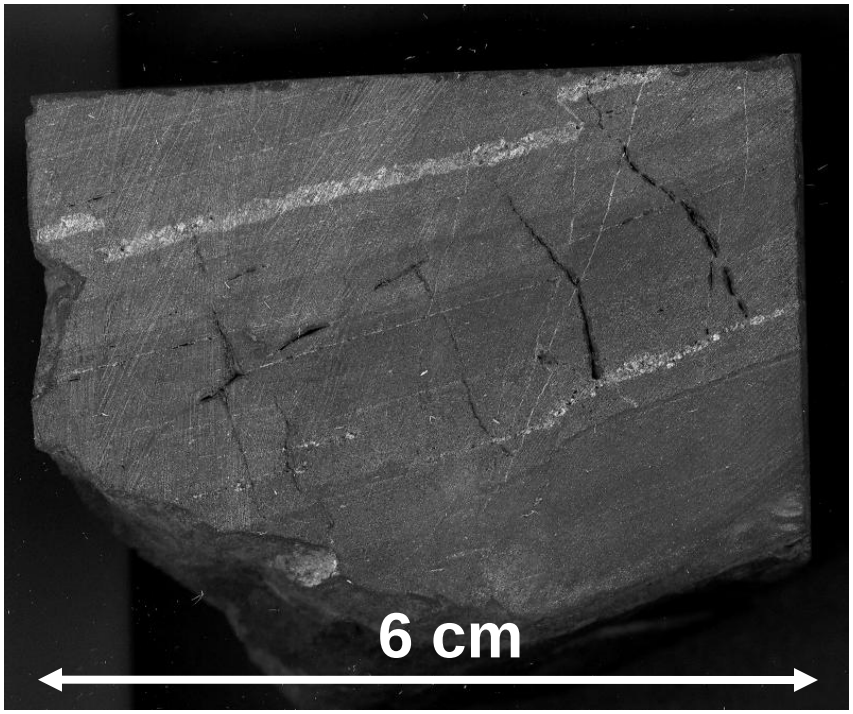
EOCENE CARLIN EVENT (39-40 Ma):

- Early Carlin Stage (Stage I)
  - Carbonate dissolution, silicification, sulfide and clay alteration (hydrothermal)
- **Main Carlin Gold Stage (Stage II):**
  - Silicification, minor clay alteration and sulfides + Au-bearing As-pyrite
- Late to Post Carlin Stage (Stage III):
  - Stibinite, realgar, orpiment, calcite and barite

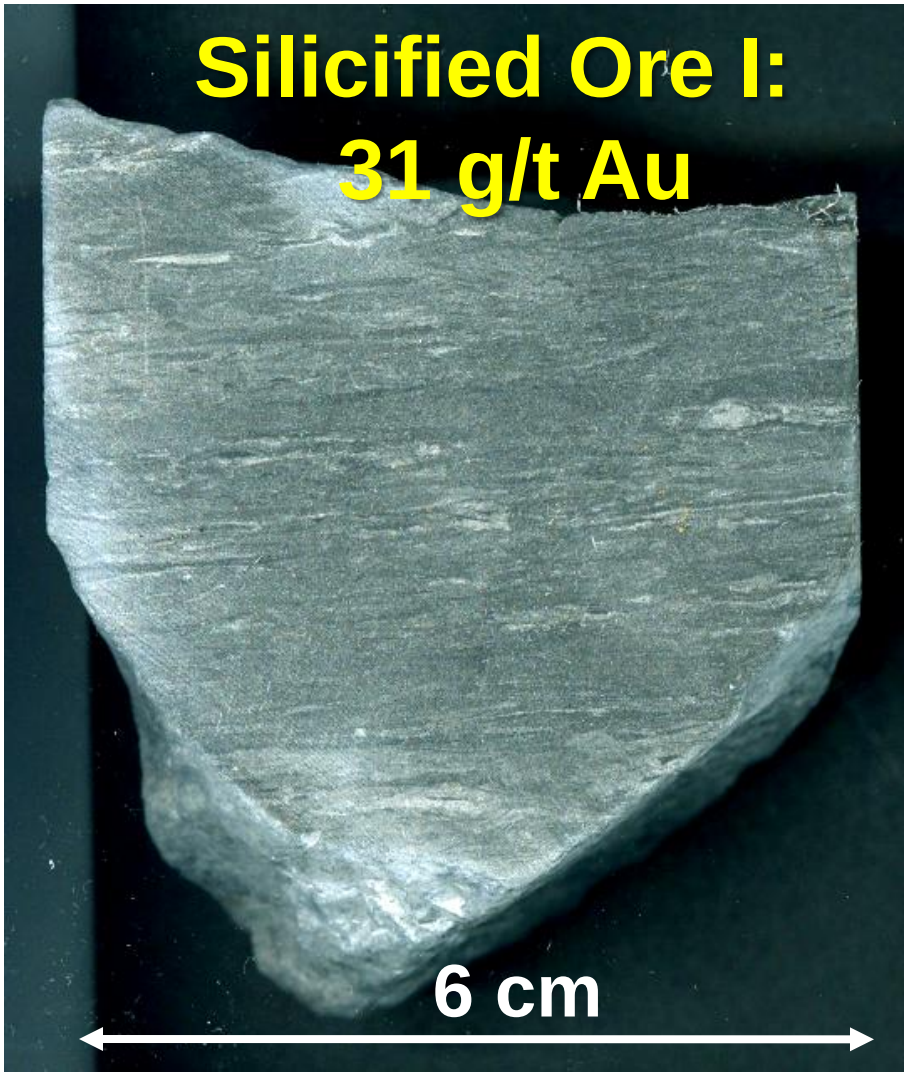
GOLDSTRIKE PARAGENESIS



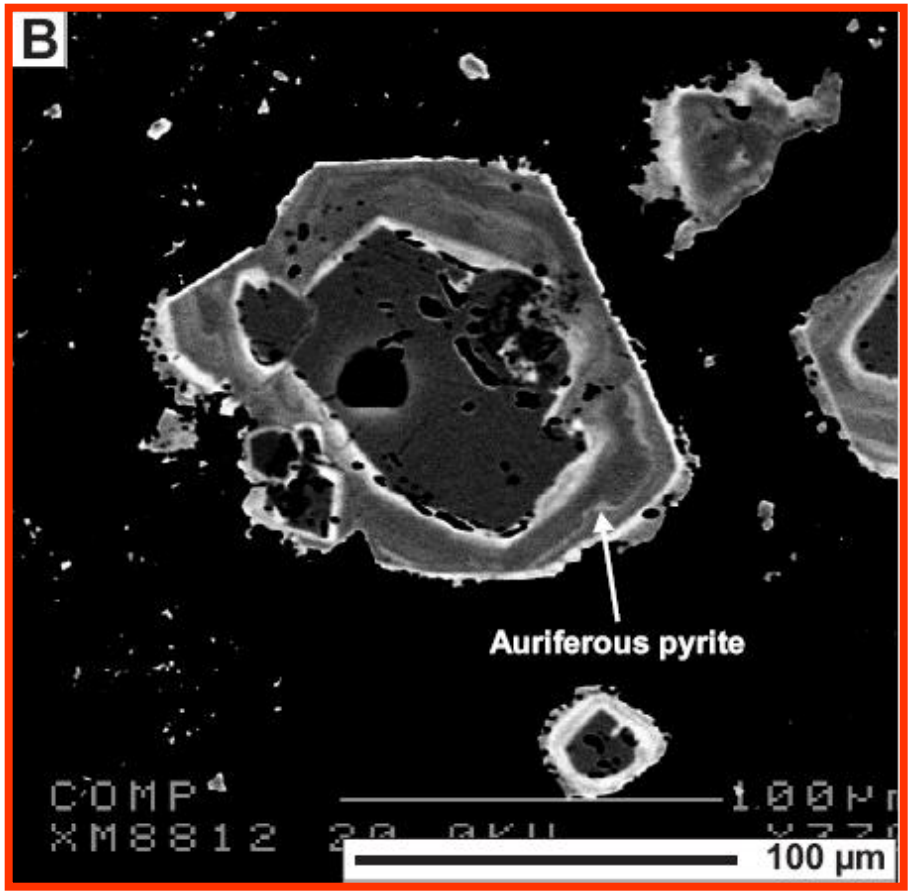
Alteration

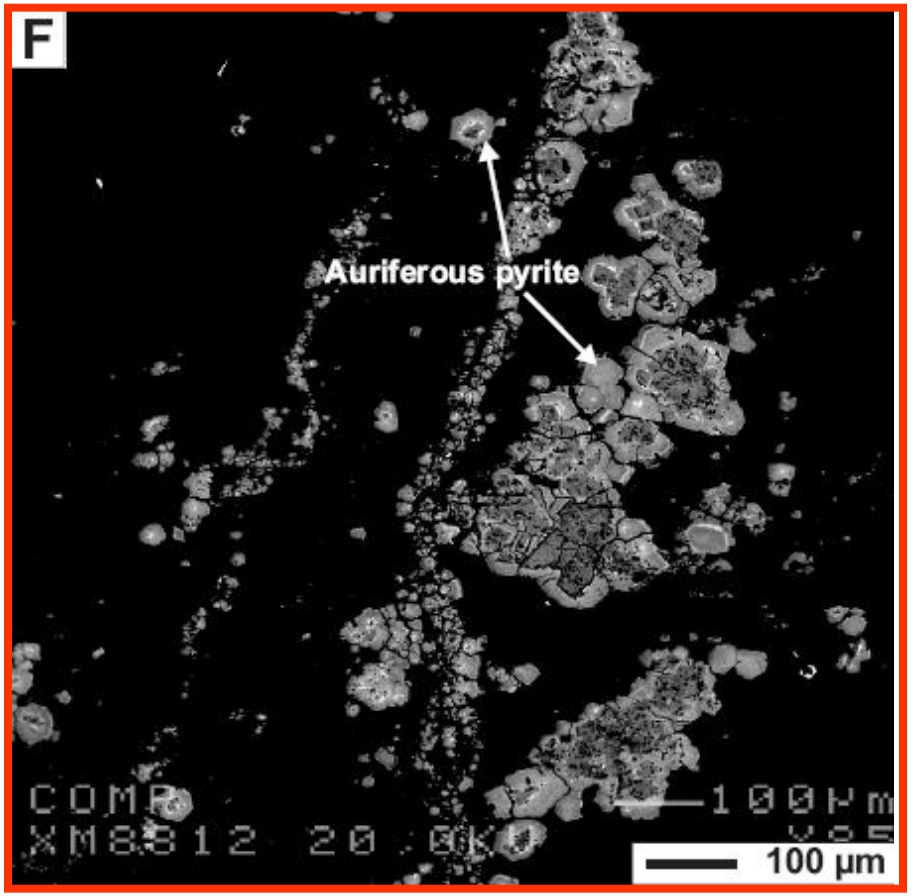


Weakly altered: barren

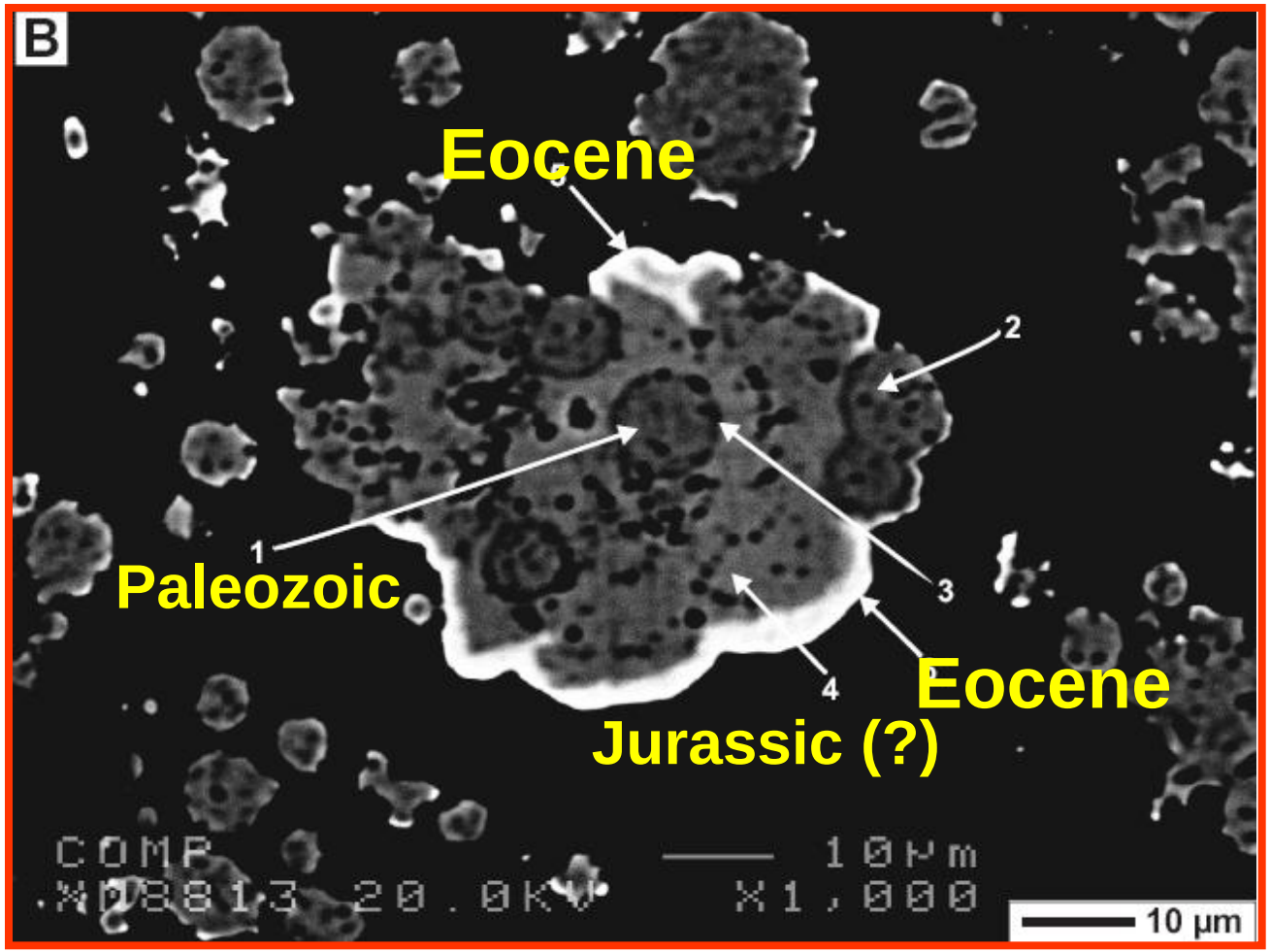


Ore Pyrite





Chouinard, Olivo and Poirer., 2005



Ore Pyrite

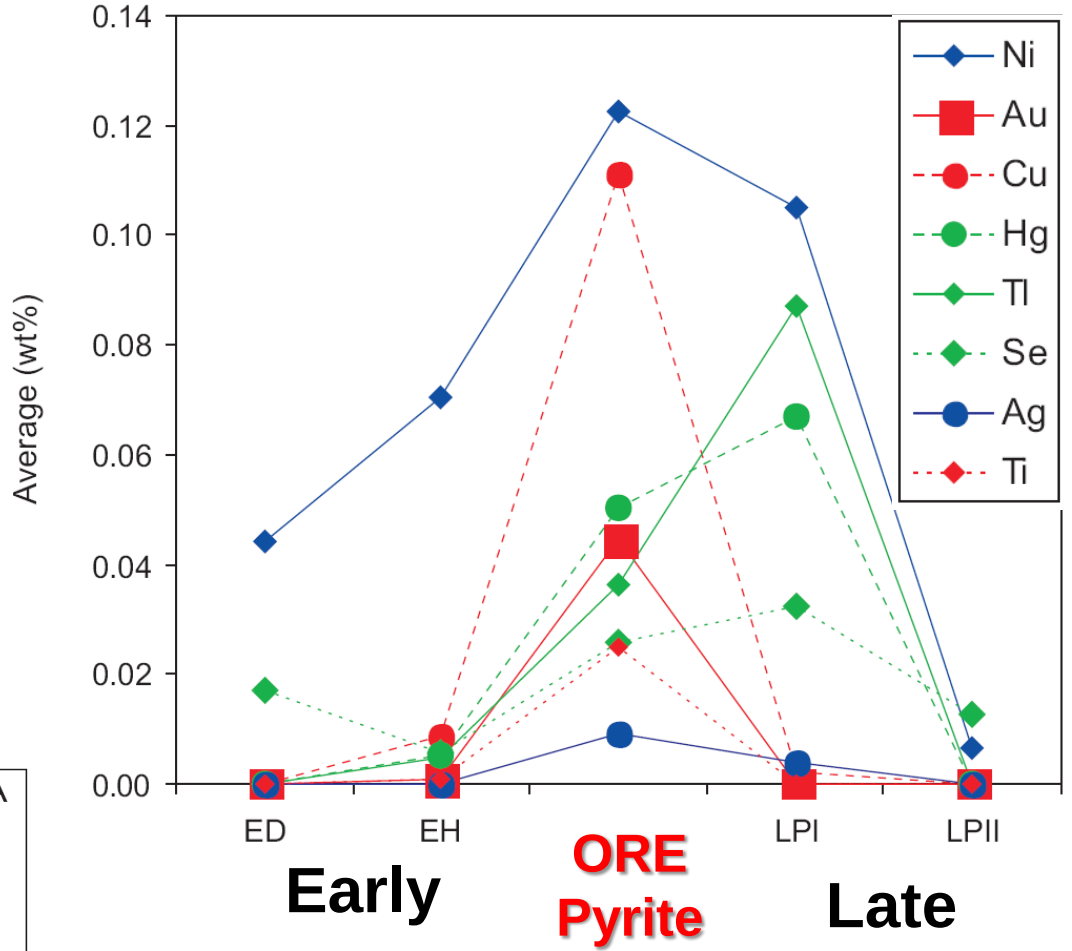
Thin rims overgrowing diagenetic, and J (?) metasomatic pyrite

Electron Microprobe Spot Analyses of Pyrite

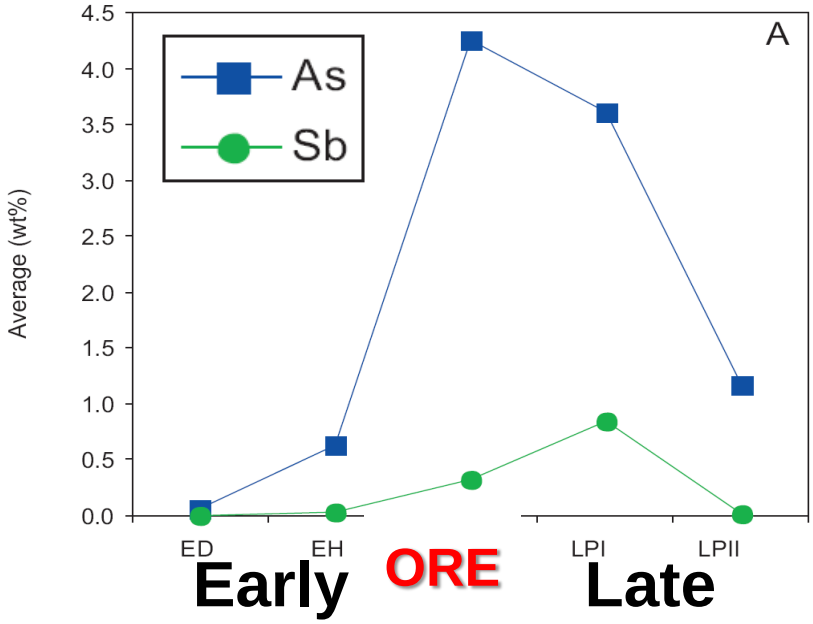
Analysis (wt%)		Ni	As	Au	Cu	Co	Sb	Hg
Framboidal Pyrite	1	0.054	0.085	-------	0.016	0.031	-------	-------
	2	0.043	0.110	-------	0.000	0.000	-------	-------
Brassy Pyrite	3	0.019	-------	-------	-------	0.239	-------	-------
	4	0.029	-------	-------	-------	0.319	-------	-------
Ore Pyrite	5	0.020	5.441	0.102	0.337	-------	0.010	0.036
	6	0.019	7.969	0.126	0.365	-------	0.010	0.000

Chouinard, Olivo and Poirer., 2005

Trace Elements in Goldstrike Pyrites



Data base: >4000 analyses

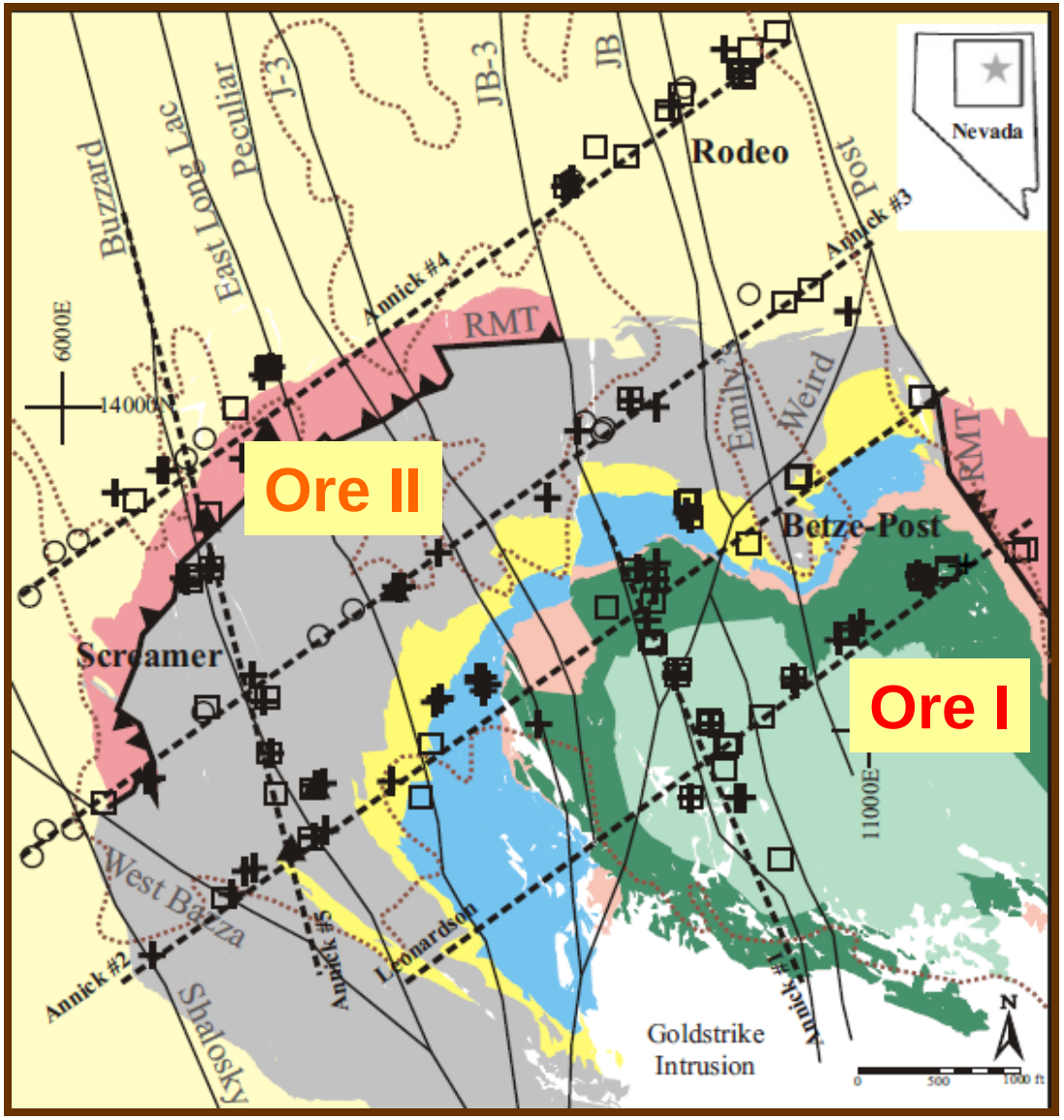


ORE PYRITE rich in:

Au, Ag, As, Cu, Hg, Ni, Tl, Sb, Se (Ti)

(Chouinard, Olivo and Poirier, 2006, Olivo et al. 2009)

Goldstrike: ORE I AND ORE II



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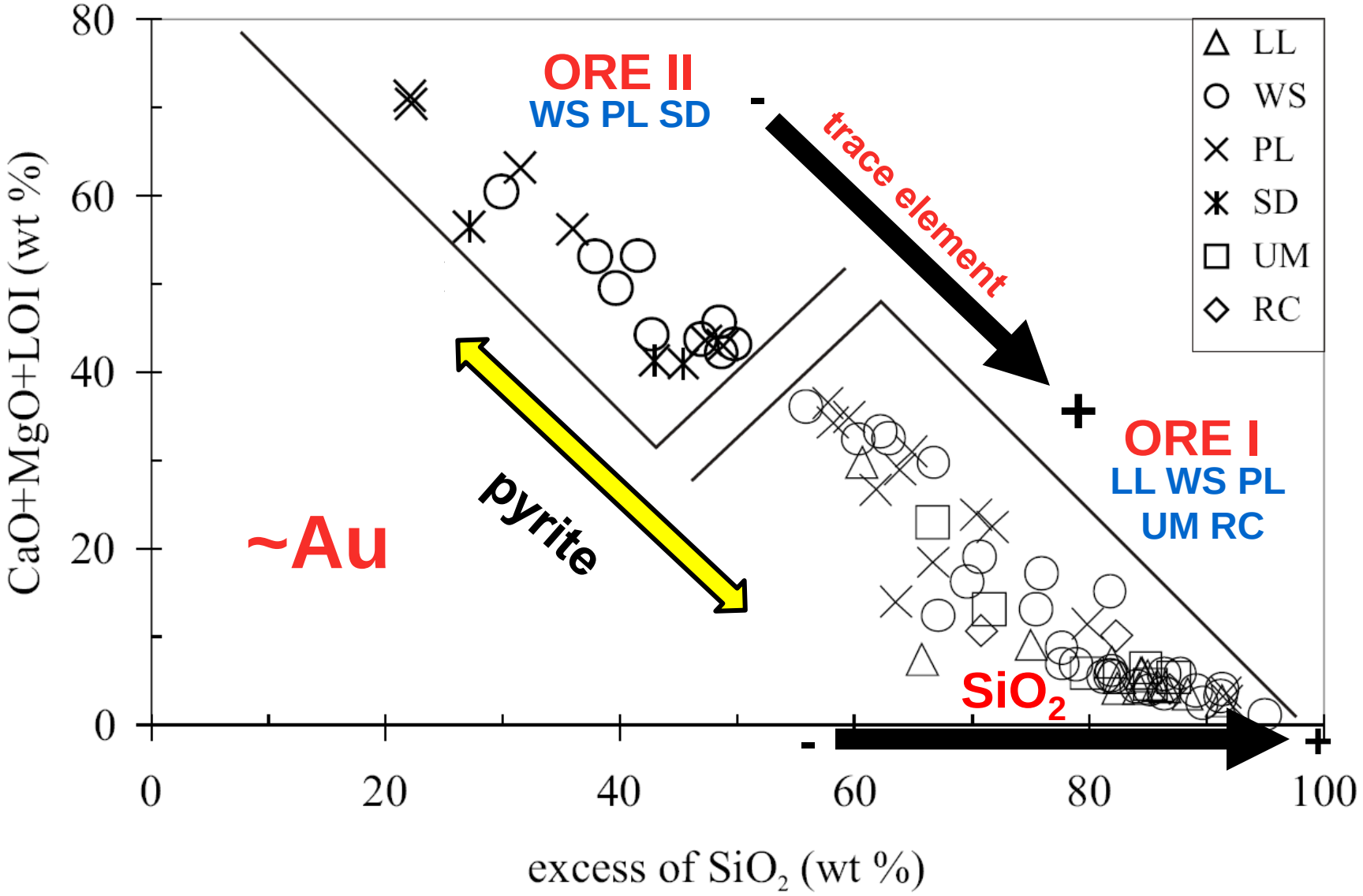
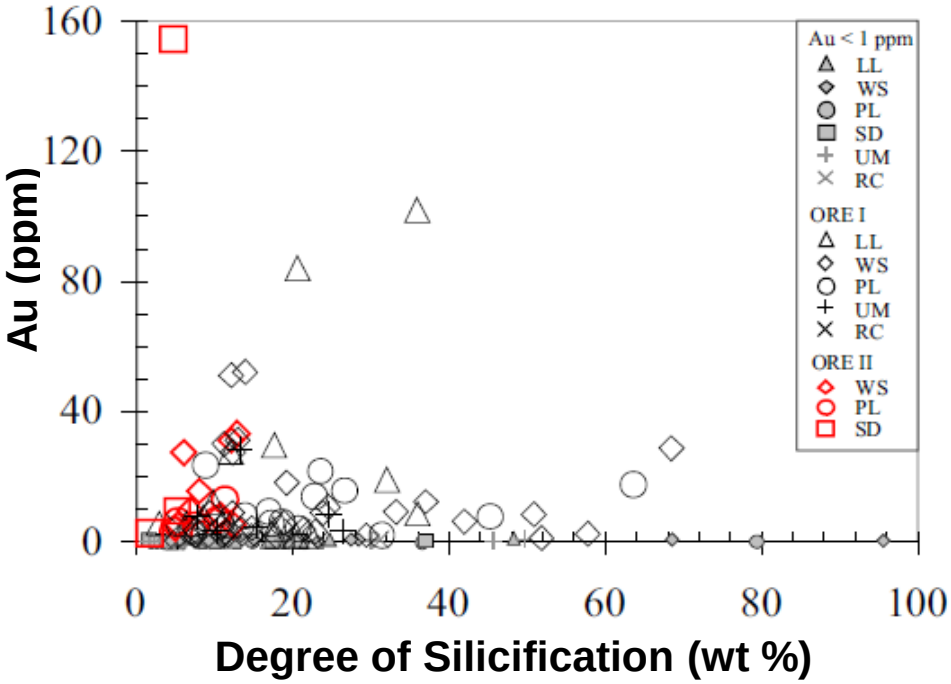
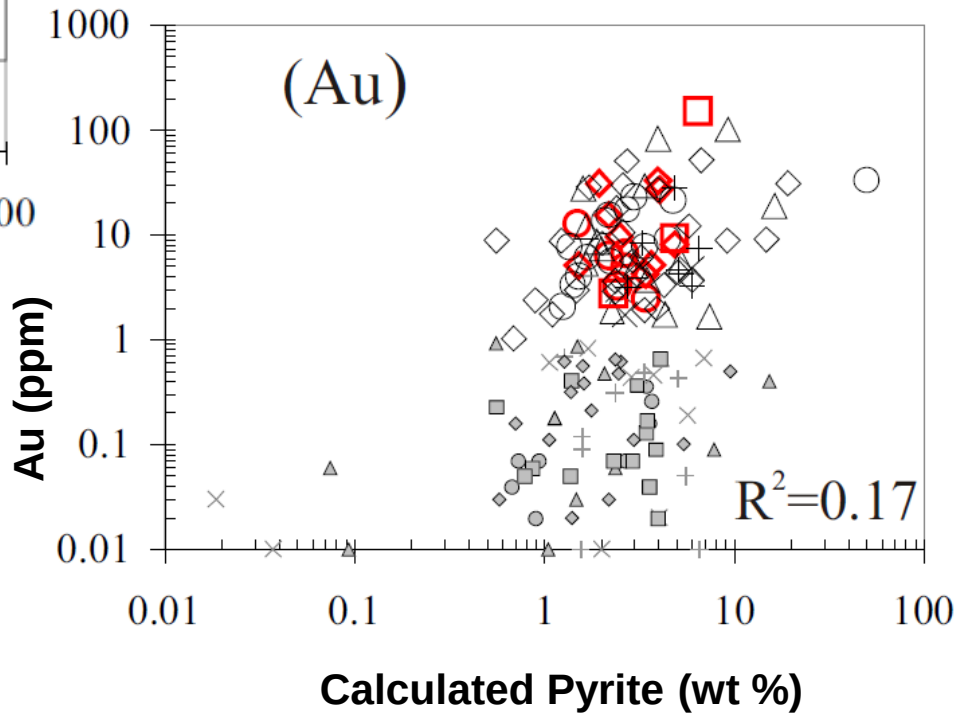
Olivo et al. (2009), Almeida et al. (2010 in press)

Types: ORE I AND ORE II



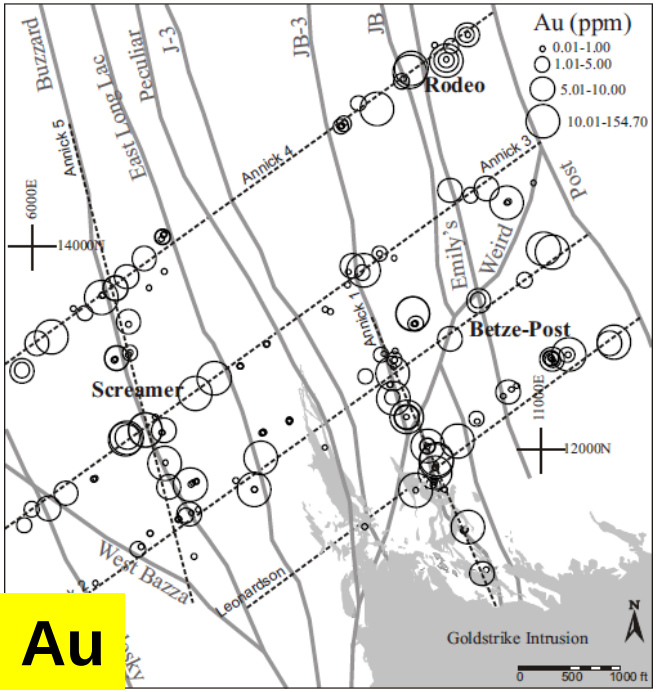
ORE I AND ORE II:
GOLD GRADE X ALTERATION

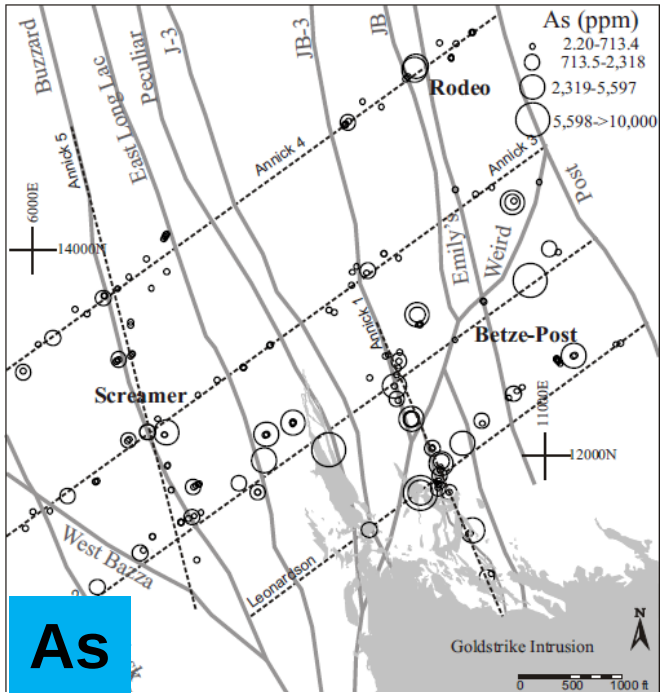


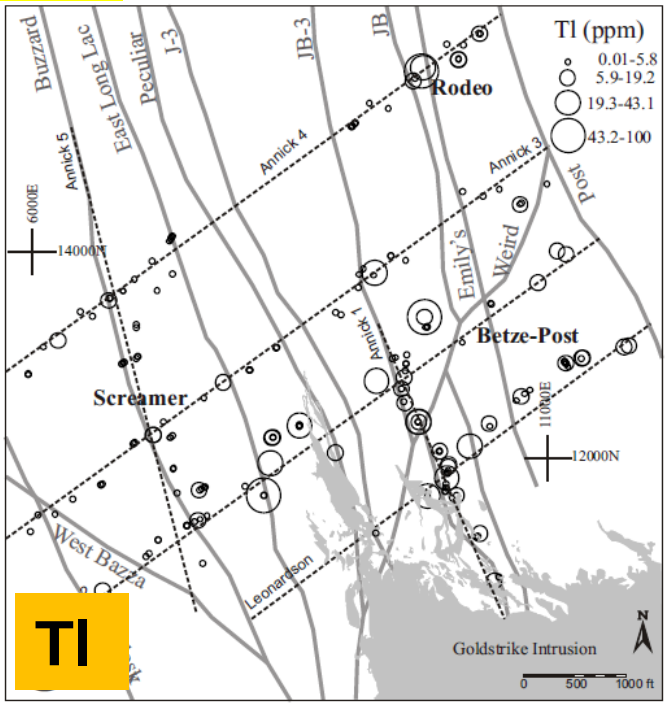


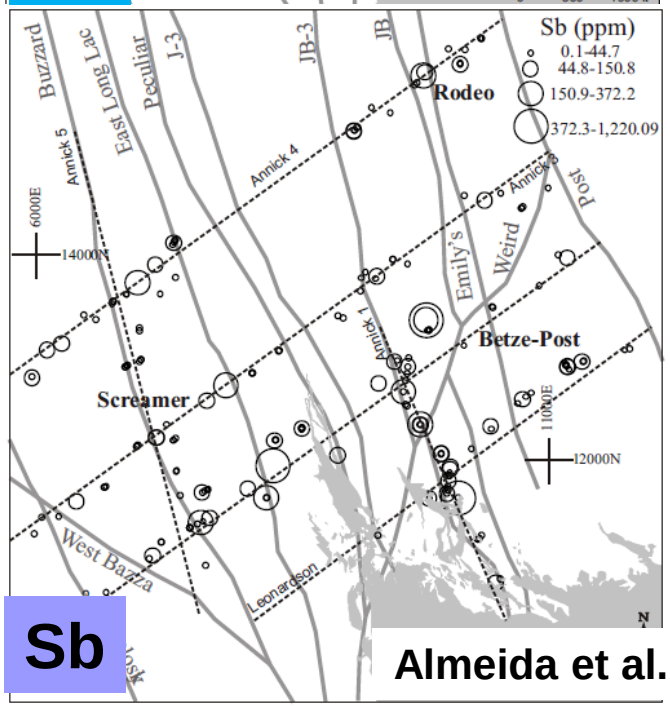
Almeida et al. (2010: in press)

TRACE ELEMENTS



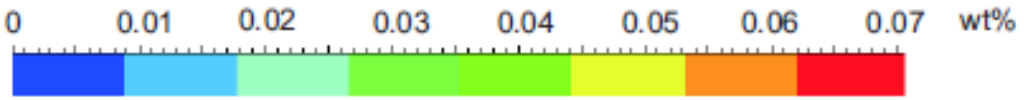


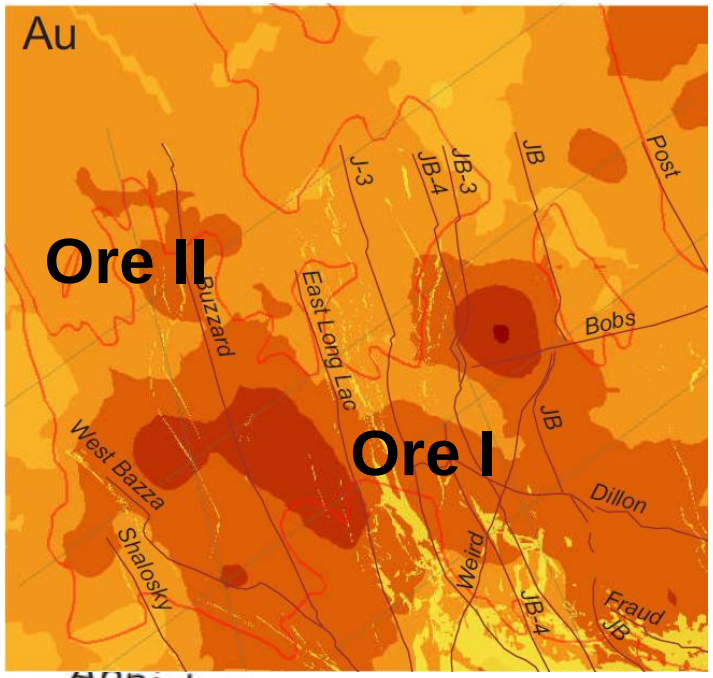


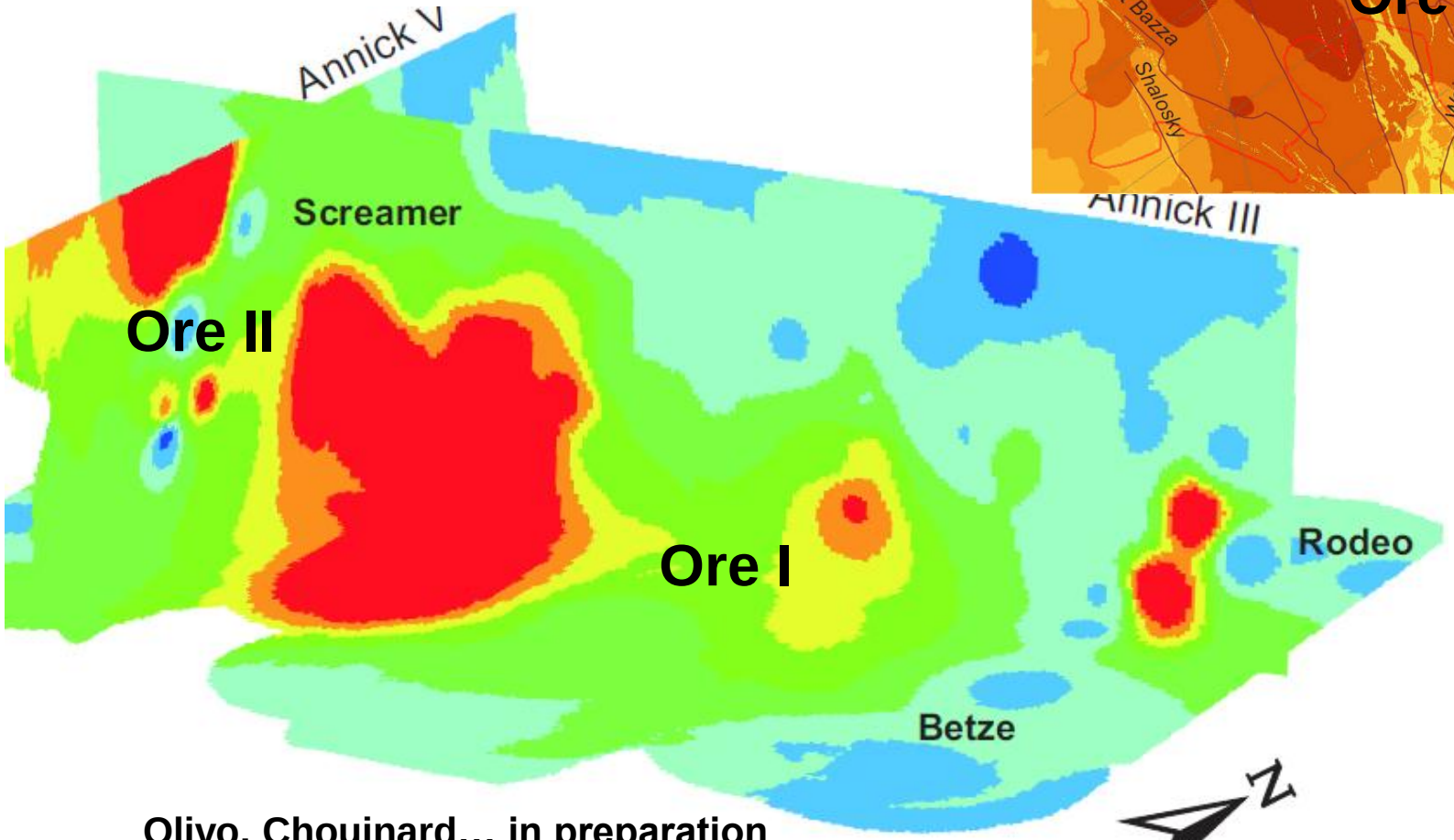


Almeida et al., 2010

Gold in Pyrite

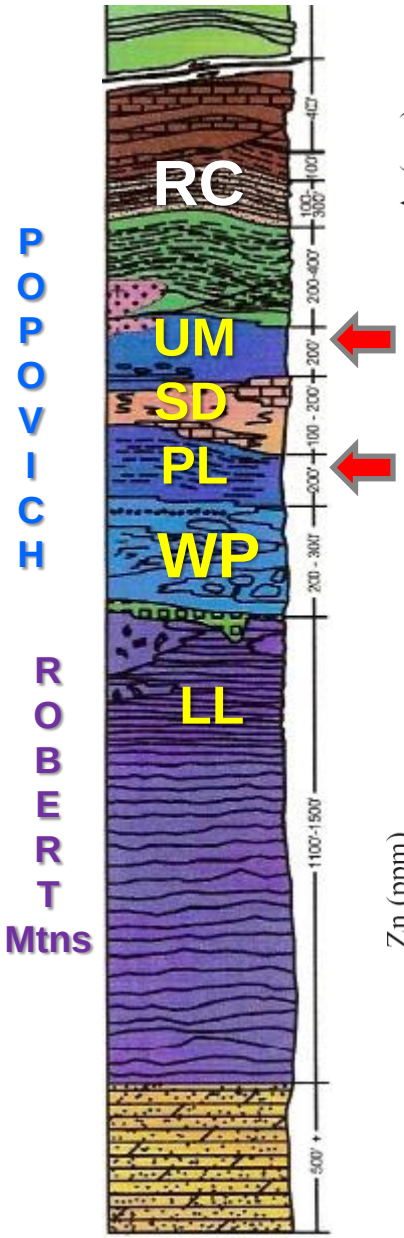


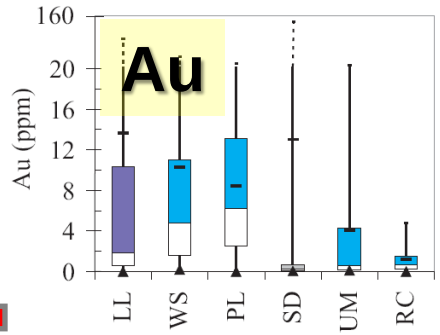


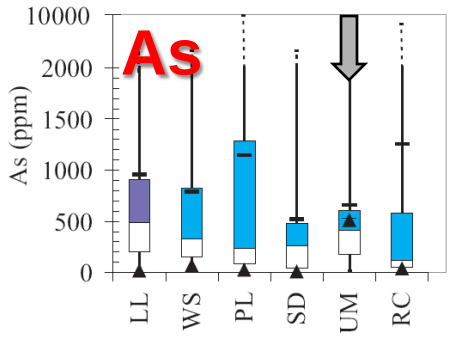


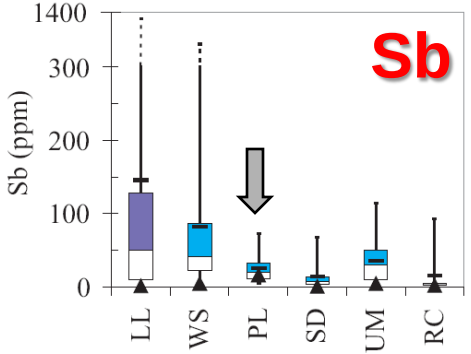
Olivo, Chouinard… in preparation

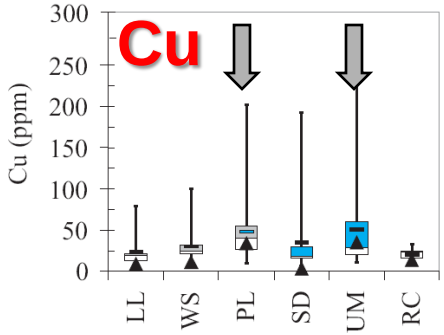
SOURCE OF GOLD AND RELATED ELEMENTS

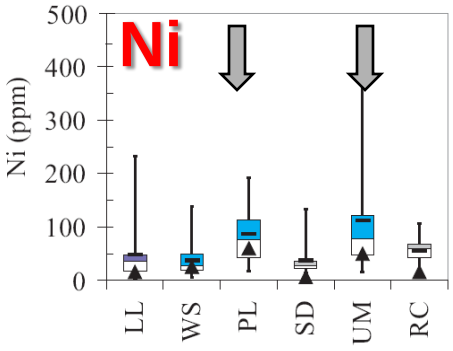


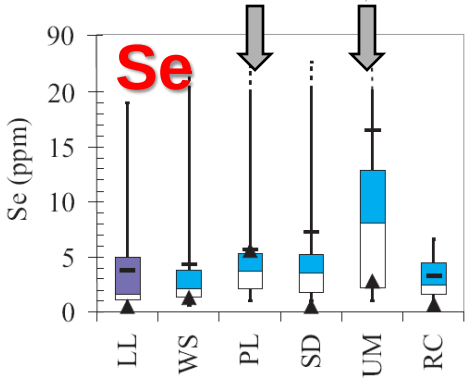


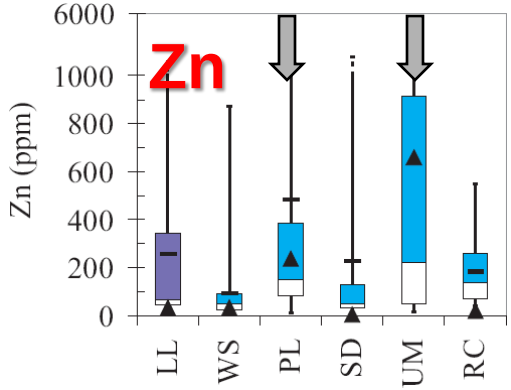


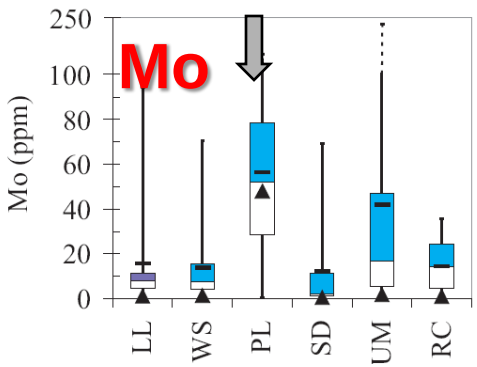


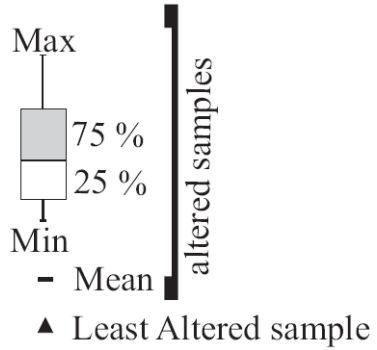










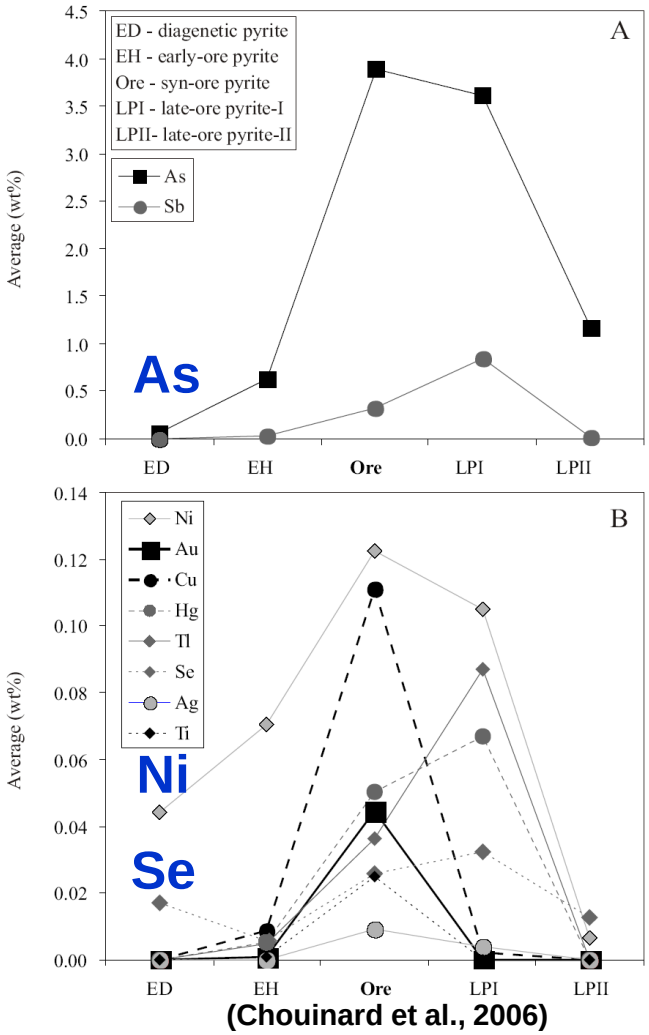


Olivo et al., 2009; Almeida et al., in press

SEDIMENTARY ROCKS

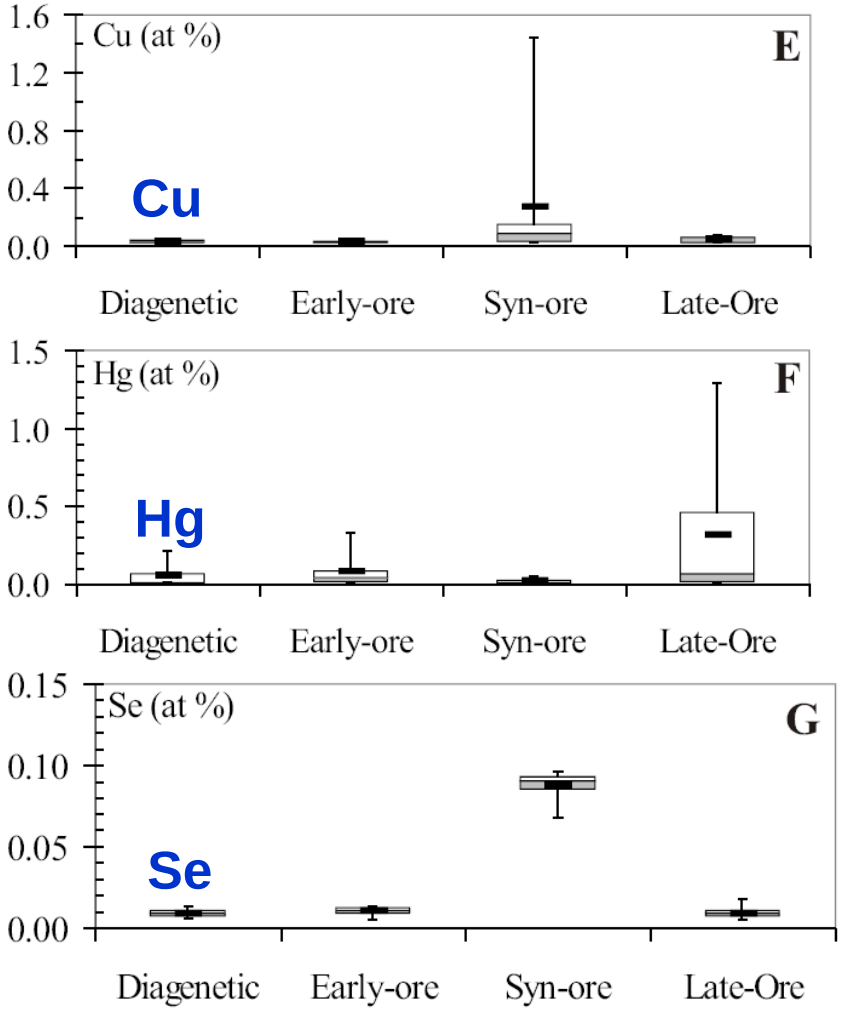
SOURCE OF ORE-RELATED ELEMENTS

Pyrite

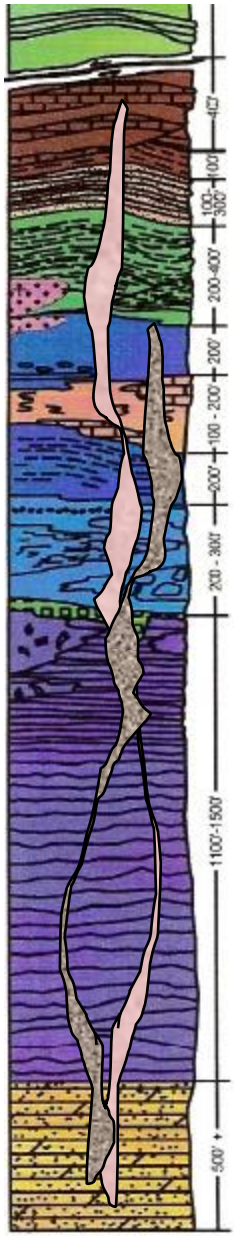


(Chouinard et al., 2006)

Sphalerite

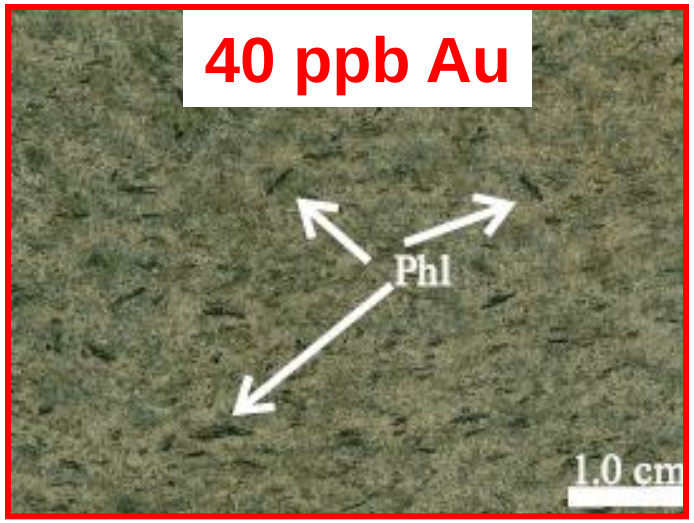


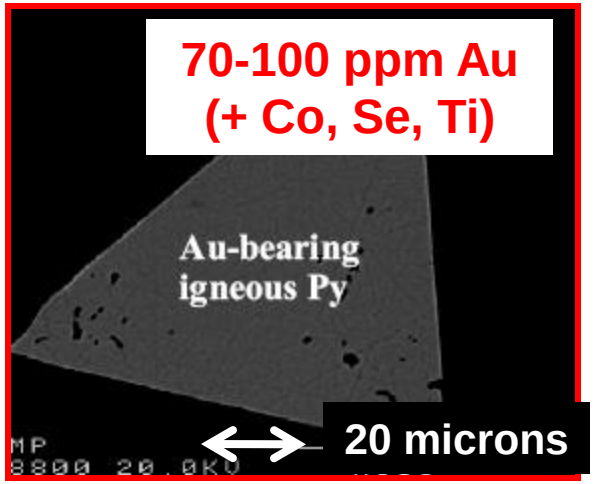
SOURCE OF ORE-RELATED ELEMENTS



- Jurassic:
  - Diorite
  - **Lamprophyre**
    - **Minor Au**
- Eocene
  - Biotite-Feldspar Porphyry

Least altered Lamprophyre

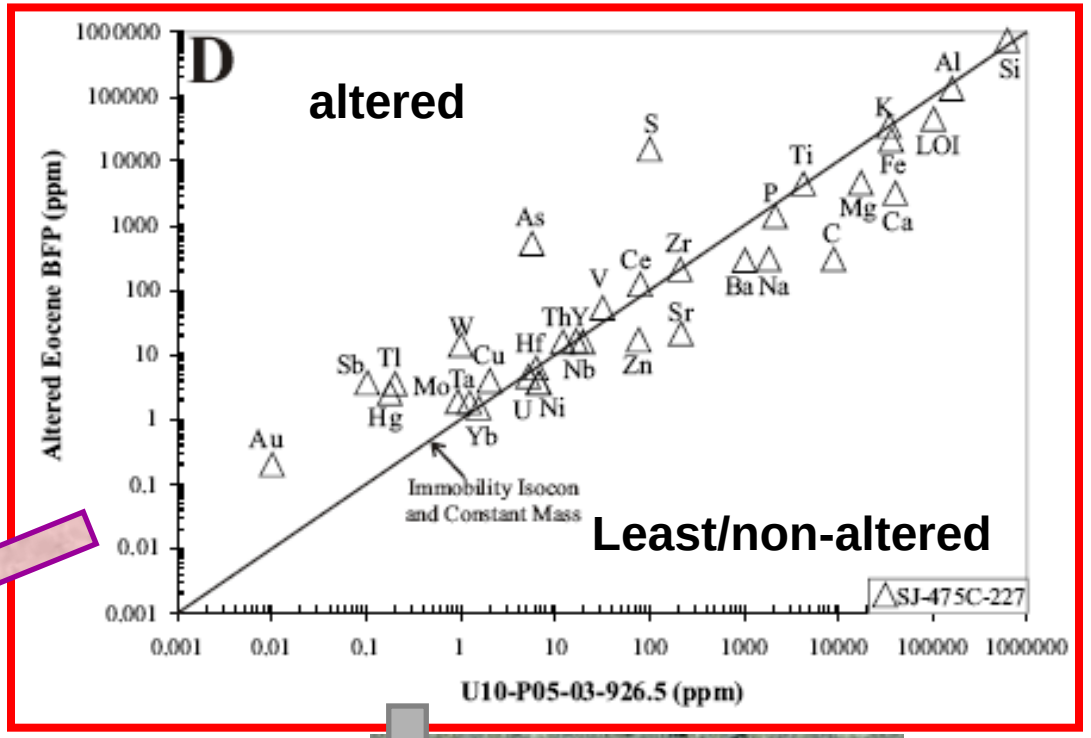


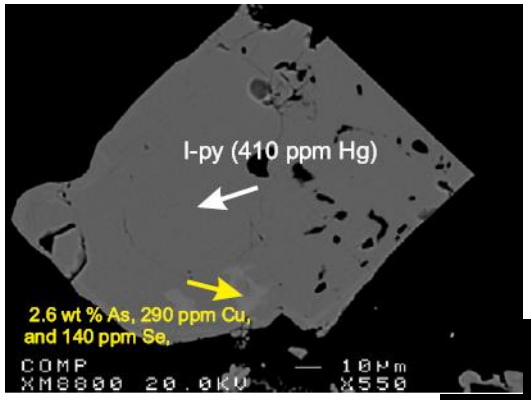


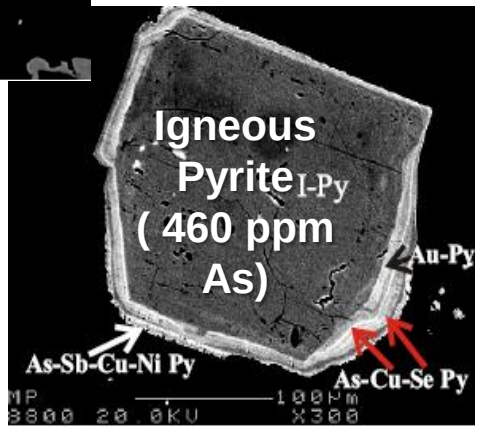
Eocene Dikes

ORE (rock) rich in:

Au, As, Tl, Hg, Sb, Mo, S, W (Cu)

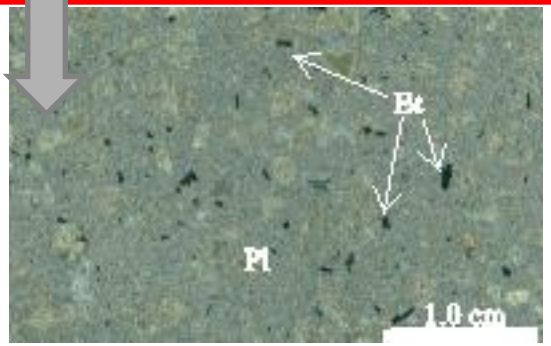






Altered Eocene Dike Core: Igneous pyrite

Rim: Hydrothermal Carlin pyrite overgrow



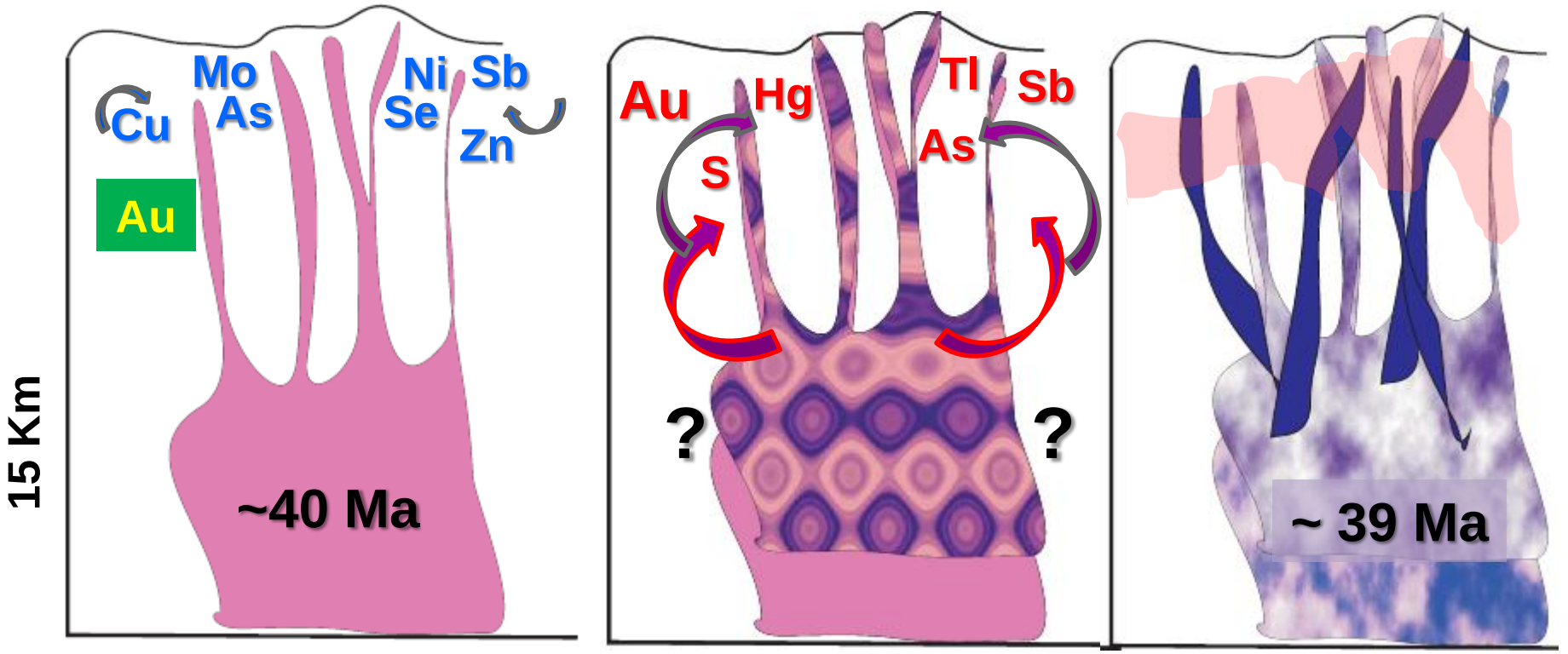
Non-Altered Eocene Dike Igneous pyrite is very rare

GENETIC MODEL: Eocene Event

Major magma emplacement
Eocene early shallow dikes

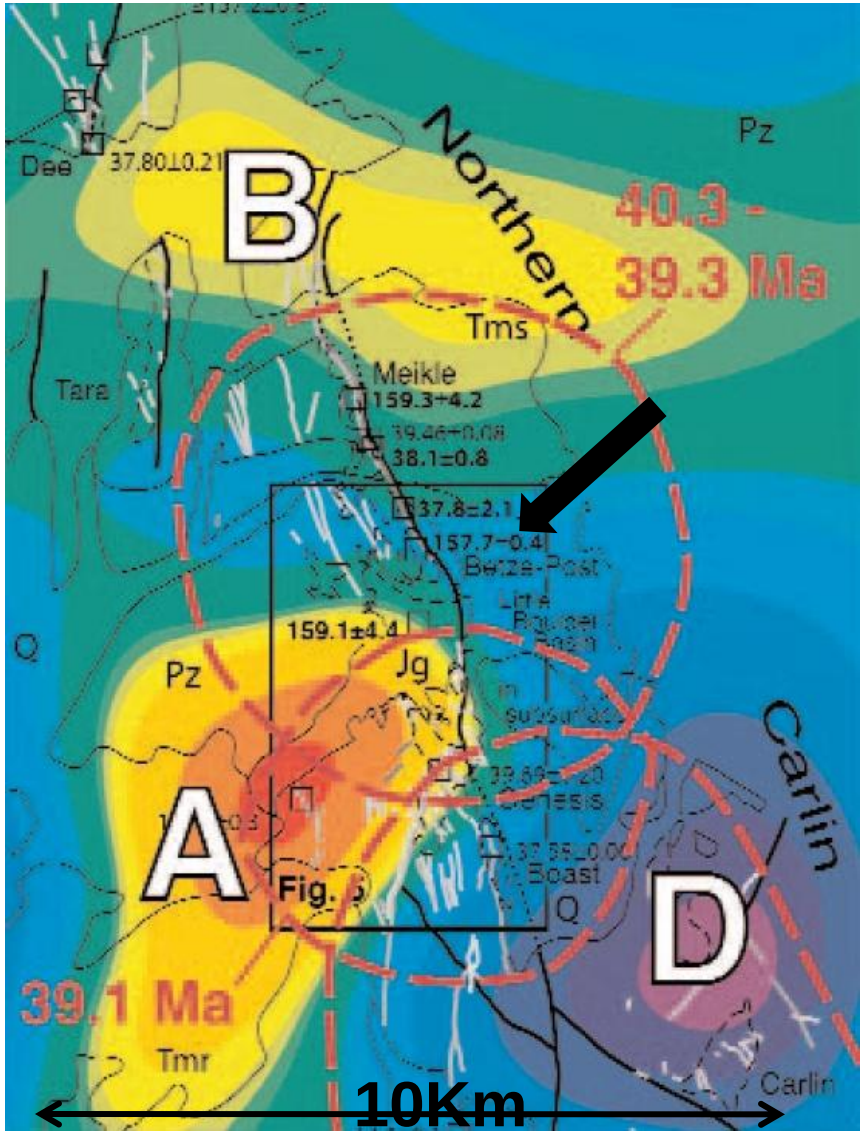
Magmatic fluid exsolution
Hydrothermal alteration of Eocene early dikes
Au mineralization

Eocene late dikes (no alteration)
Post-mineralization



Olivo et al., 2009

Deep Magmatic Sources (?)



POSITIVE AEROMAGNETIC ANOMALIES:

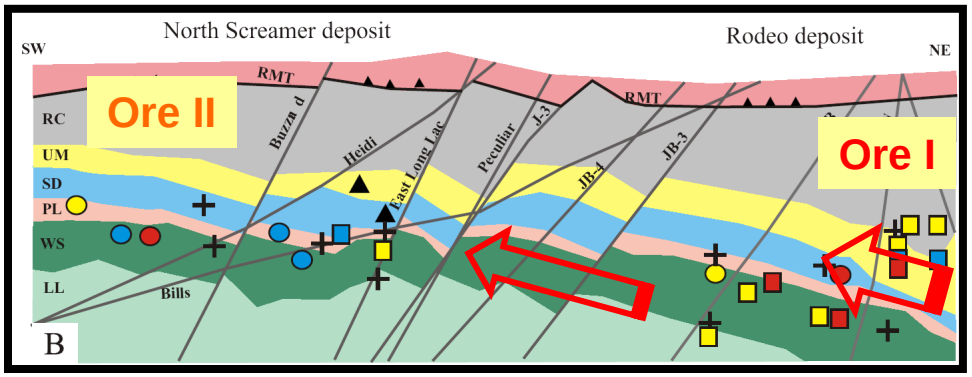
→Interpreted as composite Eocene plutons at depth

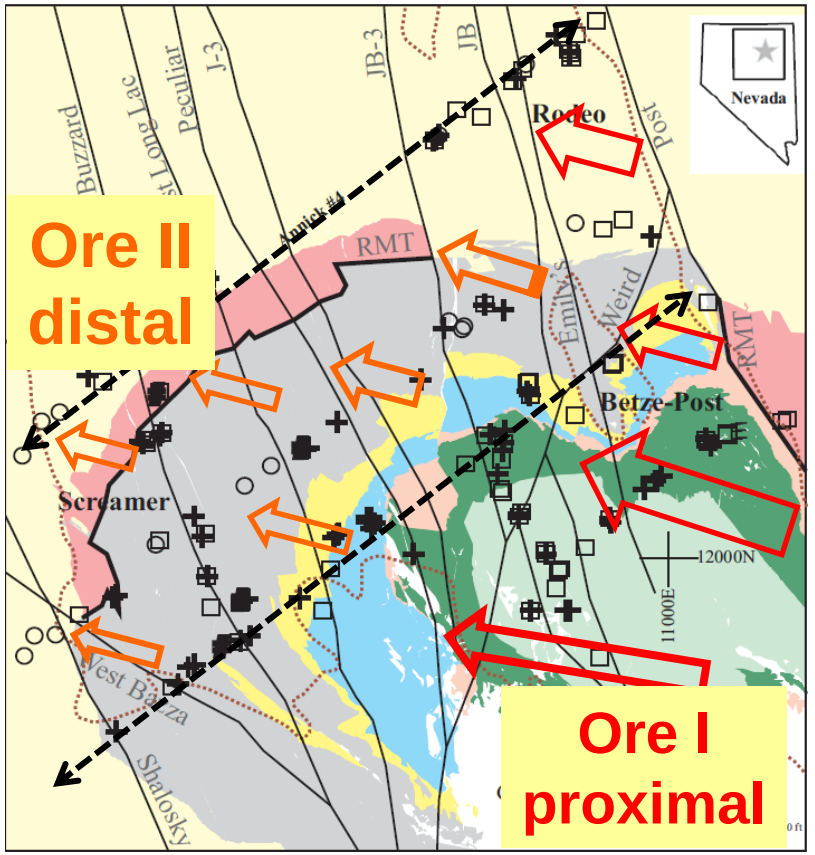
Ressel and Henry, 2006

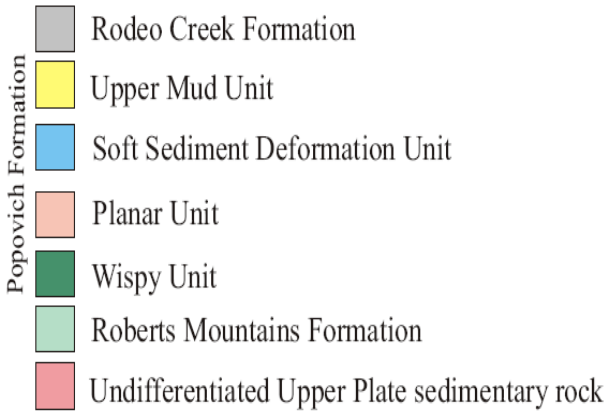
AURIFEROUS FLUID FLOW

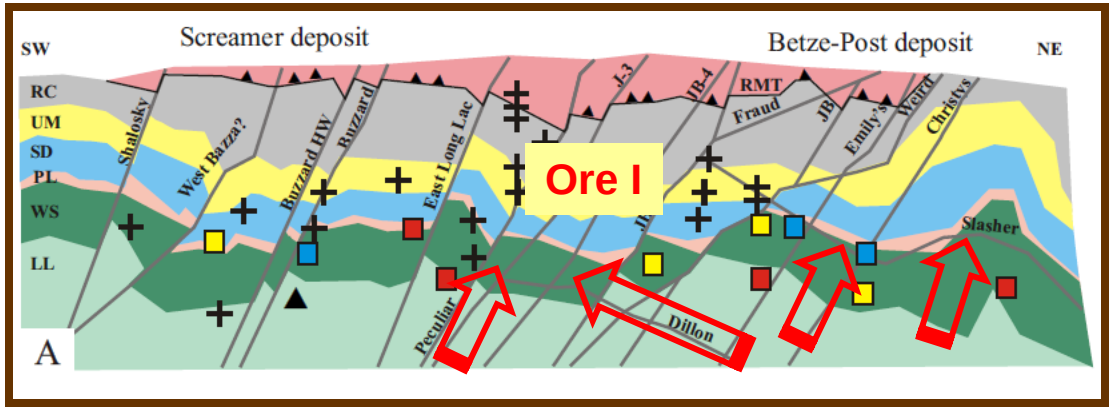
Au (g/t)
- <1.00
- 1.01-5.00
- 5.01-10.00
- >10.00

- Least altered
- Ore I
- Ore II





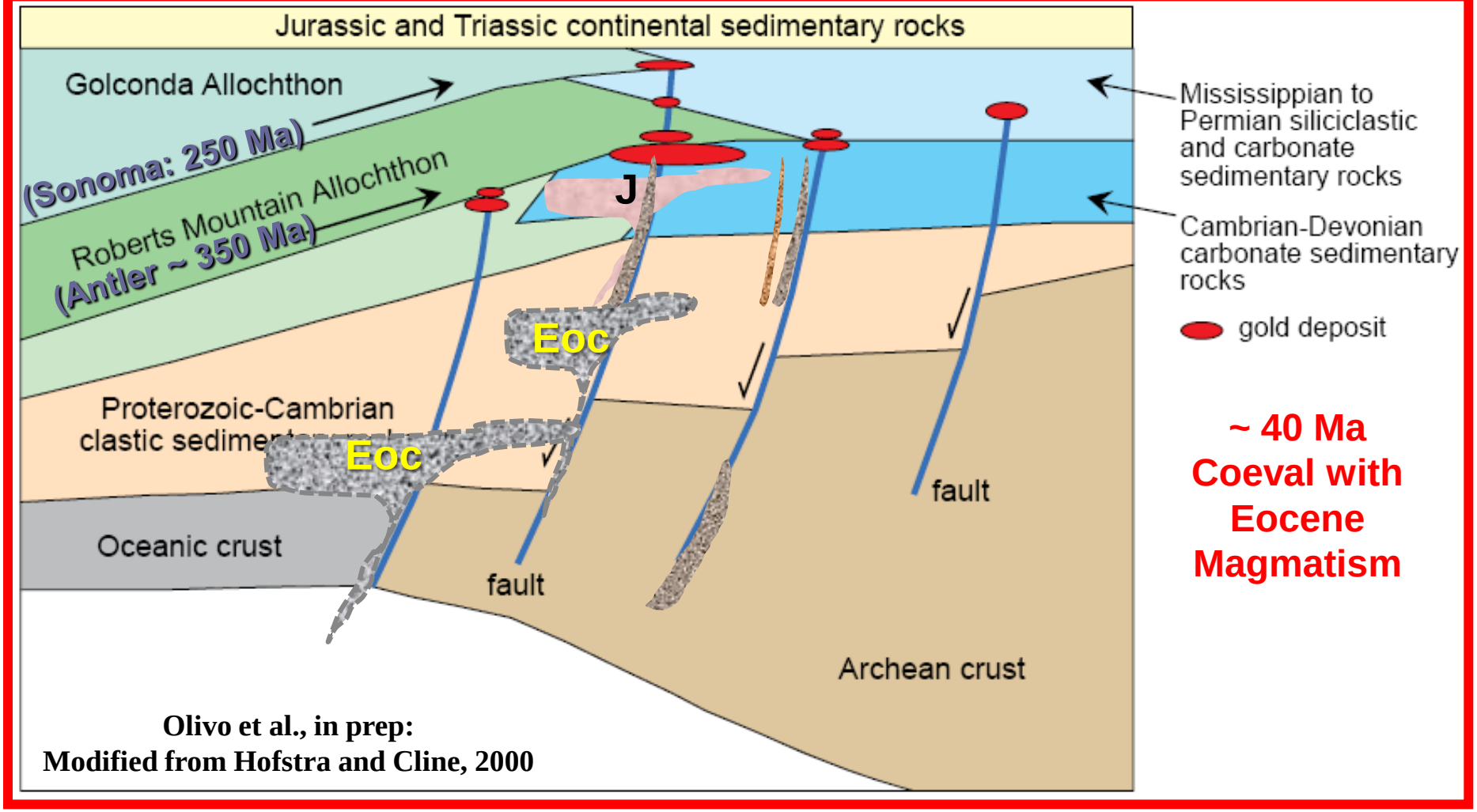




EXPLORATION GUIDELINES

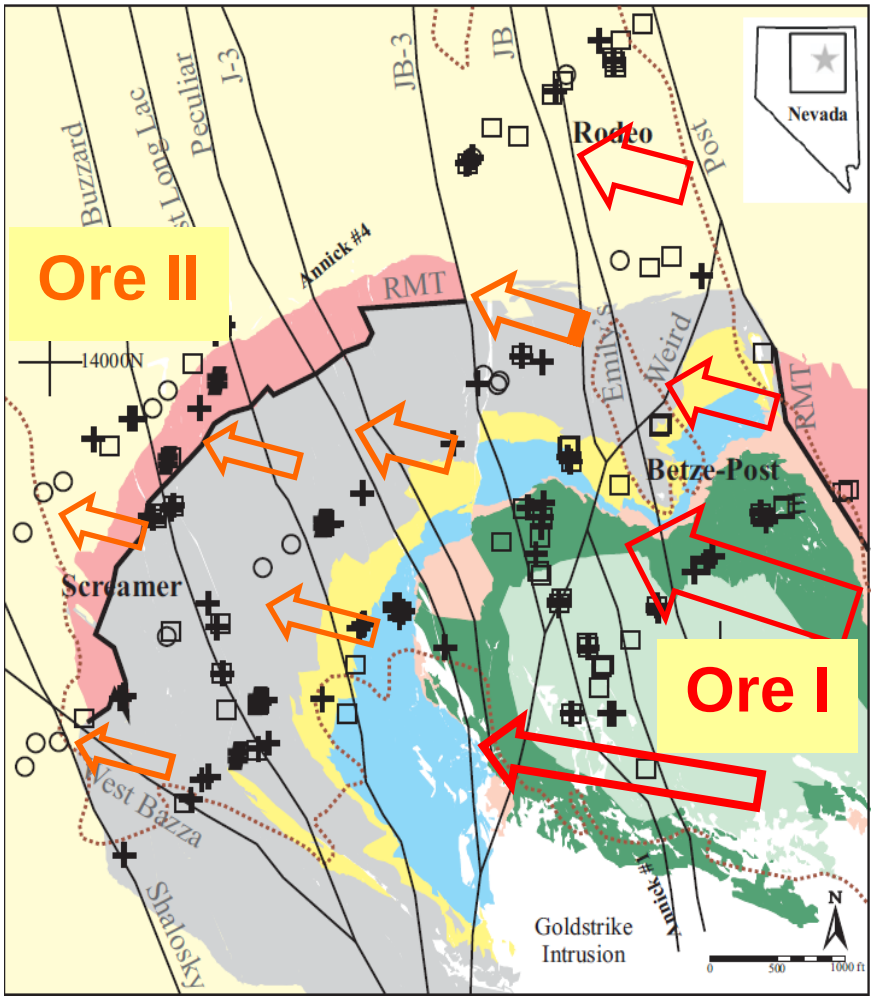
- Basement crustal boundary: Continental vs oceanic crust
- Impure carbonate underneath of the thrust
- impermeable cap
- Major structures/ intersection → as magma and fluid conduits
- Hornfelsed rocks→ secondary permeability
- Coeval with Eocene magmatism

CARLIN-TYPE DEPOSITS: GEOLOGICAL SETTING



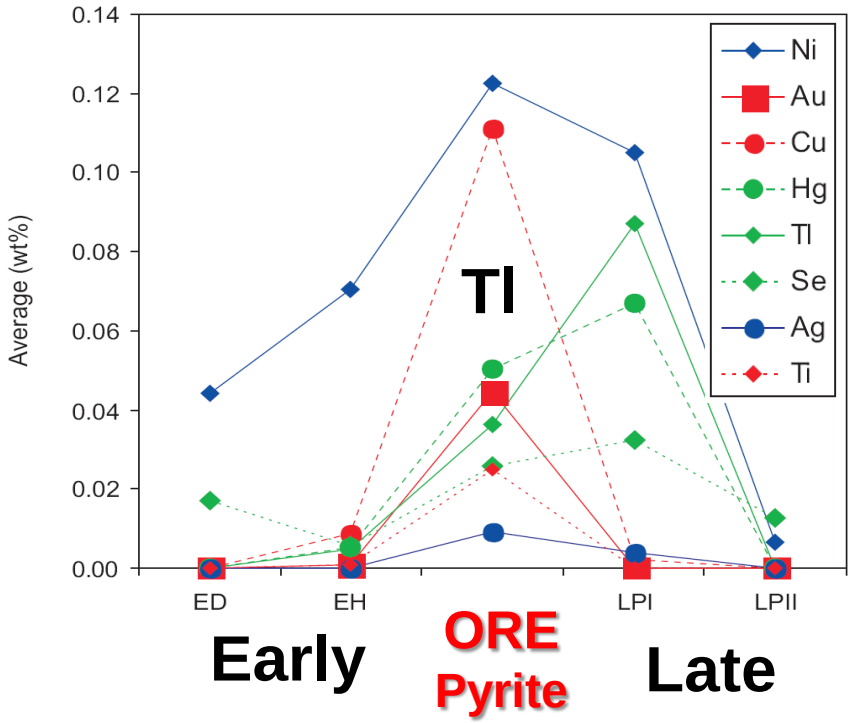
EXPLORATION GUIDELINES

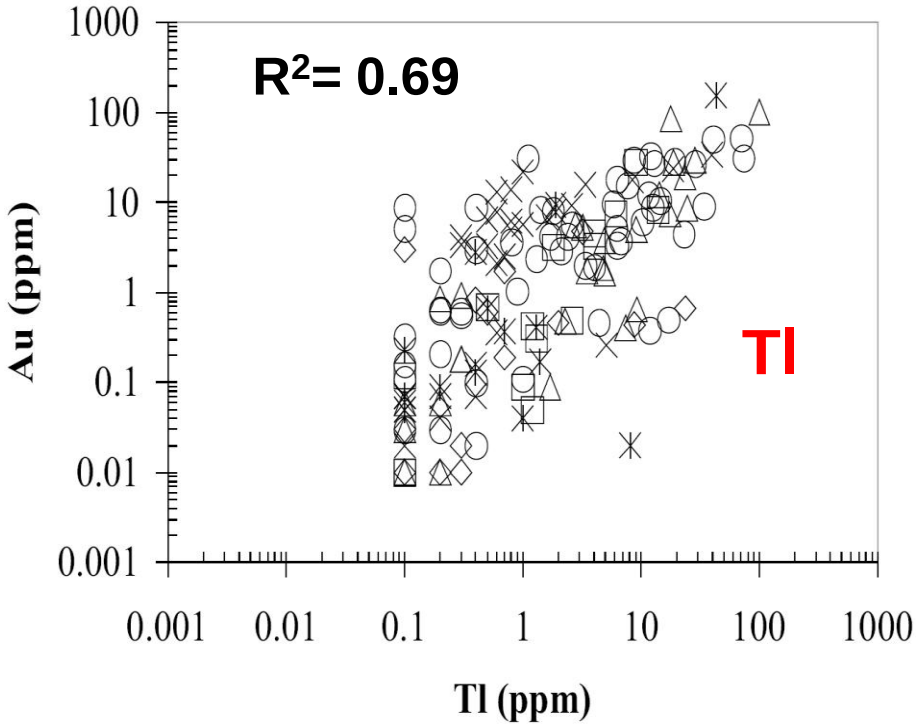
- ALTERATION
  - Decarbonatization (Ore I pervasive→ Ore II weak)
  - Silicification (Ore I pervasive→ Ore II weak)
  - Pyritization



EXPLORATION GUIDELINES

- GEOCHEMICAL ASSOCIATION: Au, Ag, As, Cu, Hg, Ni, Tl, Sb, Se
- Tl is the element that has the best correlation with Au in whole rock






THANK YOU!!!
OBRIGADA!!!
Questions?
2006 8 15