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Centre for EXPLORATION TARGETING
IGGC12 Georgetown

The Geological Setting and Hydrothermal Alteration at the Tucano Gold Deposit, Guiana Shield, Brazil

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OUTLINE OF THE TALK

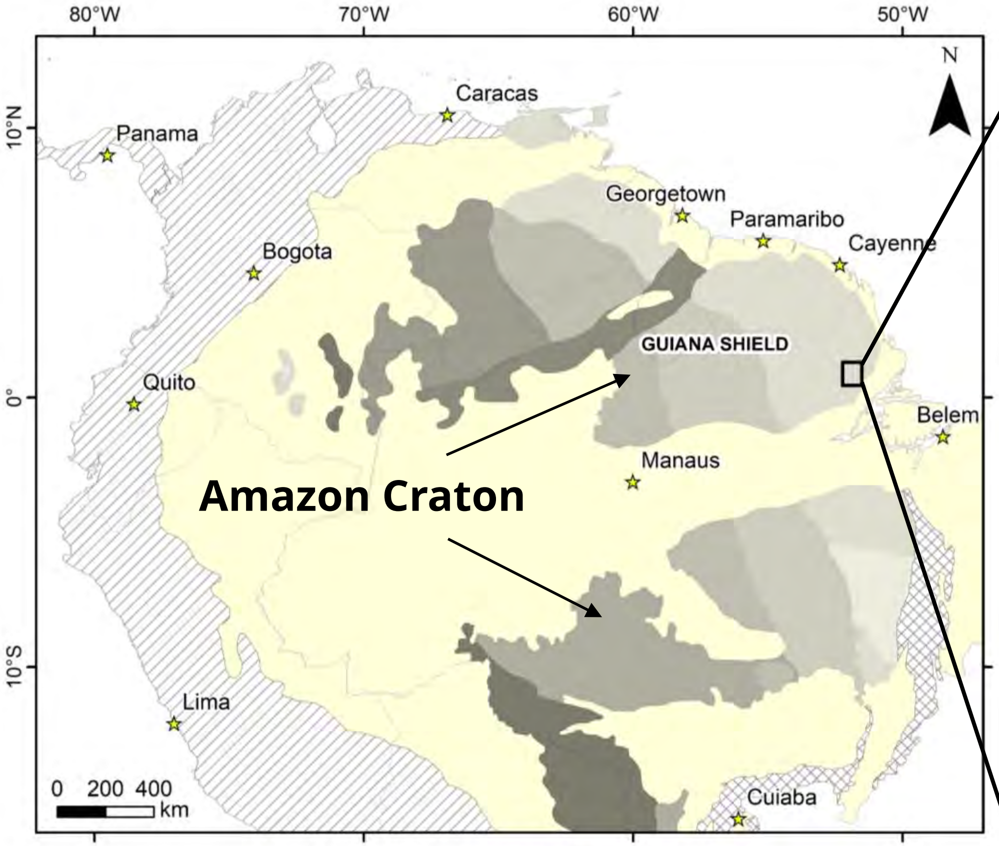
- LOCATION AND REGIONAL GEOLOGY
- DISTRICT GEOLOGY
- LITHOSTRATIGRAPHY
- METAMORPHIC P-T CONDITIONS AND DISTRICT STRUCTURAL SETTING

- HYDROTHERMAL ALTERATION FRAMEWORK
  - DRILLCORE LOGGING AND GOLD GRADES
  - PARAGENETIC SEQUENCE AND ALTERATION ASSEMBLAGES
  - P-T CONDITIONS
  - REDOX CONDITIONS

- PRELIMINARY MODEL FOR THE TUCANO DEPOSIT

- CONCLUSIONS AND IMPLICATIONS

Location and Regional Geology



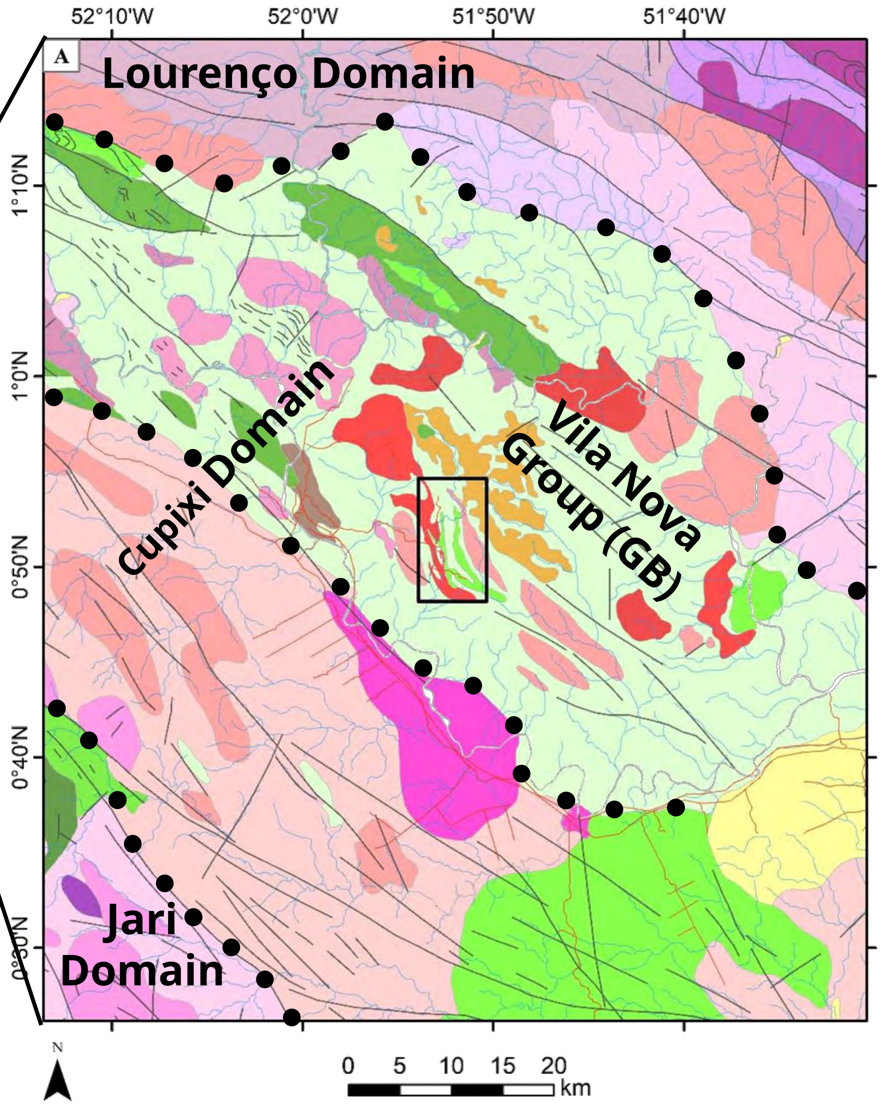
☆ Major Cities ▭ National Borders

Phanerozoic Cover ▨ Andean Cordillera ▩ Neoproterozoic Belts

Amazon Craton

Geochronological Provinces

- Sunsás (1450-1000 Ma)
- K'Mudku Belt (1450-1100 Ma)
- Rio Negro (1820-1520 Ma)
- Rondônia-Juruena (1850-1540 Ma)
- Tapajós-Parima (2040-1860 Ma)
- Amazônia Central (1990-1860 Ma)
- Transamazonas (2260-2060 Ma)
- Carajás (3000-2500 Ma)

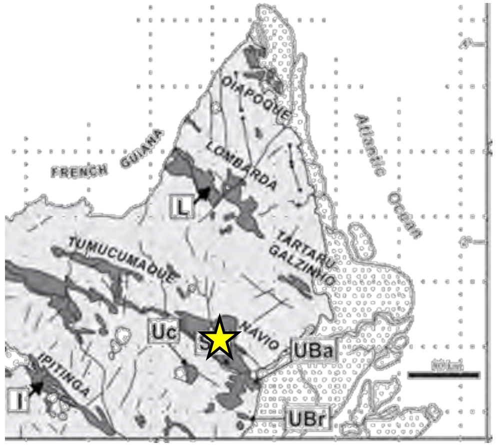


Cenozoic cover

Paleoproterozoic Granitoids

Metavolcanosedimentary rocks

Archean granitoids, gneisses and granulites



GREENSTONE BELTS

GRANITOIDS, GNEISSES AND GRANULITES

Jari Domain + Cupixi Domain

=

Amapá Block

(*reworked Archean continental landmass*)

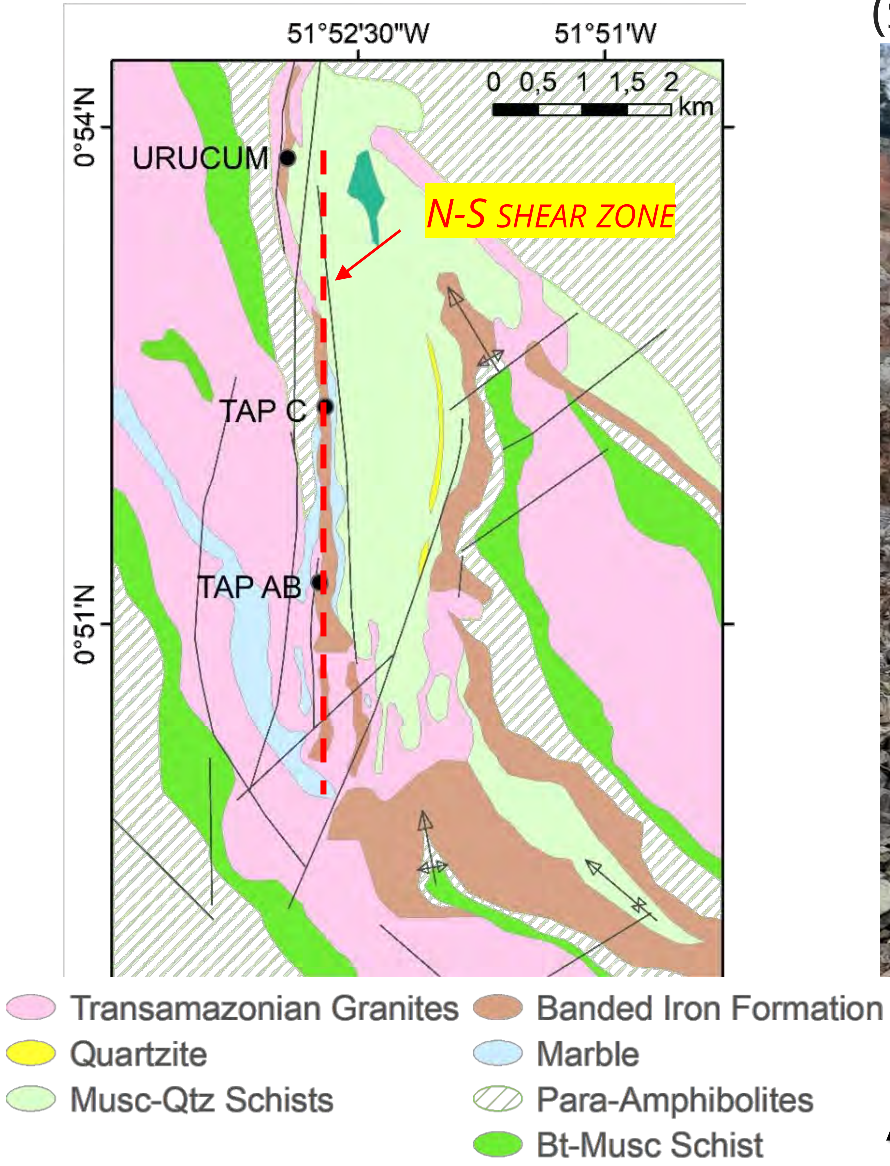
Lourenço Domain

(*dominantly juvenile Rhyacian terrain*)

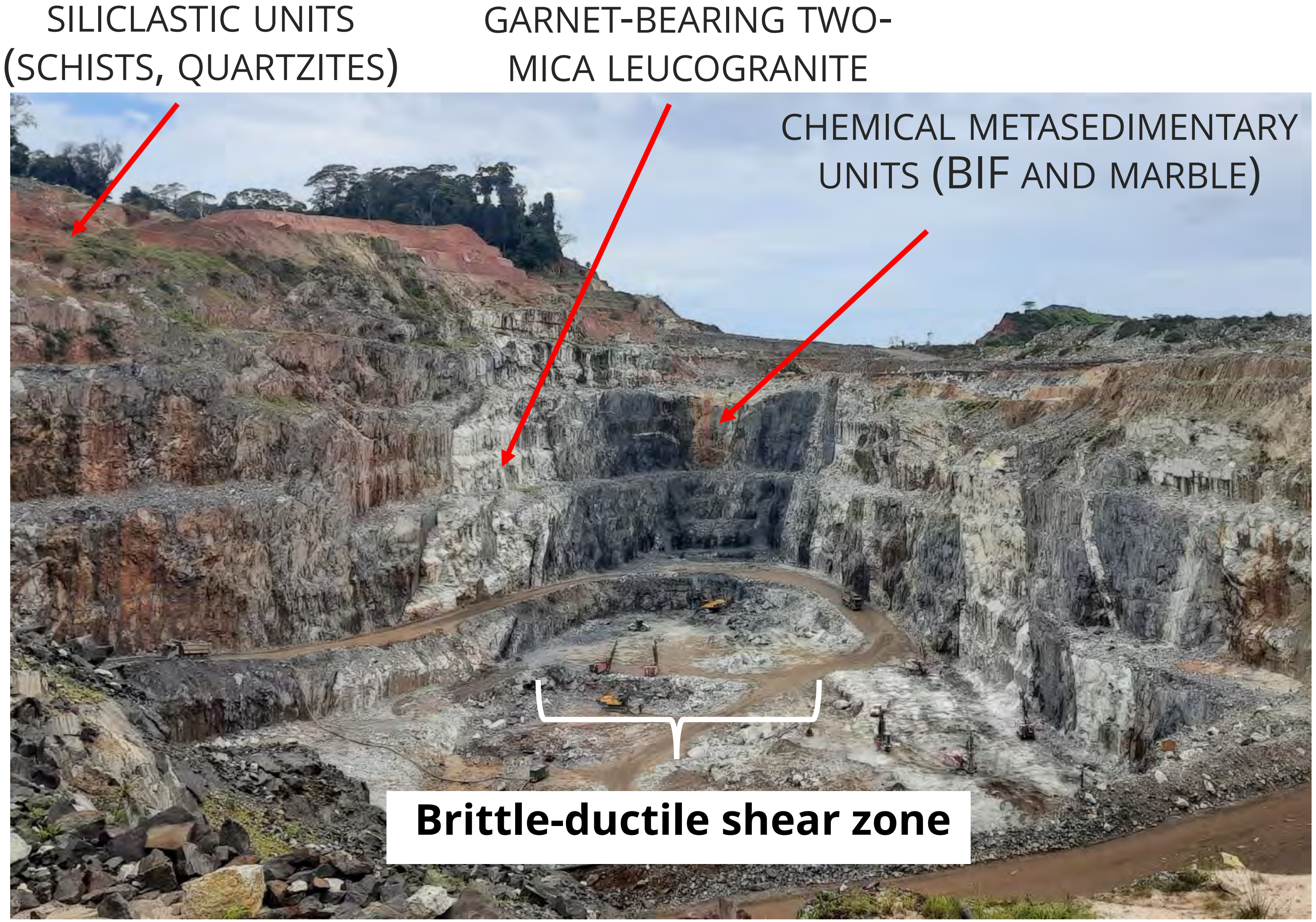
Barbosa et al. (2015)
McReath & Faraco (2006)
Rosa Costa et al. (2014)
Santos et al. (2006)
Vasquez & Rosa Costa (2008)

District Geology

Lithostratigraphic Map



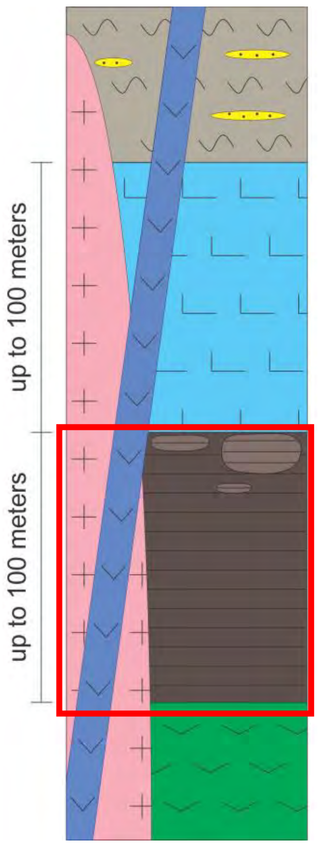
Adapted from Scarpelli & Horikava (2017)



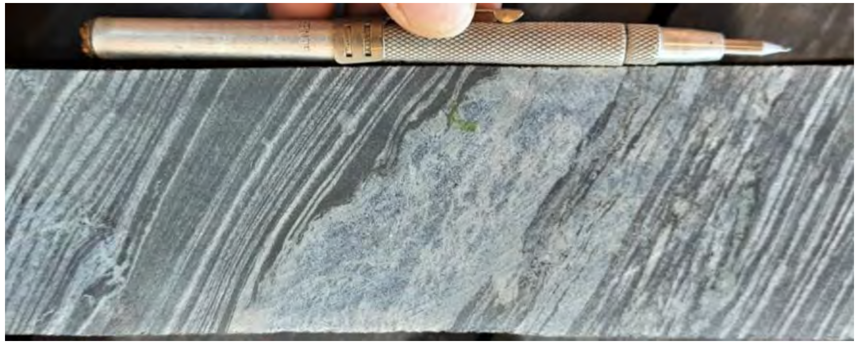
Cross Section of Urucum pit looking south

As of December 31, 2020, the Mine has produced a total of approximately 1,421,625 ounces of gold since commencing operation in 2005

LITHOSTRATIGRAPHY – BANDED IRON FORMATION



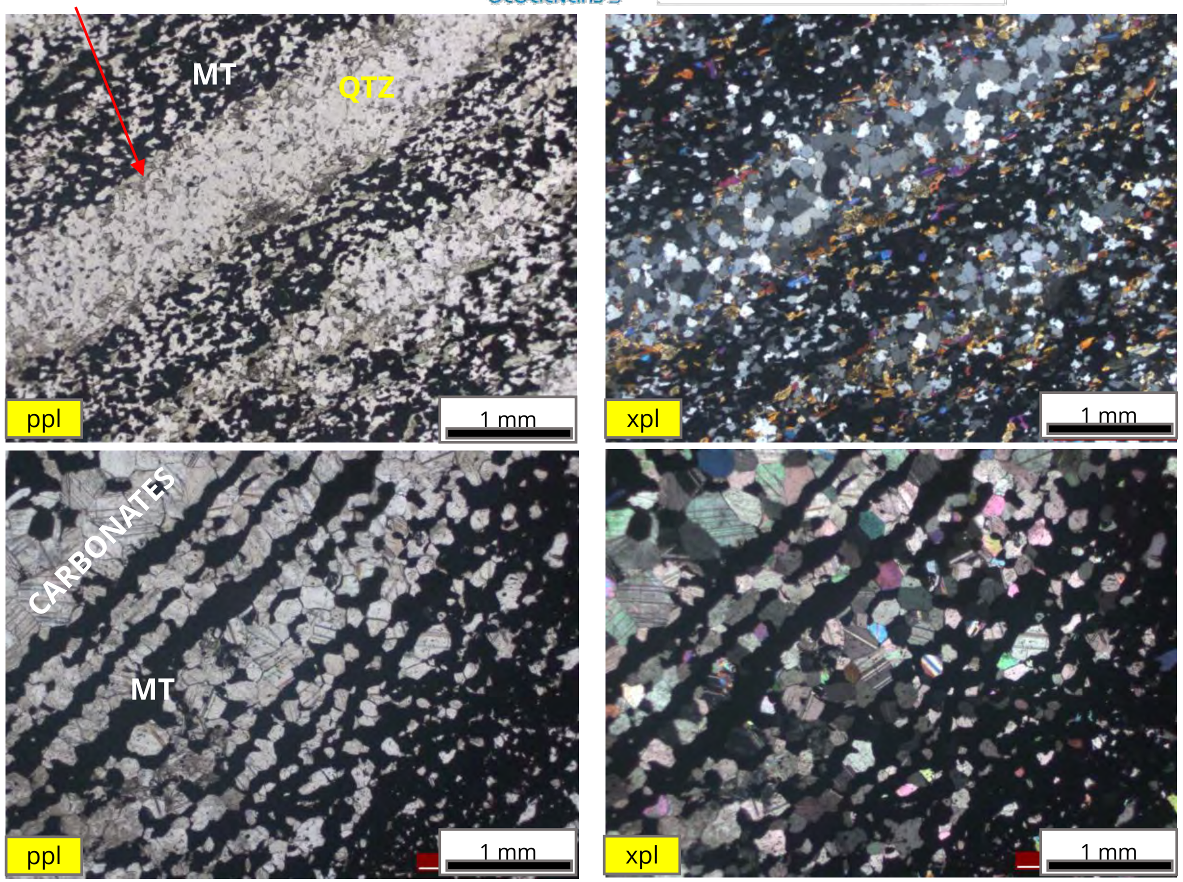
NOT TO SCALE



QUARTZ + MAGNETITE + GRUNERITE + ACTINOLITE

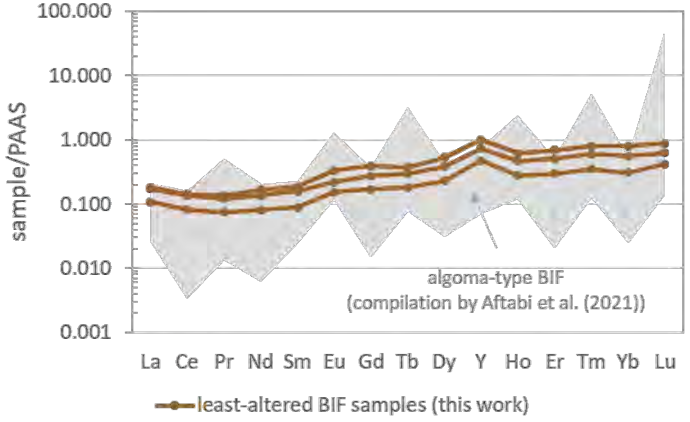
MAGNETITE + CALCITE + FE-DOLOMITE

AMPHIBOLES

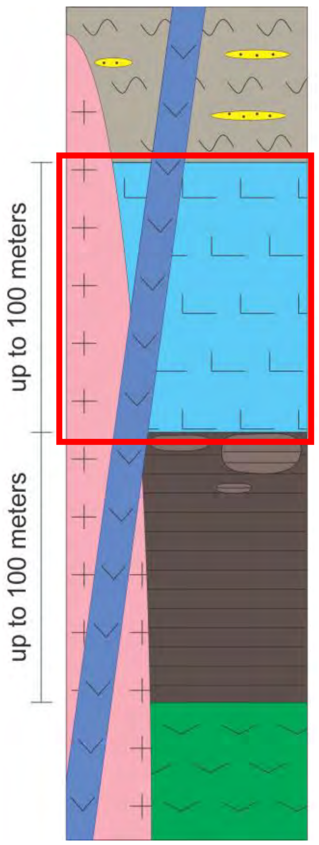


- DIABASE
- GARNET-BEARING LEUCOGRANITE
- QUARTZ-BIOTITE SCHIST
- QUARTZITE
- MARBLE
- CARBONATE-MAGNETITE-RICH IRON FORMATION
- AMPHIBOLE-QUARTZ-MAGNETITE-RICH IRON FORMATION
- AMPHIBOLITE

PAAS-NORMALIZED REE+Y PATTERNS (MCLENNAN, 1989)



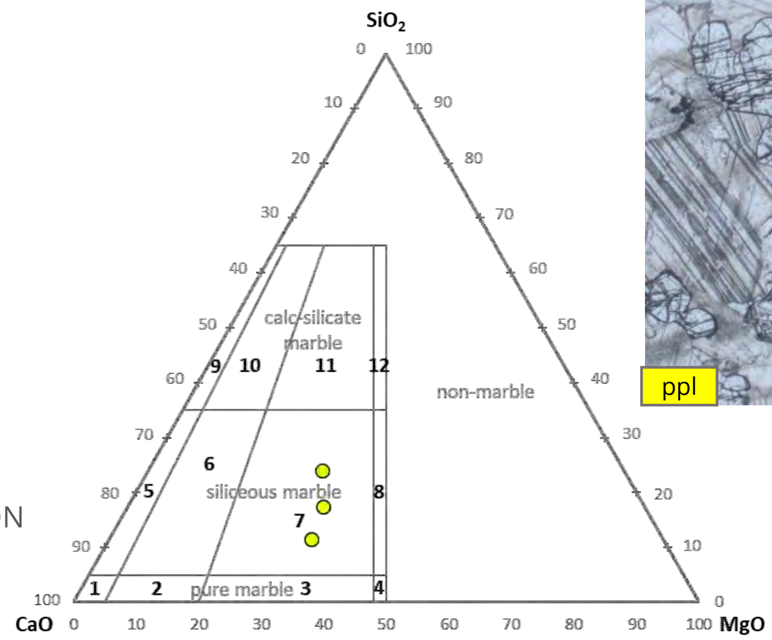
LITHOSTRATIGRAPHY - FORSTERITE ± PHLOGOPITE ± TREMOLITE MARBLE

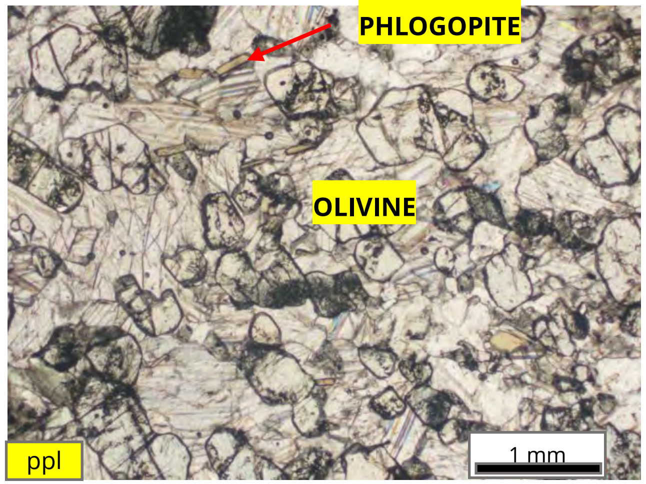


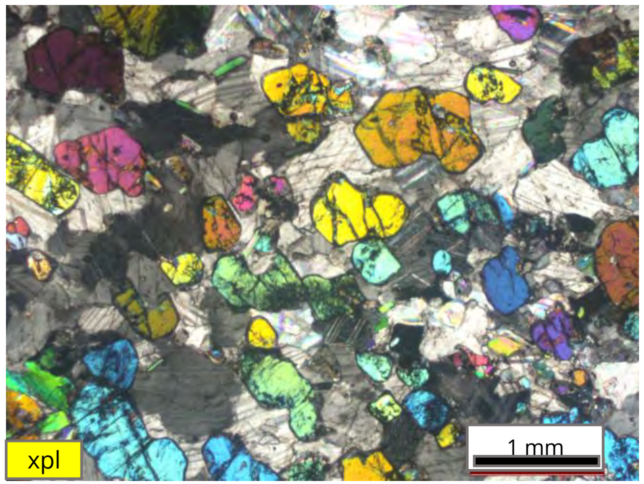
NOT TO SCALE

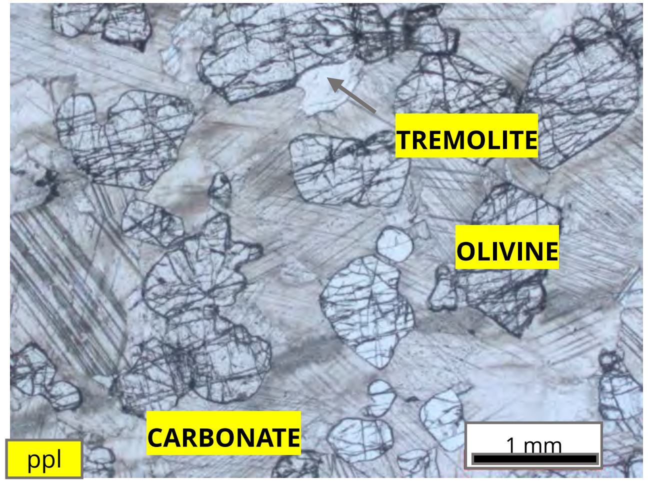
- DIABASE
- GARNET-BEARING LEUCOGRANITE
- QUARTZ-BIOTITE SCHIST
- QUARTZITE
- MARBLE
- CARBONATE-MAGNETITE-RICH IRON FORMATION
- AMPHIBOLE-QUARTZ-MAGNETITE-RICH IRON FORMATION
- AMPHIBOLITE

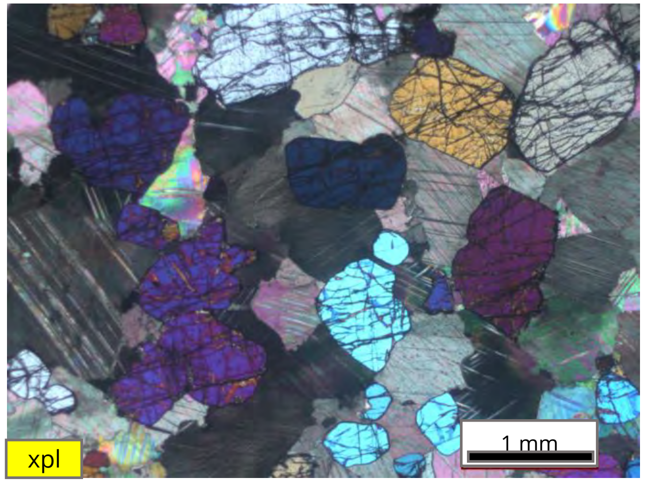
TERNARY DIAGRAM FOR CLASSIFICATION OF MARBLES (STOREY AND VOS, 1981)











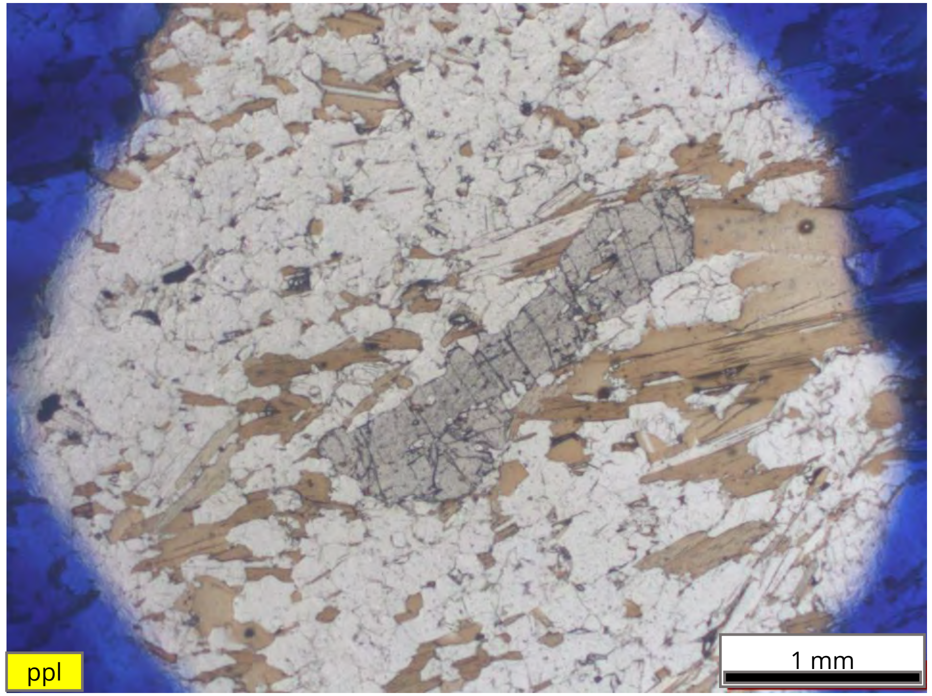
7 – SILICEOUS CALCITIC DOLOMITE MARBLE

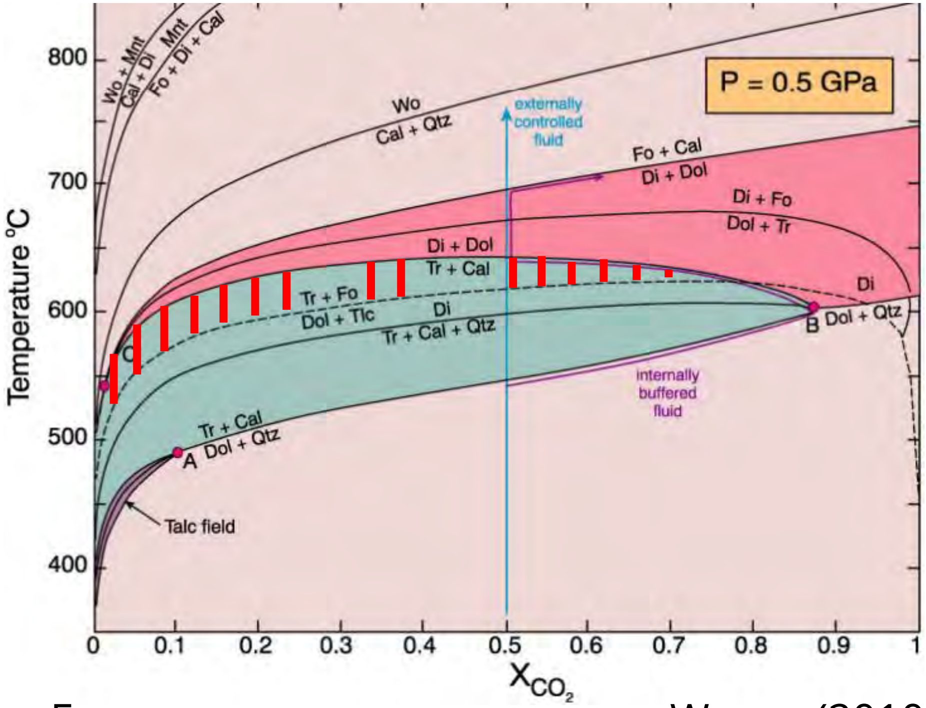
Metamorphic P-T conditions

I) Garnet-Biotite Geothermometry (Holdaway, 2000) and Garnet Geobarometry (Wu, 2019) in metapelite

- Peak metamorphic T estimation based on 5 garnet-biotite pairs: **T(°C) = 592 ± 14 (1σ)** (amphibolite facies)
- **P(Kbar) = 4.2 ± 0.6 (1σ)** (mid crustal conditions)

II) Fo-rich olivine in metacarbonate rocks agree with temperatures in excess of 500 °C. The absence of Di in equilibrium with Fo suggests that peak temperatures have not exceeded 630 °C





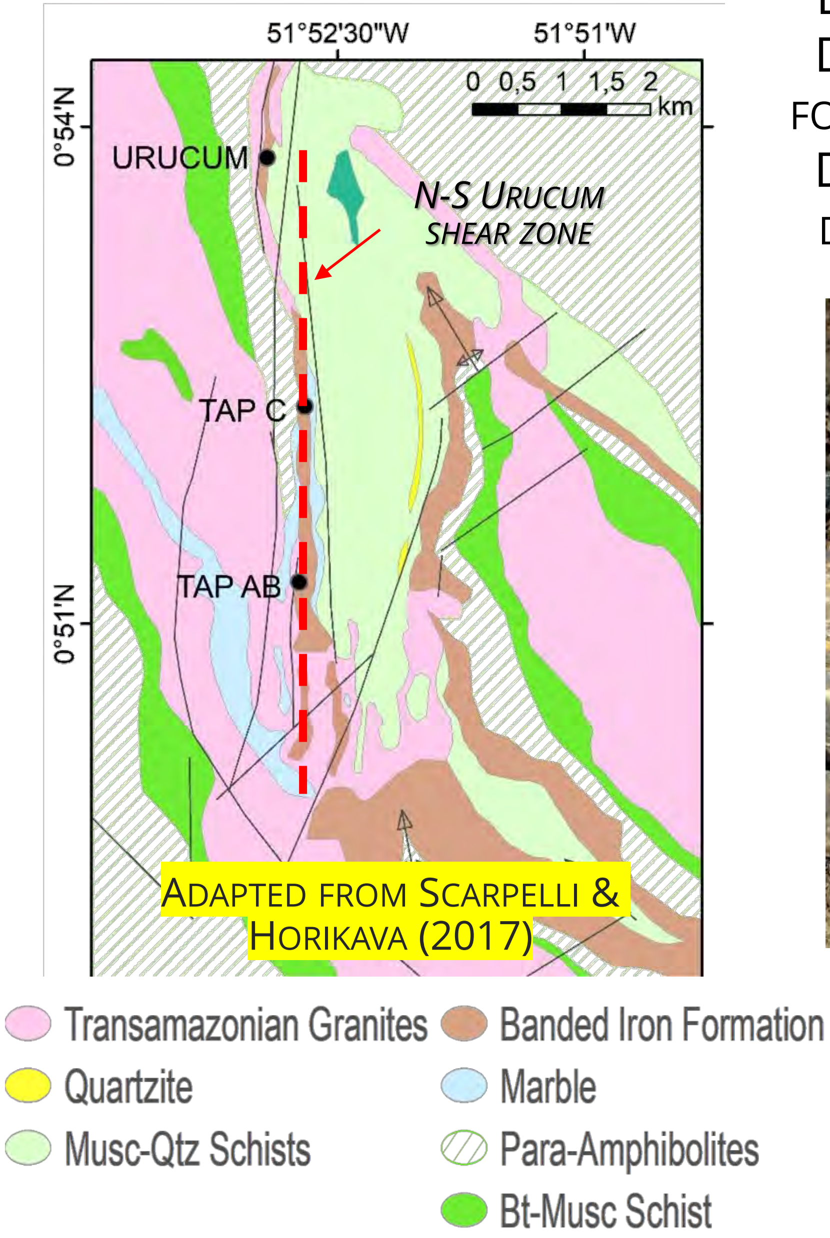
Equilibrium phase diagram from Winter (2010)

District Structural Setting

*D1 – regional NW-SE foliation in the Guiana Shield

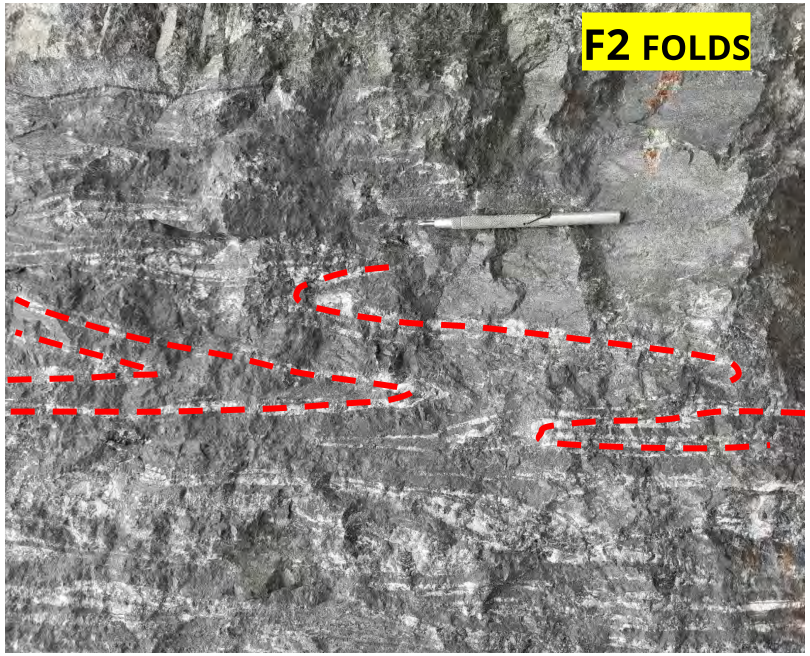
D2 – dextral N-S shearing with subvertical foliation and tight intraband folds

D3 – E-W and NW-SE fractures with quartz, carbonate, serpentine, dolomite and/or pyrrhotite filling



Adapted from Scarpelli & Horikava (2017)

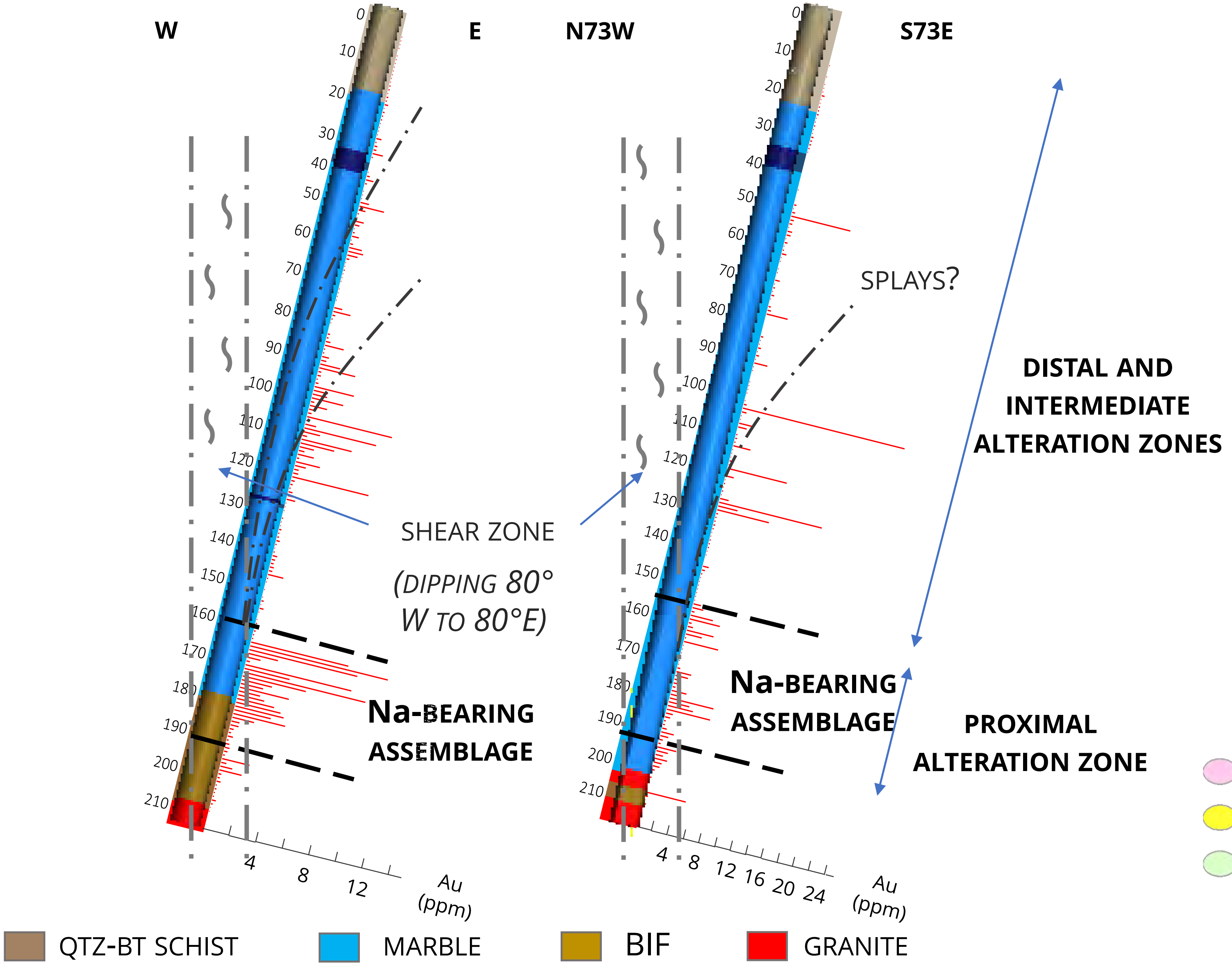
N-S striking shear zone (informally named Urucum Shear Zone) - Red arrow shows shear band indicating dextral movement

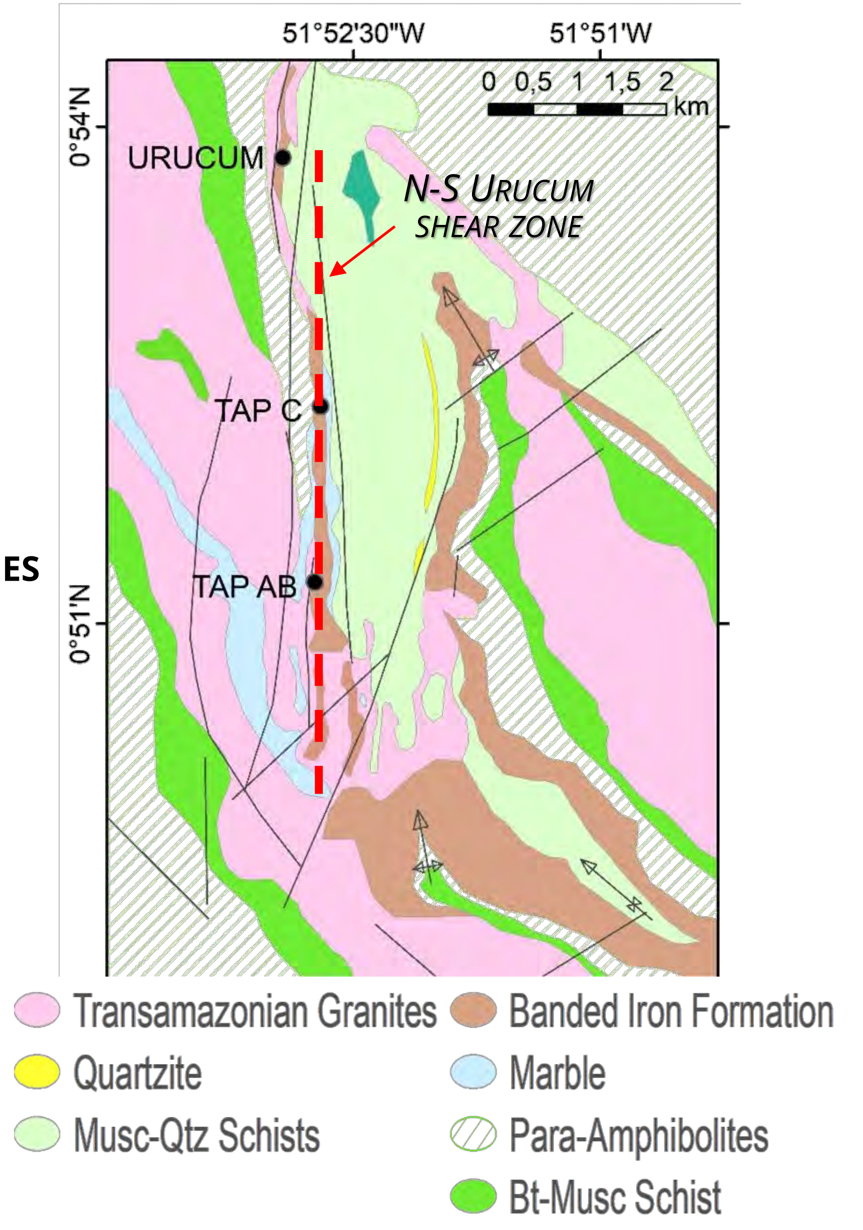


Tight isoclinal folds in the high strain zone of the Urucum Shear Zone

*Modified after company reports

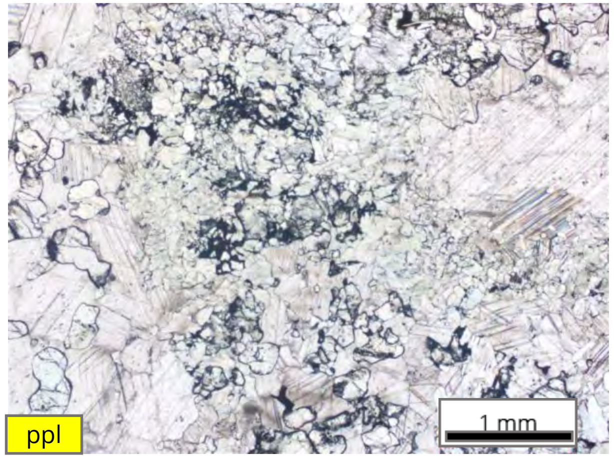
HYDROTHERMAL ALTERATION – DRILLCORES AND GOLD GRADES

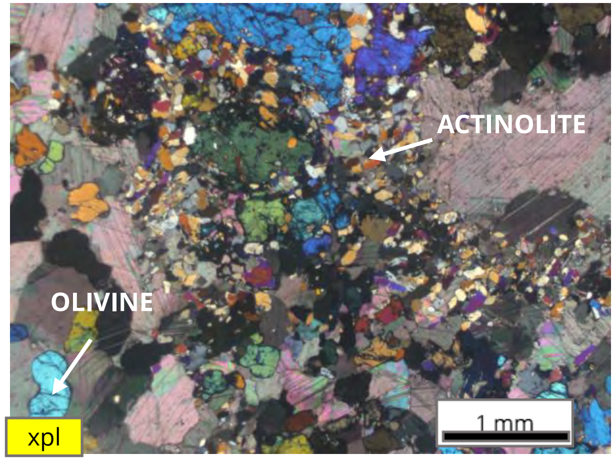


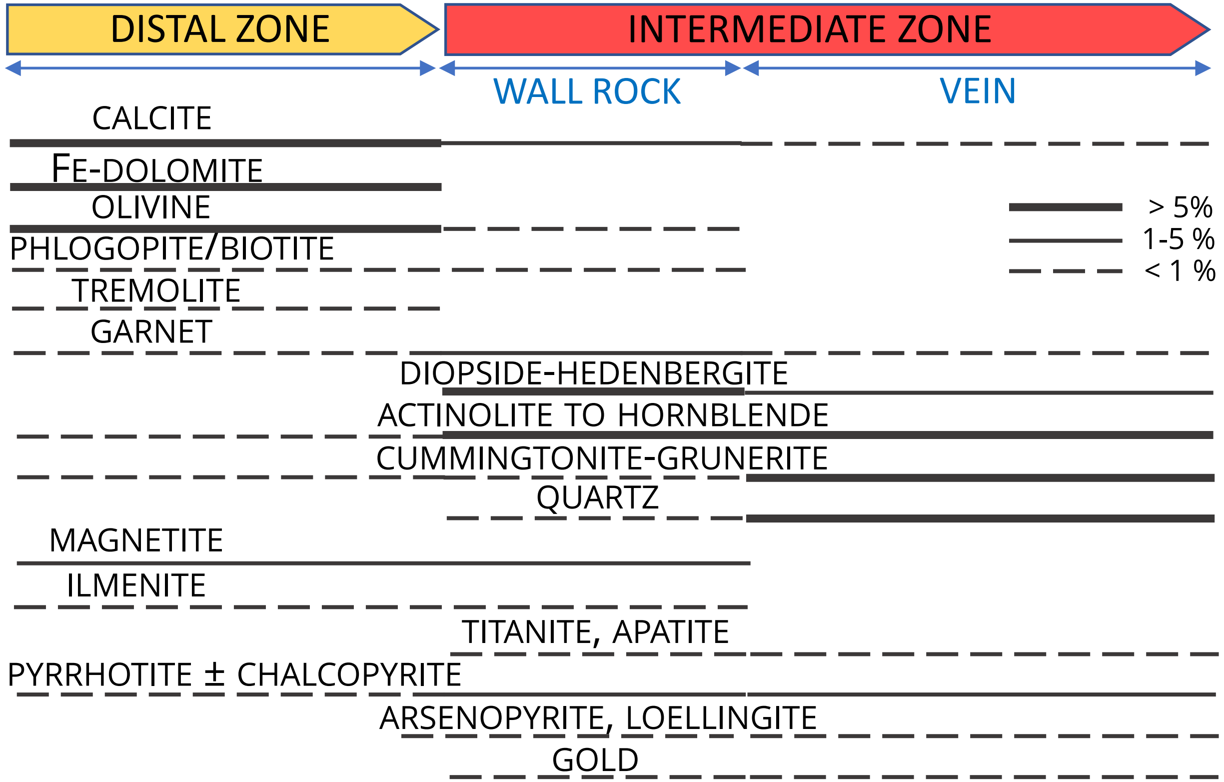


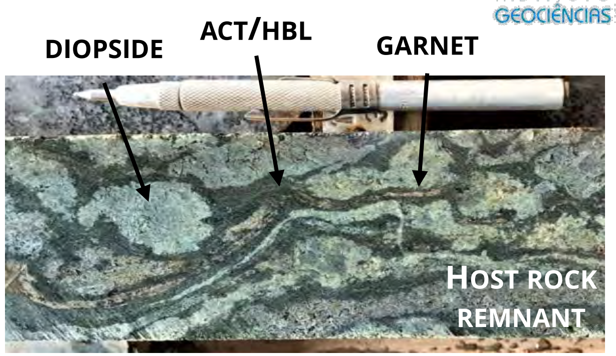
ADAPTED FROM SCARPELLI & HORIKAVA (2017)

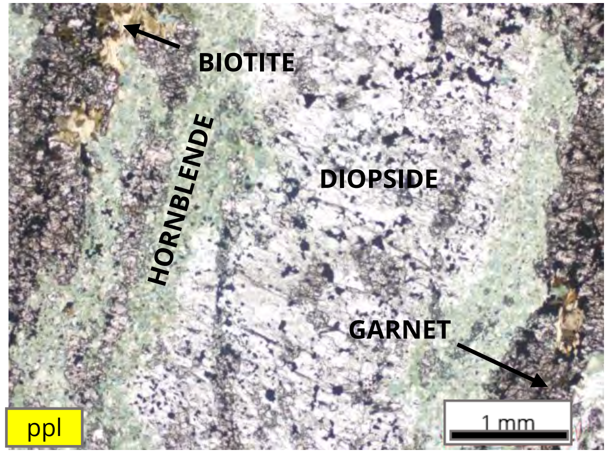
Hydrothermal Alteration - Distal and intermediate zones

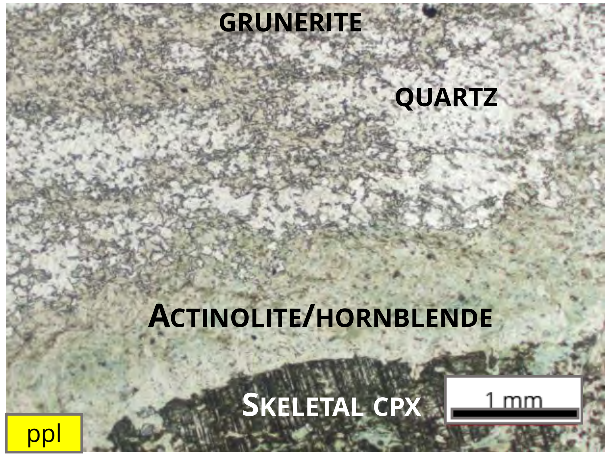


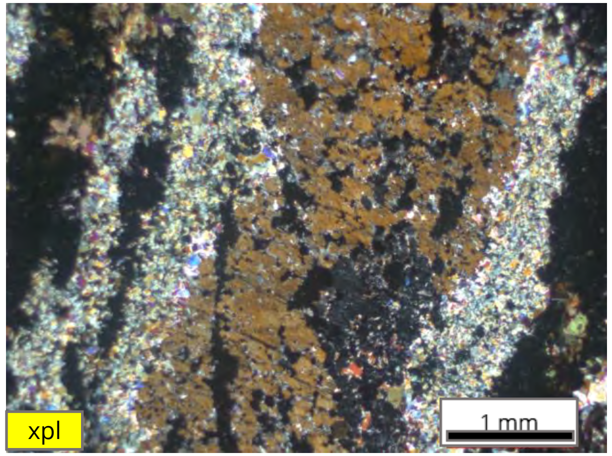


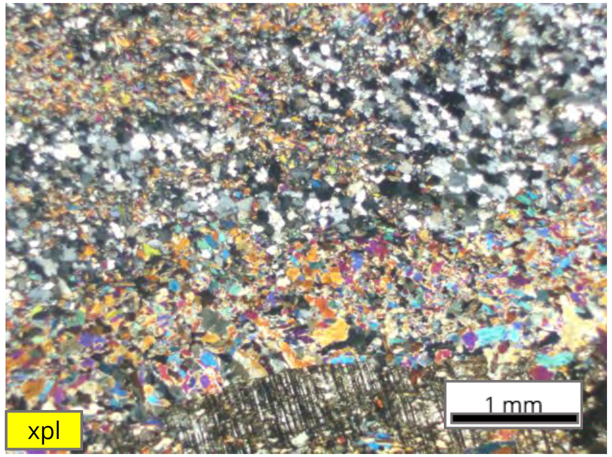




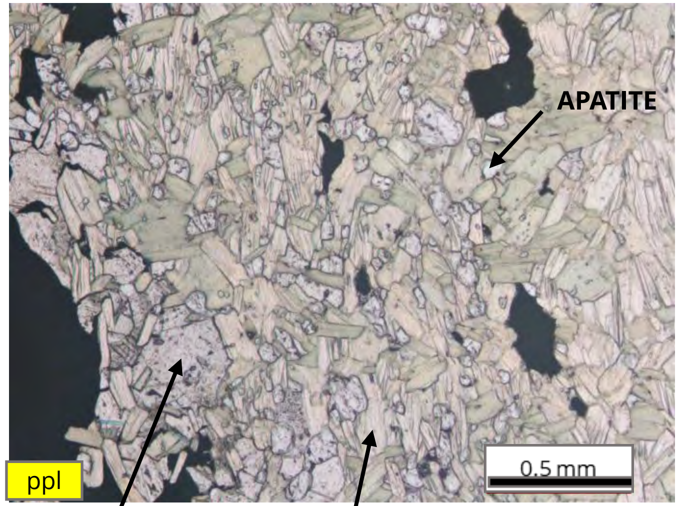


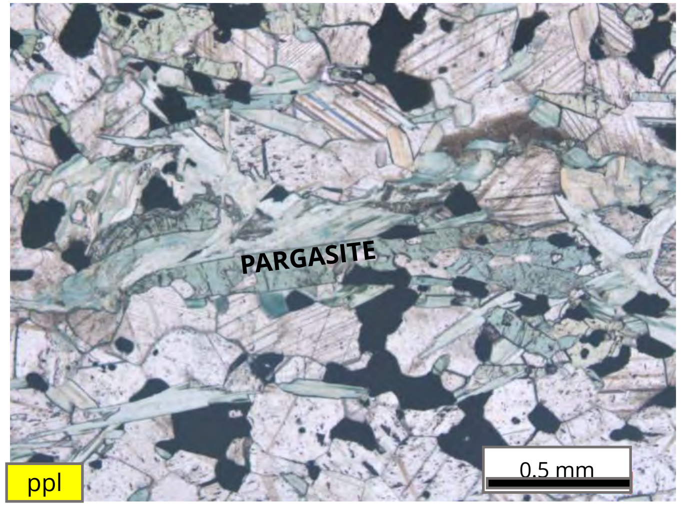


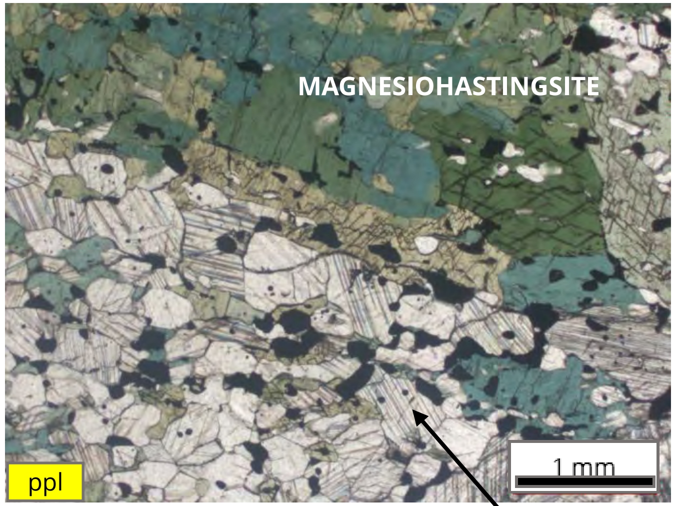




Hydrothermal Alteration – Proximal zone

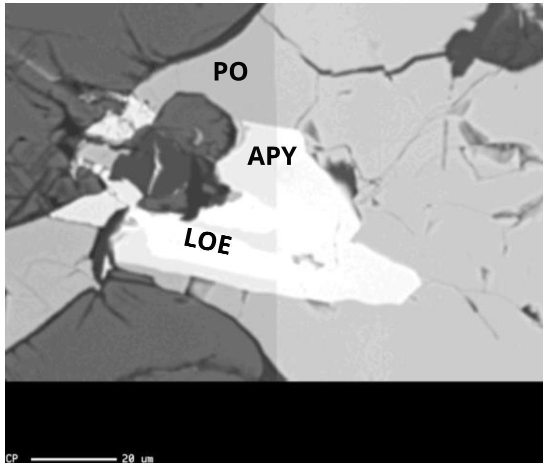


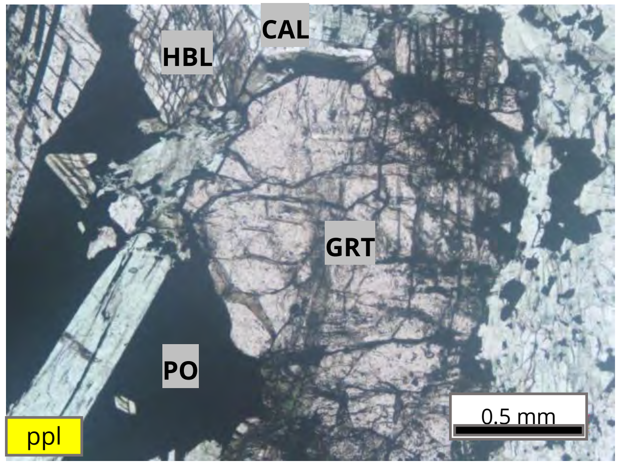


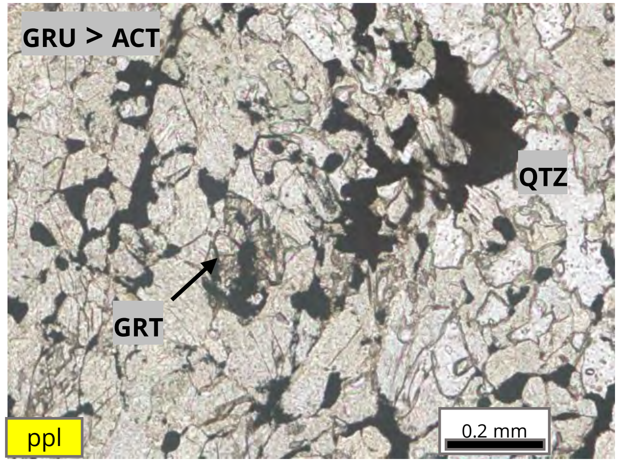


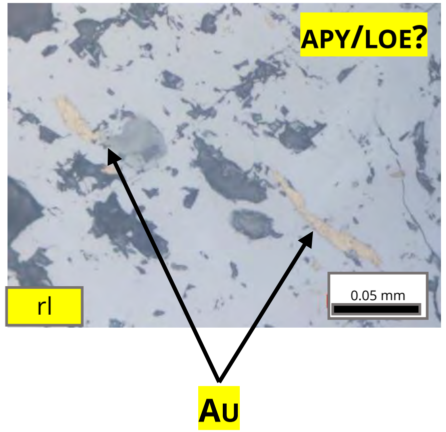
- **Na-bearing hydrothermal alteration assemblage** – Na-bearing ferriphlogopite and Na-bearing amphiboles (pargasite and magnesiohastingsite)
- Ca-poor amphibole, whenever present, is cummingtonite
- **Abundant hydrothermal magnetite** and significant volume percent sulphides
- Apatite as the most importante accessory phase, locally abundant
- Locally displaying strong foliation defined by subparallel magnetite and/or pyrrhotite stringers

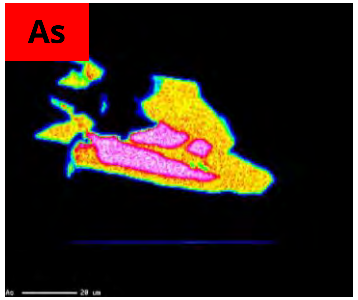
Hydrothermal Alteration – Sulfide-gold and silicate-gold assemblages

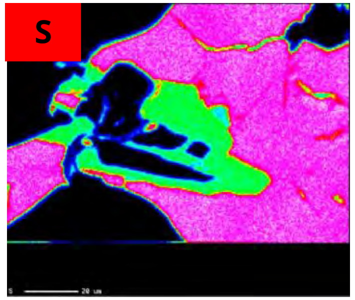


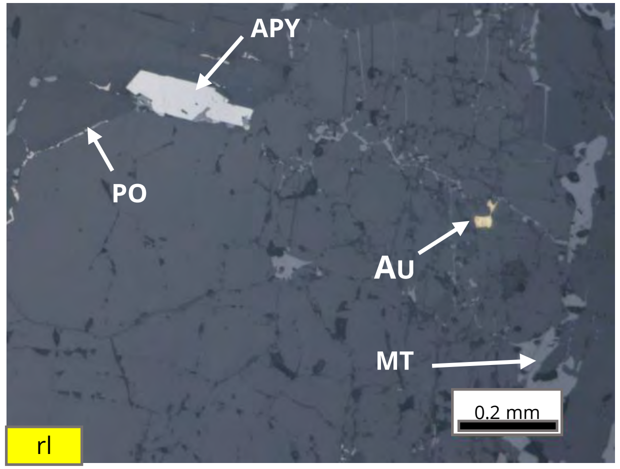


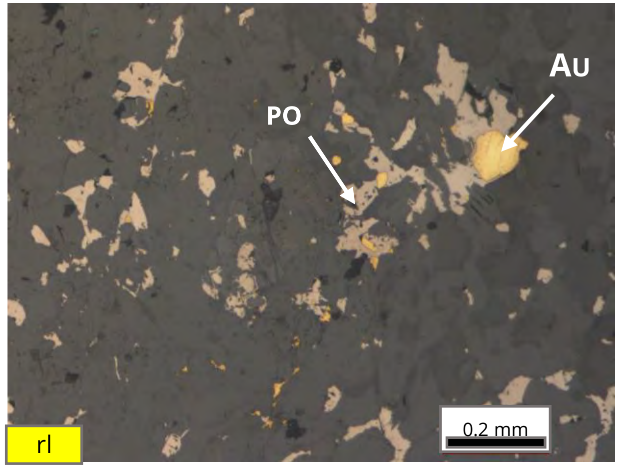


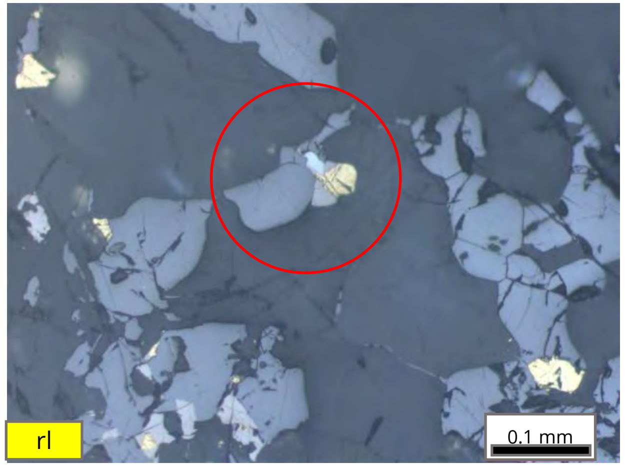


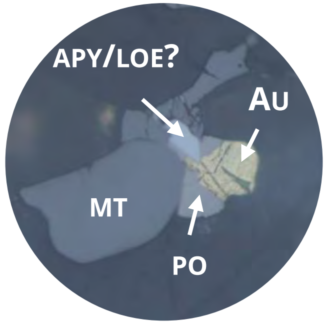












- Visible gold in equilibrium with pyrrhotite and locally with arsenopyrite
- Also in equilibrium with silicates, such as intergranular gold in amphibole matrix. Locally, early-stage garnet is fractured and filled with garnet

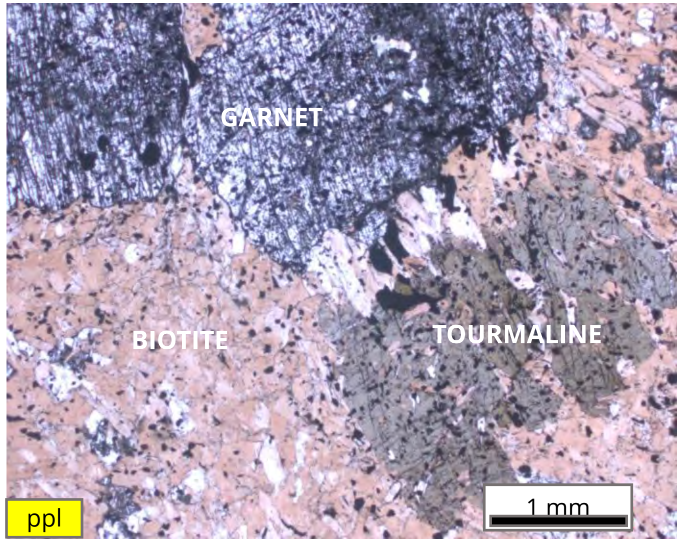
HYDROTHERMAL ALTERATION – P-T CONDITIONS

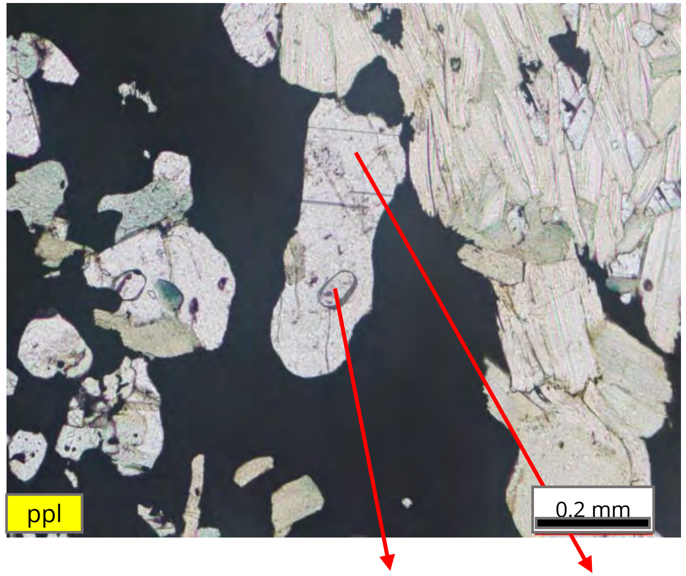
- **PYRRHOTITE-LOELLINGITE EQUILIBRIUM ASSEMBLAGE** INDICATES HIGH-TEMPERATURE ALTERATION – LOWER T LIMIT FOR LOELLINGITE = 491 °C (CLARK, 1960)

- **GARNET-BIOTITE GEOTHERMOMETRY** (HOLDAWAY, 2000) FOR HYDROTHERMAL GARNET-BIOTITE PAIRS YIELDED T(°C) = 574 ± 24 (1σ) (N = 3)

- **CALCITE-DOLOMITE SOLVUS GEOTHERMOMETER** (ANNOVITZ & ESSENE, 1987) RESULTED IN A TEMPERATURE OF T(°C) = 546 (N = 1)

- **GARNET GEOBAROMETRY** (WU, 2019) FOR HYDROTHERMAL GARNET YIELDED PRESSURE VALUES OF P(KBAR) = 4.8 ± 0.6 (1σ) (N = 3)

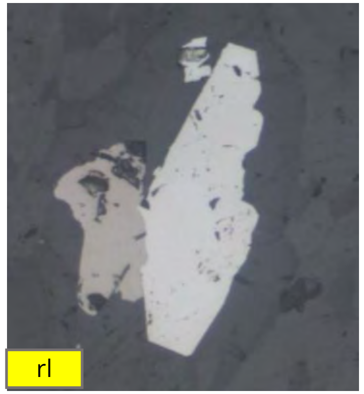


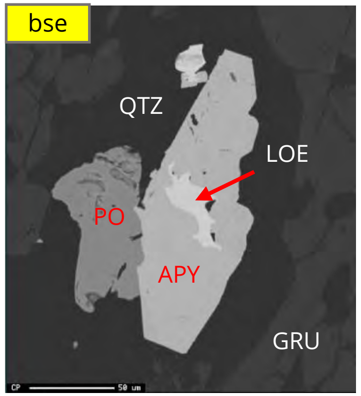


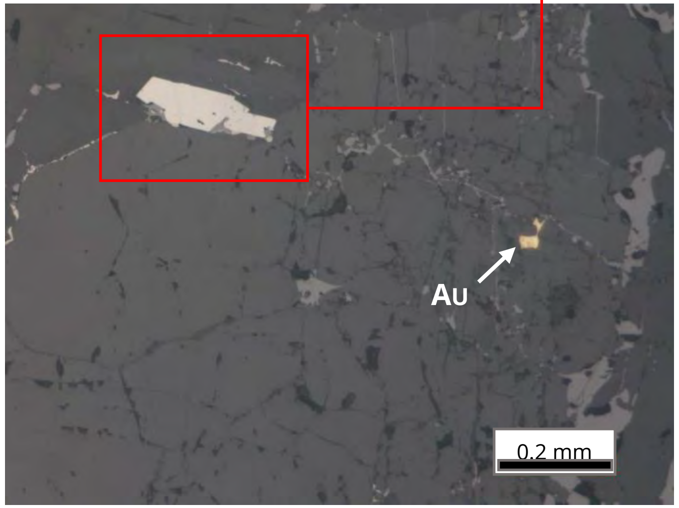
CALCITE **DOLOMITE**

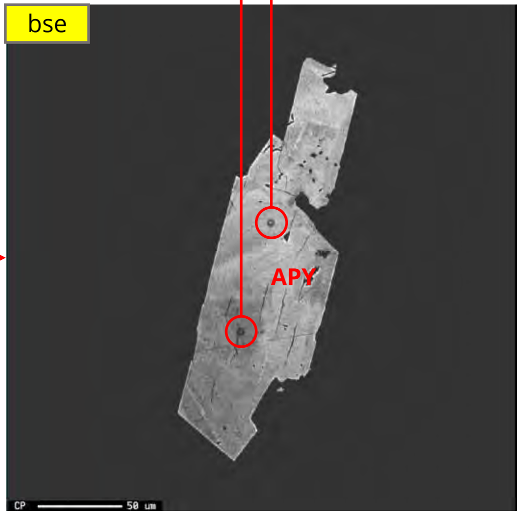
Hydrothermal Alteration - P-T Sulfide Chemistry

- Textural evidence (rimming of loellingite by arsenopyrite) suggests simultaneous crystallization of pyrrhotite and loellingite and subsequent retrograde solid-solid reaction to produce arsenopyrite.
- Most arsenopyrite grains are internally zoned and/or have combined minor element contents > 1 wt% (mainly Co), precluding their use as a geothermometer. Nevertheless, four grains were analyzed, with As atomic percent ranging from 32.73 to 33.16, corresponding to (384 < T(°C) < 410)

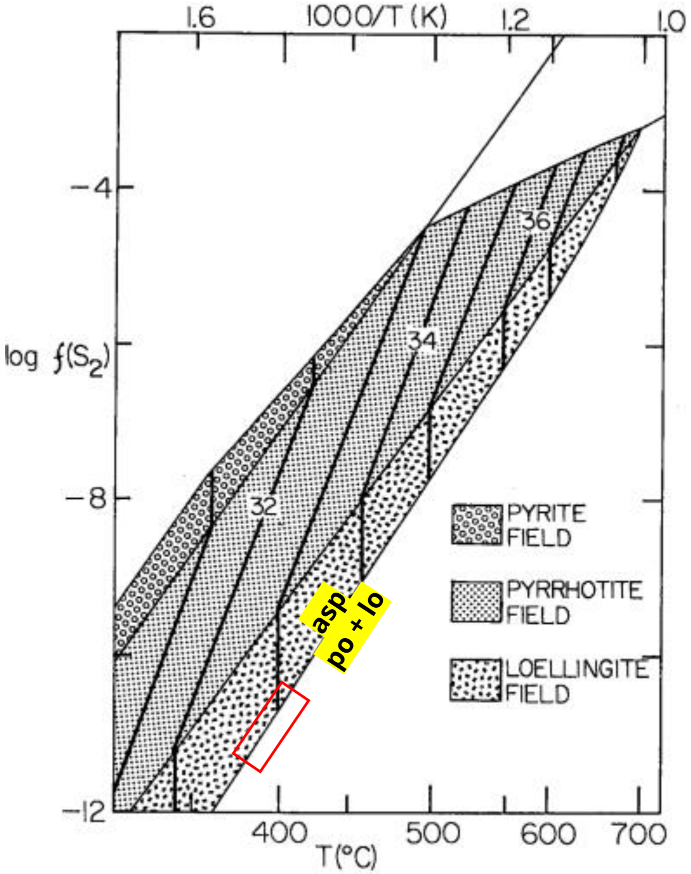








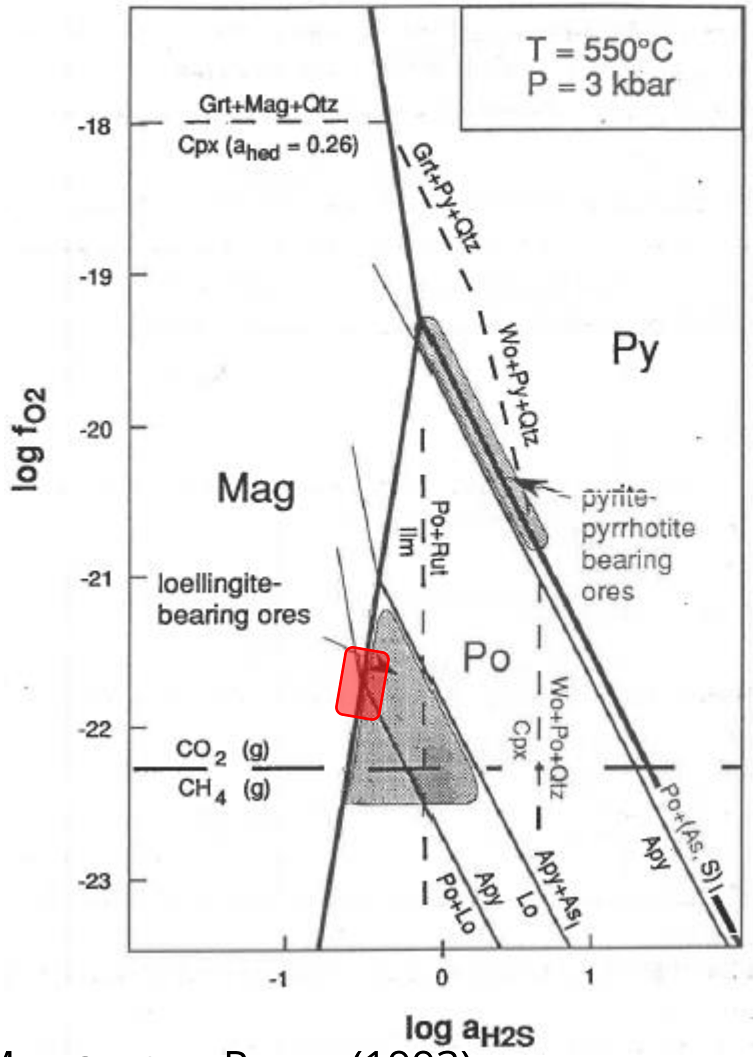
S	18.665	19.519
Fe	32.632	34.596
Co	2.242	0.927
Ni	0.080	0.102
Cu	*bdl*	*bdl*
Zn	*bdl*	*bdl*
As	47.123	45.918
Ag	*bdl*	*bdl*
Sb	0.084	0.042
Te	*bdl*	0.017
Au	*bdl*	*bdl*
Pb	*bdl*	*bdl*
Bi	*bdl*	0.042
Total	100.826	101.163



Sharp et al., 1985 after Kretschmar and Scott, 1976

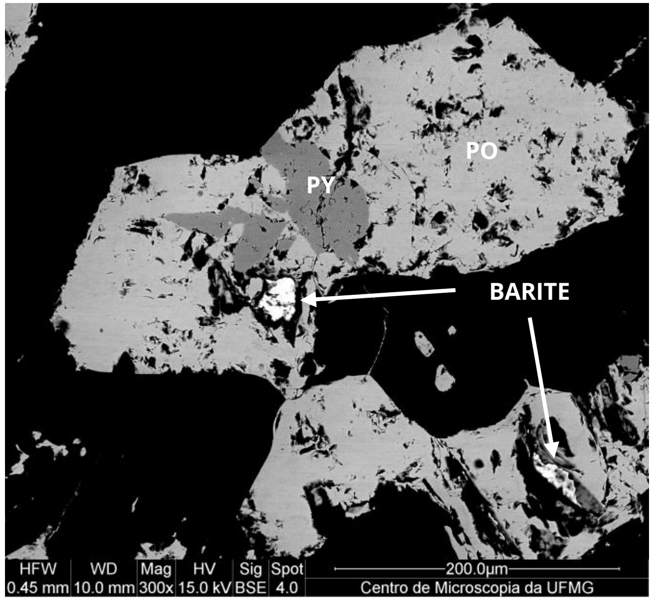
Hydrothermal Alteration – Redox Conditions

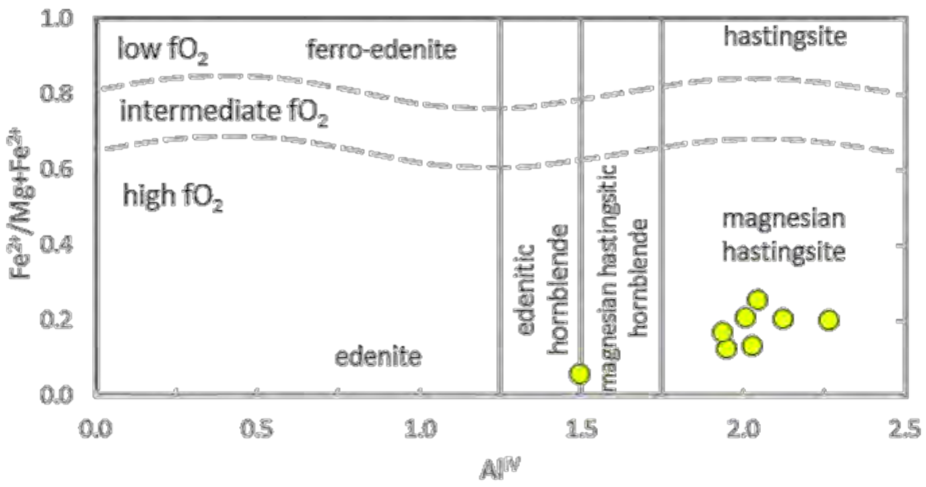
- The stability of magnetite throughout most of the hydrothermal activity enables a constrained assessment on oxygen fugacity and sulphur activity conditions



Mikuchi and Ridley (1993)

- In addition, other features suggest relatively oxidized conditions during hydrothermal fluid flow, such as:
  - ✓ Fe speciation in proximal alteration minerals (significant Fe^{3+} in Na-bearing phlogopite and amphiboles)
  - ✓ V-bearing magnetite
  - ✓ Barite inclusions in pyrrhotite





Anderson & Smith (1995)

HYDROTHERMAL ALTERATION - PRELIMINARY MODEL FOR THE TUCANO GOLD DEPOSIT

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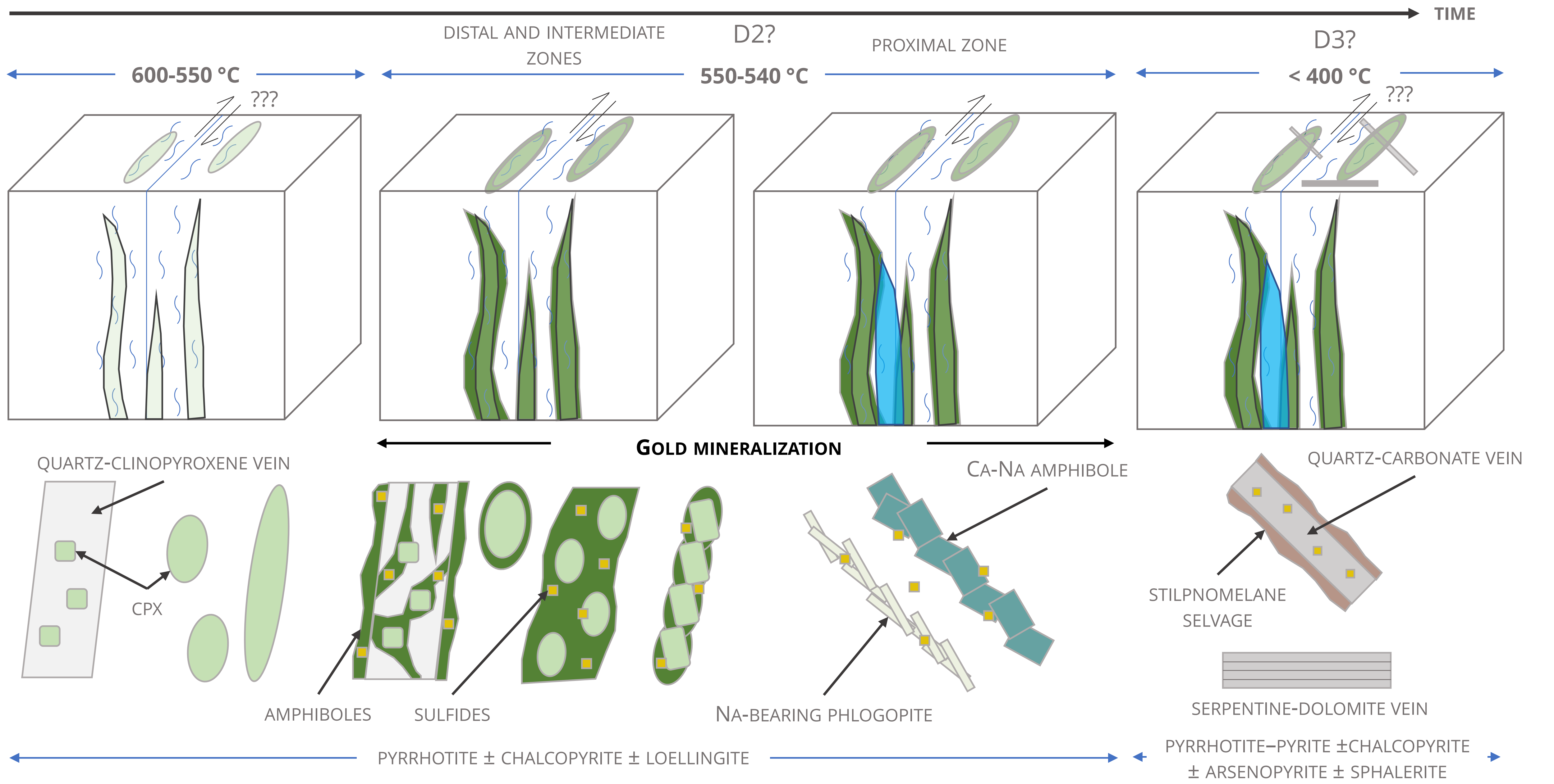

Conclusions

- Tucano is a rare example of a **high-temperature (hypozonal)** orogenic gold deposit
  - ✓ Alteration assemblage: Silicates – *amphibole-phlogopite, diopside-garnet*
    Sulphides – *pyrrhotite-loellingite*
  - ✓ Gold: free grains in silicate matrix, fracture-filling in silicates, equiilibrium with or inclusions in sulphides, free gold in magnetite
  - ✓ T constraints of hydrothermal fluids: garnet-biotite (574 ± 24 °C)
    calcite-dolomite (546 °C)
    loellingite (not stable below 491 °C)
  - ✓ P constraint: garnet (4.8 ± 0.6 kbars)
- Magnetite is stable in the ore zone (locally exceeding 50 volume percent)
- Evidence for oxidized fluids: Fe^{3+} in amphiboles and phlogopite; V-bearing magnetite; barite inclusion in pyrrhotite; magnetite in equilibrium with pyrrhotite

Implications

- First fully documented high-temperature (hypozonal) orogenic gold system in Brazil
- Oxidized conditions compatible with magmatic-hydrothermal fluids
- Open exploration search space for high-T orogenic gold systems hosted in amphibolite facies terrains


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THANK YOU!