Província Aurífera Alto Guaporé (MT):

Metalogênese, controles da mineralização e implicações para a exploração em escala regional

Alto Guaporé Gold Province (MT):

metalogenesis, ore controls and implications to exploration on regional scale

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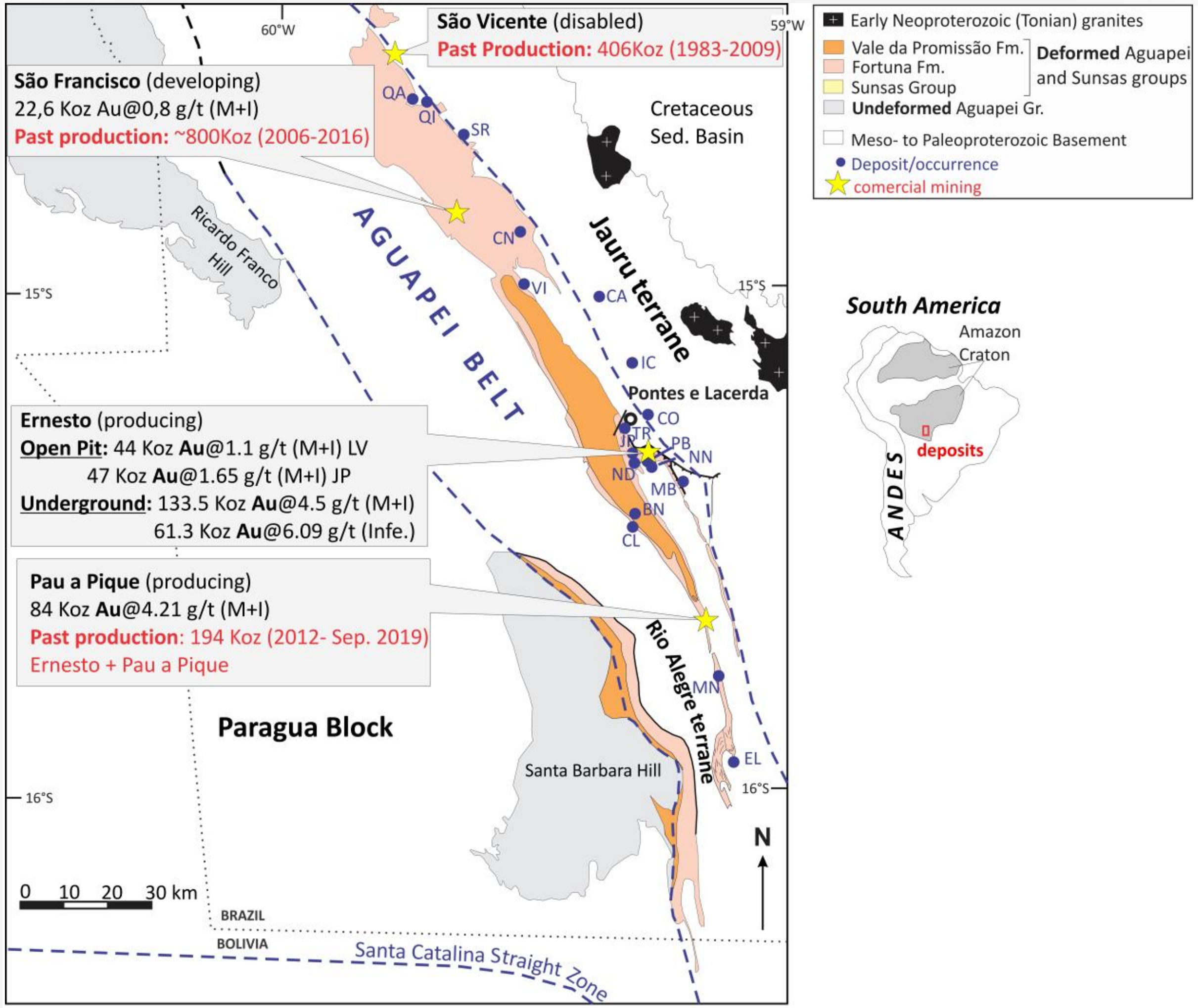
X SIMPÓSIO BRASILEIRO DE EXPLORAÇÃO MINERAL
X BRAZILIAN SYMPOSIUM ON MINERAL EXPLORATION

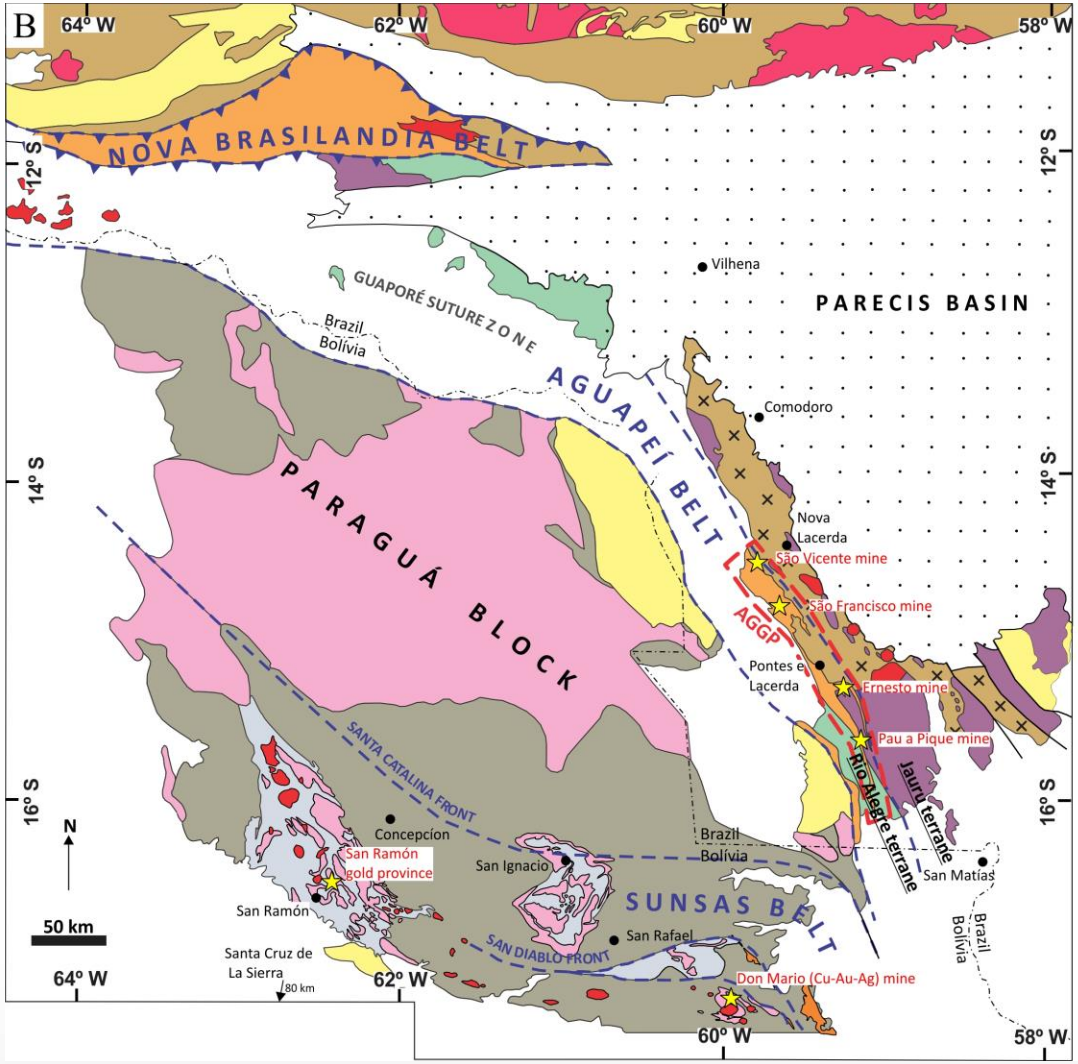
Alto Guaporé Gold Province (AGGP)

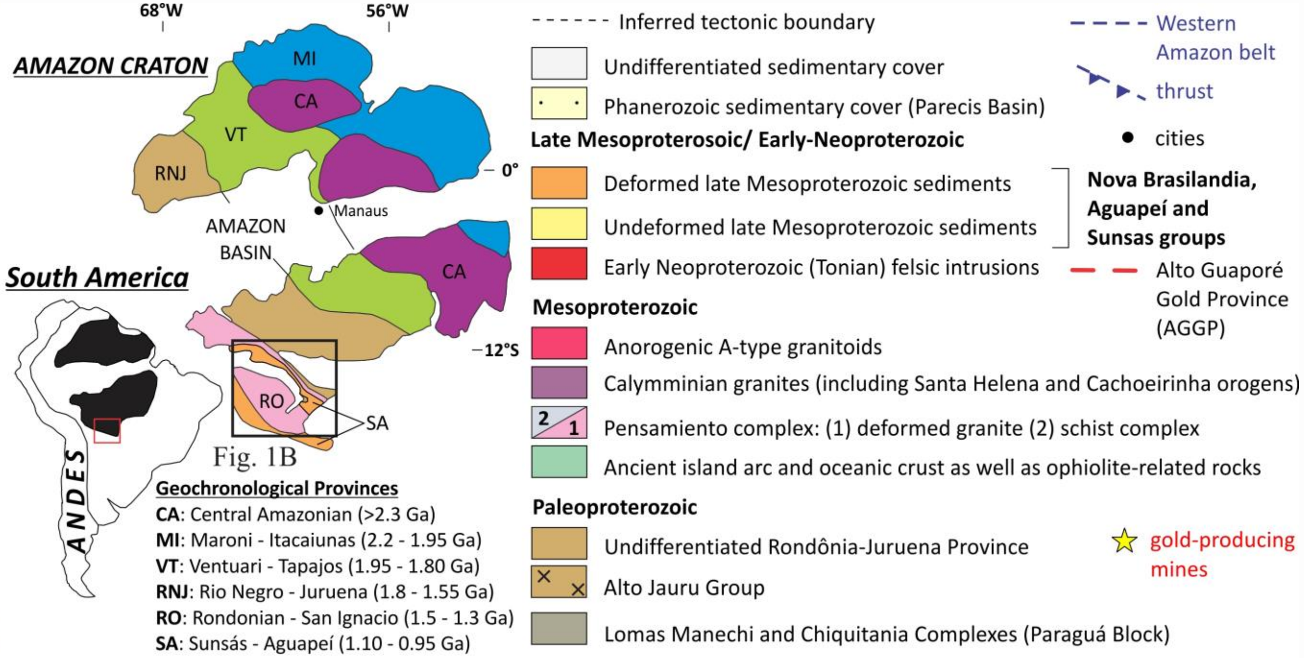


- ✓ ~200km-long belt located in the southern portion of Amazon Craton, close to Brazil (MT) - Bolivia boundary, with at least 20 known gold deposits and occurrences;
- ✓ Two operating mines (Pau a Pique and Ernesto) – central portion;
- ✓ Two disabled mines (S. Vicente e S. Francisco) – northern portion;
- ✓ **Past production + reserves + resources** (last 40 years) = **1.8 Moz**;
- ✓ **Most economically important early-Neoproterozoic orogenic gold province;**

Alto Guaporé Province

Geology and location





- Orogenic gold deposits located within the **Aguapeí belt**, one of the three early Neoproterozoic fold and thrust belt of the **Western Amazon belt;**
- **Aguapeí belt** sits at the boundary between Paraguá block and the Mesoproterozoic margin of Amazon Craton;
- Formed at **the end** of a long and complex geologic evolution started at 1470Ma that includes:
- rifting and sedimentation at ca. 1150 – 1100 Ma; closure of the rift basins and deformation between 1100 – 950 Ma; transpression along Aguapeí belt (964 -908 Ma) with coeval felsic intrusions (964 – 914 Ma)

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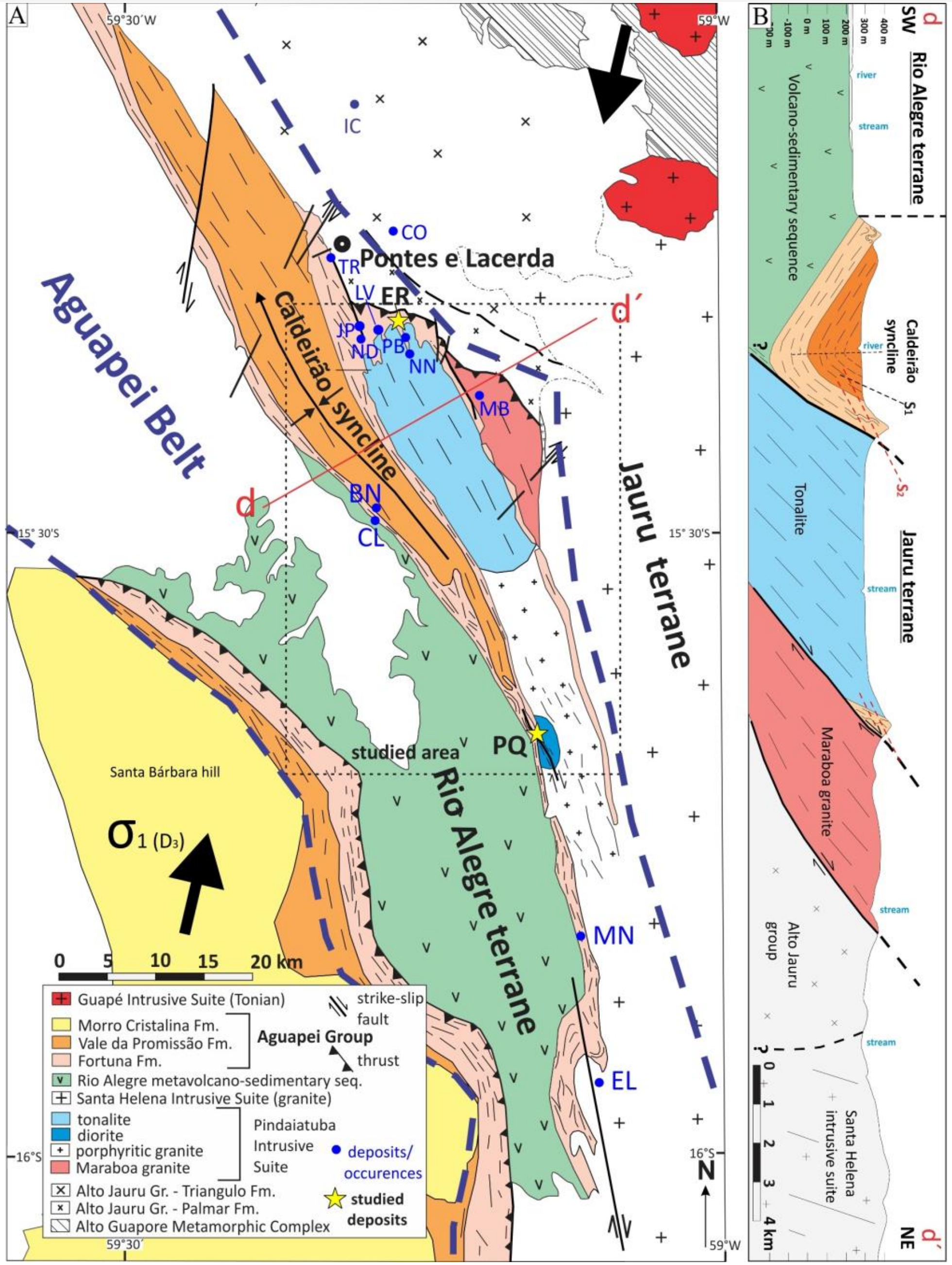

Geologic map of the central portion of Alto Guaporé Gold Belt (AGGP)

Central AGGP

Geological settings

- **Guapé Intrusive suite** (964-914 Ma)**:** felsic anorogenic granites;
- **Aguapeí group:** Marine and continental siliciclastic metasediments overlying Mesoproterozoic basement;

  - *Morro cristalina Fm*.: fluvial sandstones;

  - *Vale da Promissão Fm*.: psamintes and pelites;

  -Fotuna Fm.: Basal sandstone and conglomerates
- **Rio Alegre terrane**: Mesoproterozoic upper greenschist to granulite facies volcanosedimentary sequences (oceanic);
- **Alto Jauru Terrane**

-Mesoproterozoic (1470 – 1420 Ma) granitic batholiths (Santa Helena and Pindaituba suites);

-Paleoproterozoic (1780 – 1720 Ma) metavolcanosedimentary sequences (Alto Jauru group) and ortogneiss and migmatites (Alto Guaporé metamorphic complex).

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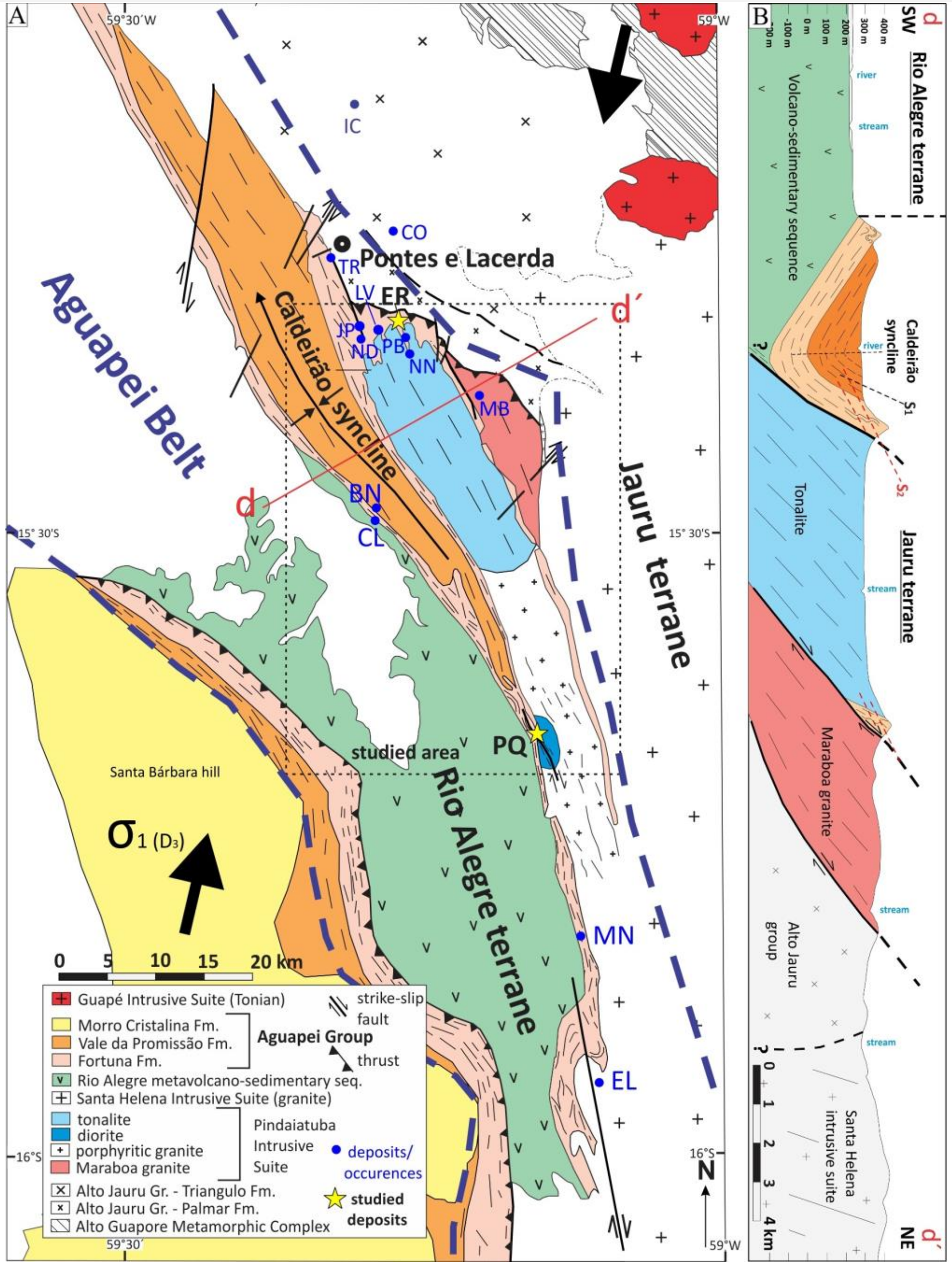
Central AGGP



Geologic map of the central portion of Alto Guaporé Gold Belt (AGGP)

- ❖ **Two “mining district” located 40km apart**:
- ▪ Pau a Pique
- ▪ Ernesto
- ❖ **Structural settings: three deformational** phases developed due to evolution from compression (1150 – 950Ma) to transpression (950 – 900Ma) :

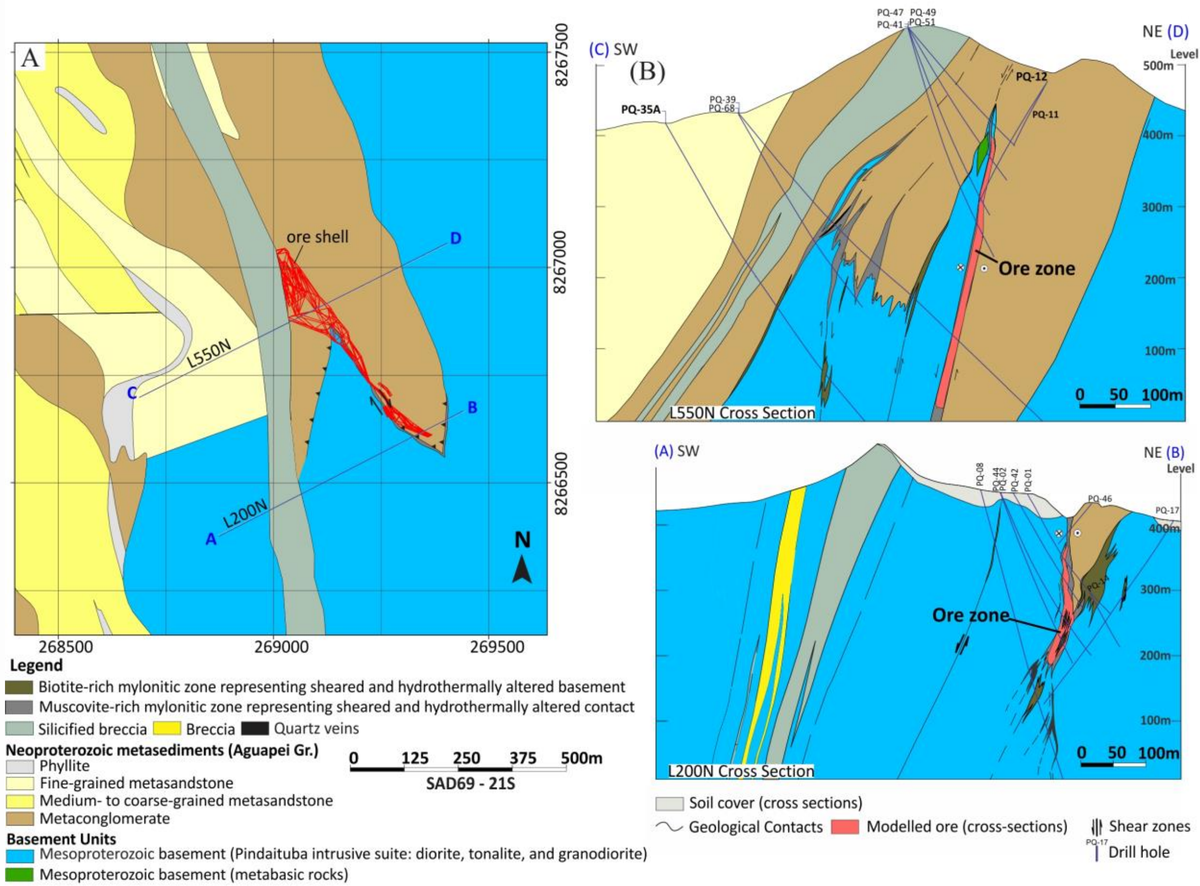
D_1 – folding of S_o with NW-SE fold axis and axial planar foliation (S_1)

D_2 – NW-strinking strike-slip shearing and thrusting (S_2)

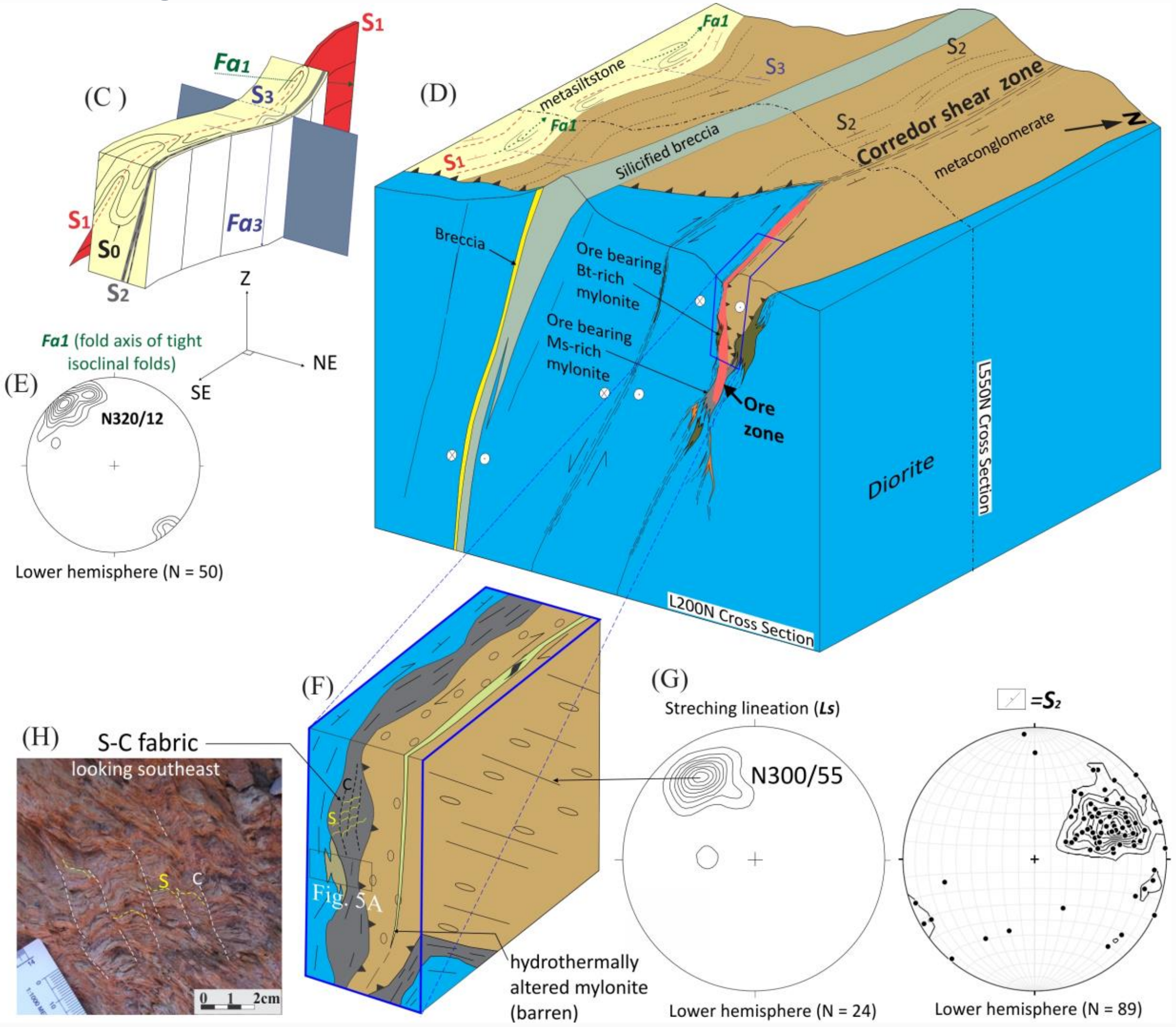
D_3- NE-striking faults **(coeval with gold)**

Pau a Pique deposit

Cross sections and map of Pau a Pique deposit



Geology and structural settings



Schematic block diagrams summarizing the relationship between the main structures

- **Ore body:** is steeply dipping and narrow (500m long; >15m width; 400m in depth;
- **Hosted** by mica-rich altered sheared contact between the foot wall metaconglomerate and arkosic metasandstone and the hanging wall Mesoproterozoic igneous basement (1461 Ma);

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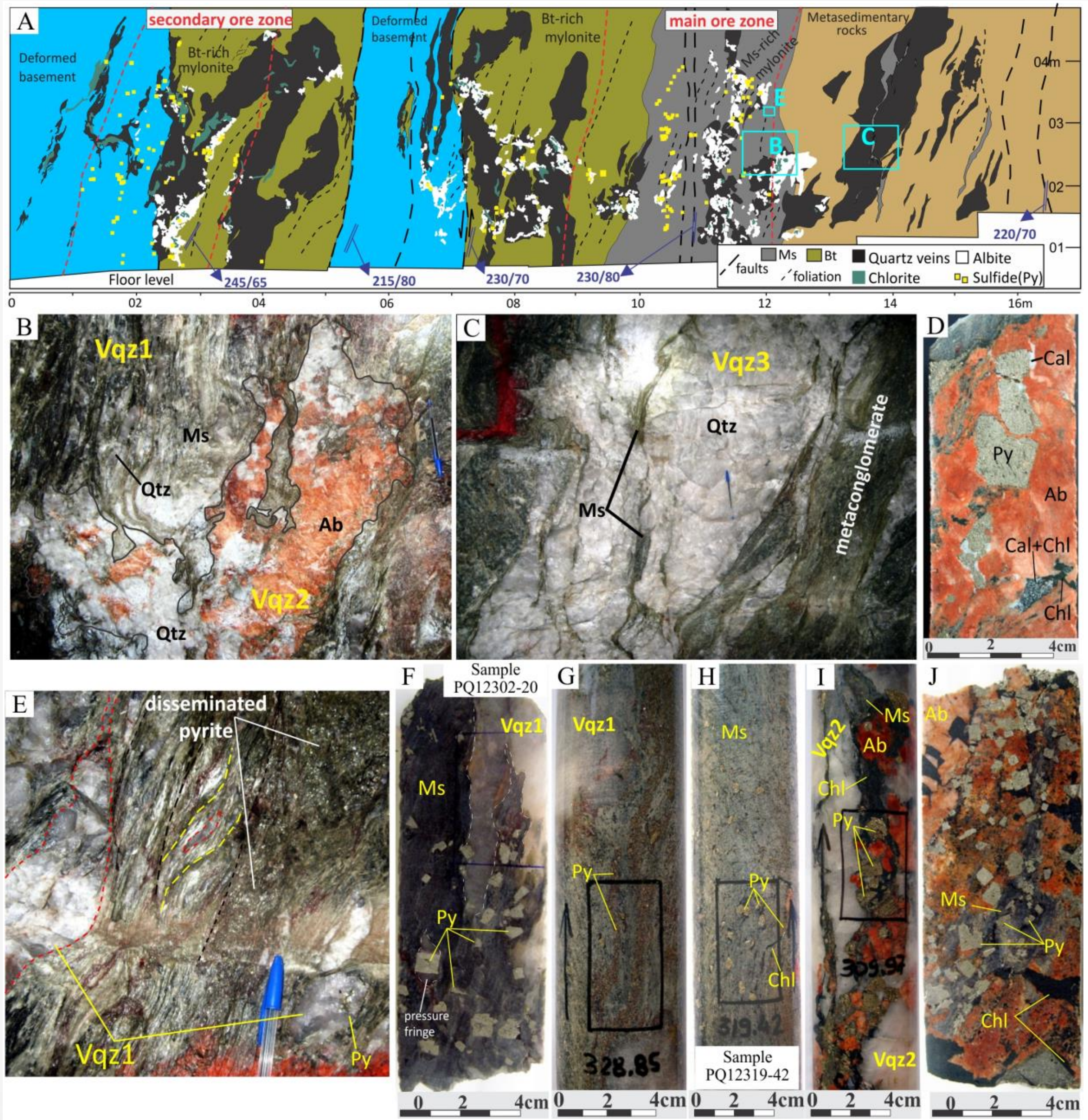
Veining and hydrothermal alteration

Pau a Pique



Veining and hydrothermal mineralogy

- **Ore:** coarse pyrite disseminated throughout the layers of mica and associated swarms of laminated quartz veins;
- **Mineralization style**: disseminated and vein-type ore
- **Veining:** swarms of laminated quartz veins with highly sulfidized margin and less deformed quartz albite veins
- **Hydrothermal gangue phases** includes: biotite, muscovite, Fe-Ti oxides (magnetite, rutile and ilmenite), albite, chlorite, calcite and apatite.

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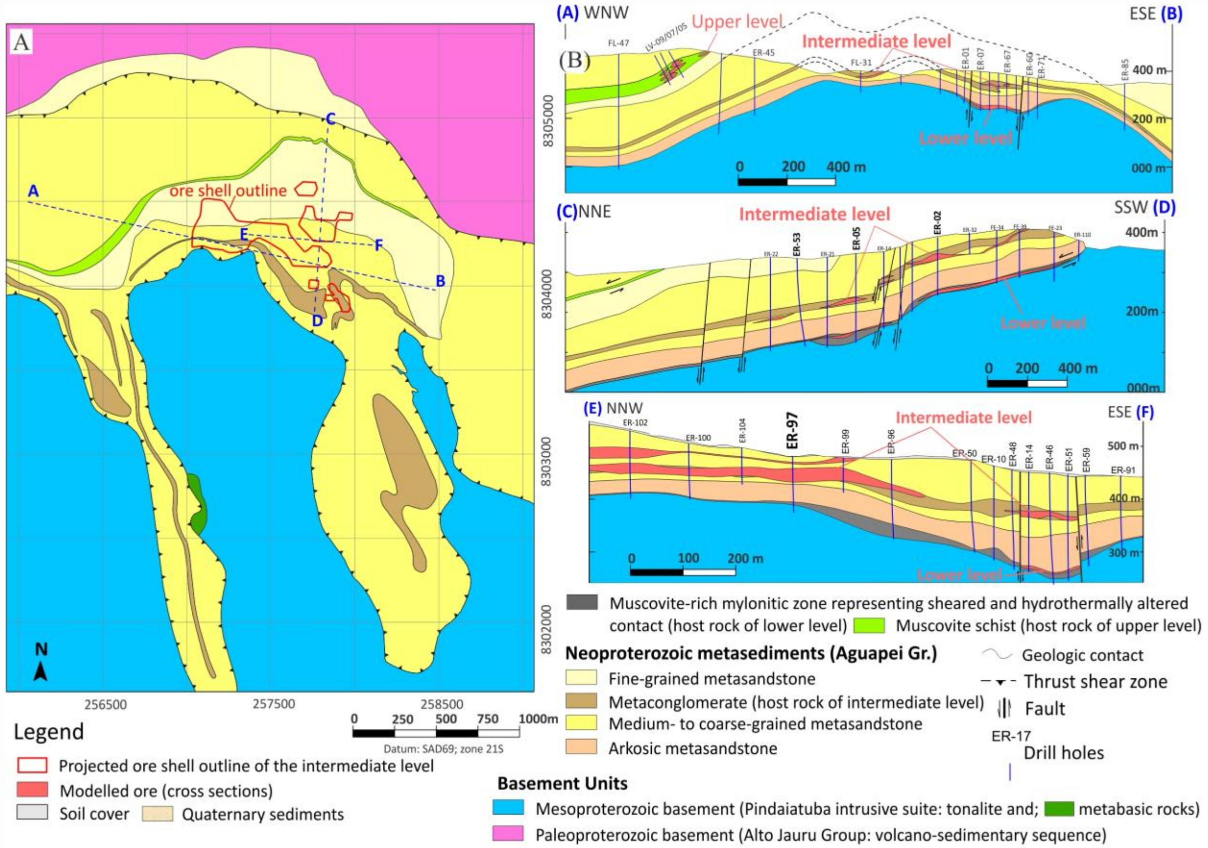
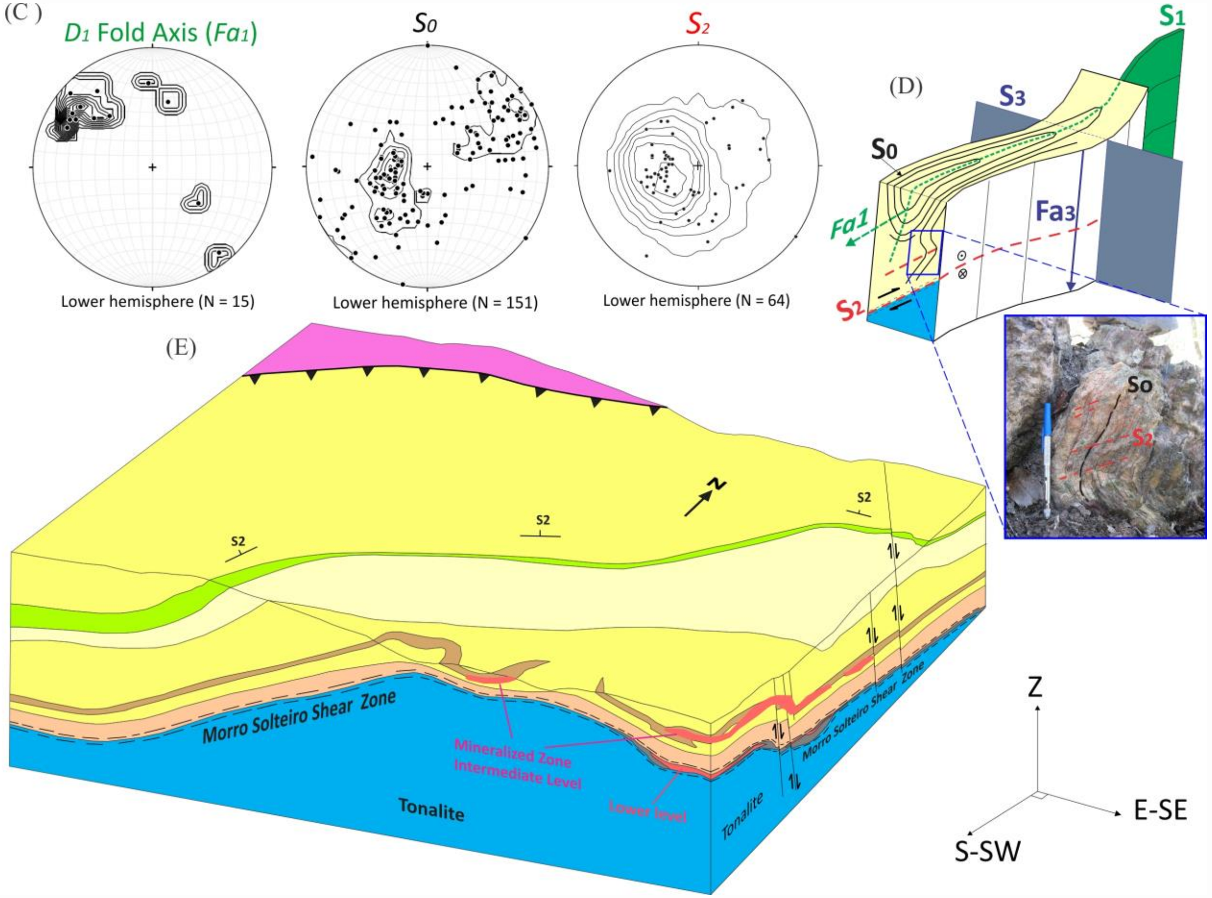
Ernesto deposits

Cross sections and map of Ernesto deposit



Geology and structural settings



Schematic block diagrams summarizing the relationship between the main structures

- **Two main ore bodies** located at different stratigraphic levels.
- **The larger ore body** is in the deeper levels, at the contact between Fortuna sedimentary rocks and the underlying tonalite basement (1465 Ma).
- Similar to Pau a Pique, it is a narrow and tabular feature, and is **hosted** along shear zone which consist of 5- to 25-m-thick layer of hydrothermal muscovite with disseminated coarse pyrite, and associated laminated quartz veins

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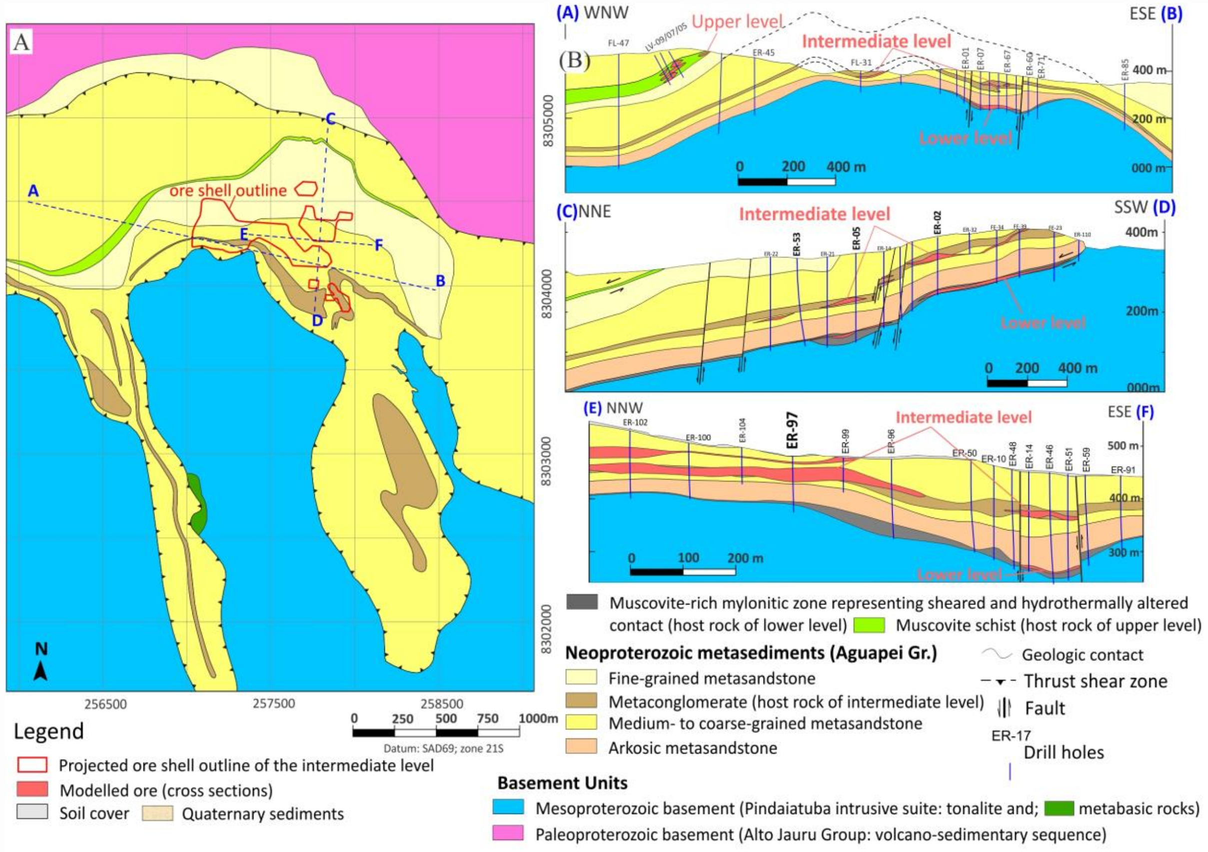
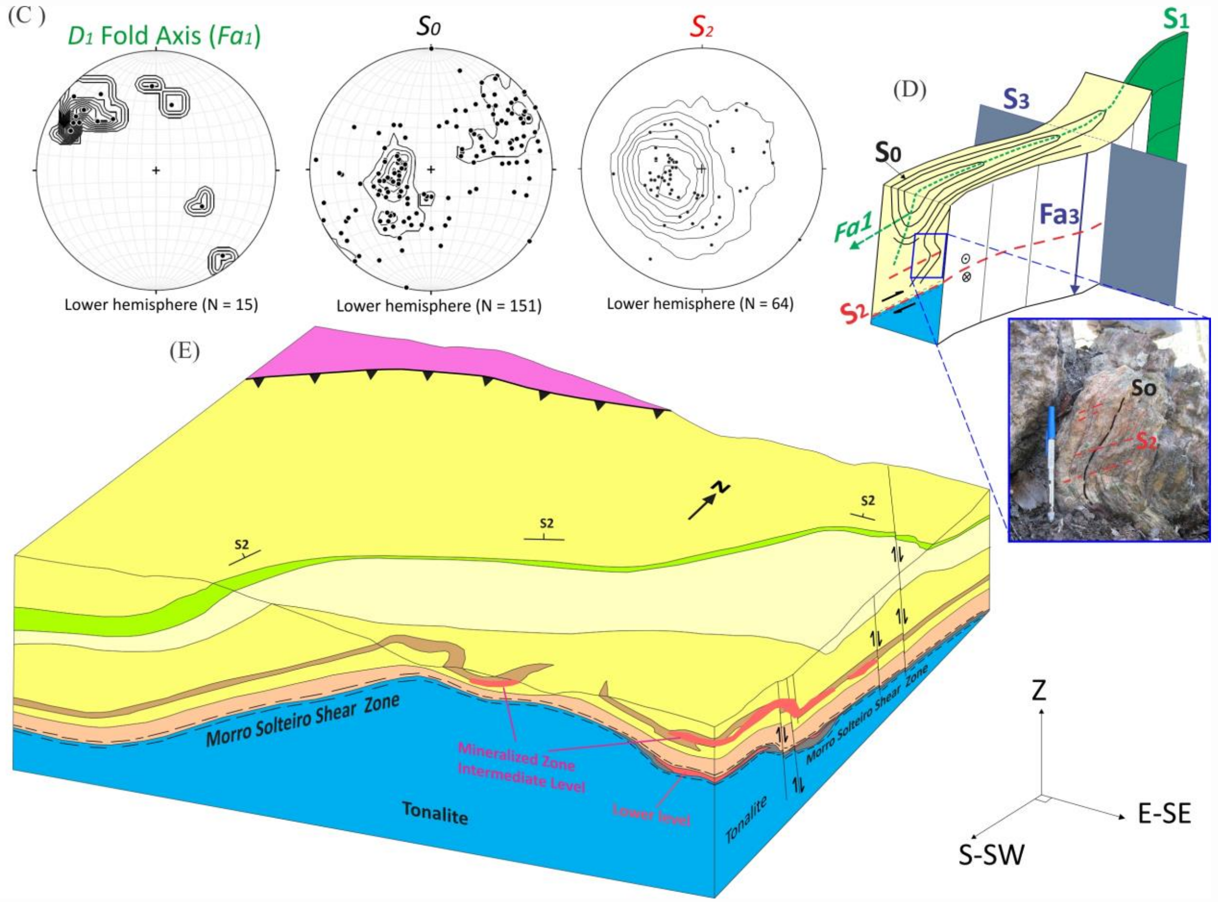
Ernesto deposits

Geology and structural settings

Cross sections and map of Ernesto deposit





Schematic block diagrams summarizing the relationship between the main structures

- The other ore body is located at the **intermediate level.**
- It is an irregularly shaped but stratabound mineralized zone with maximum 50m width, that dips ~25° to NNE.
- Stratigraphically **located** at the base of Fortuna formation, in a ~20m thick metaconglomerate layer;

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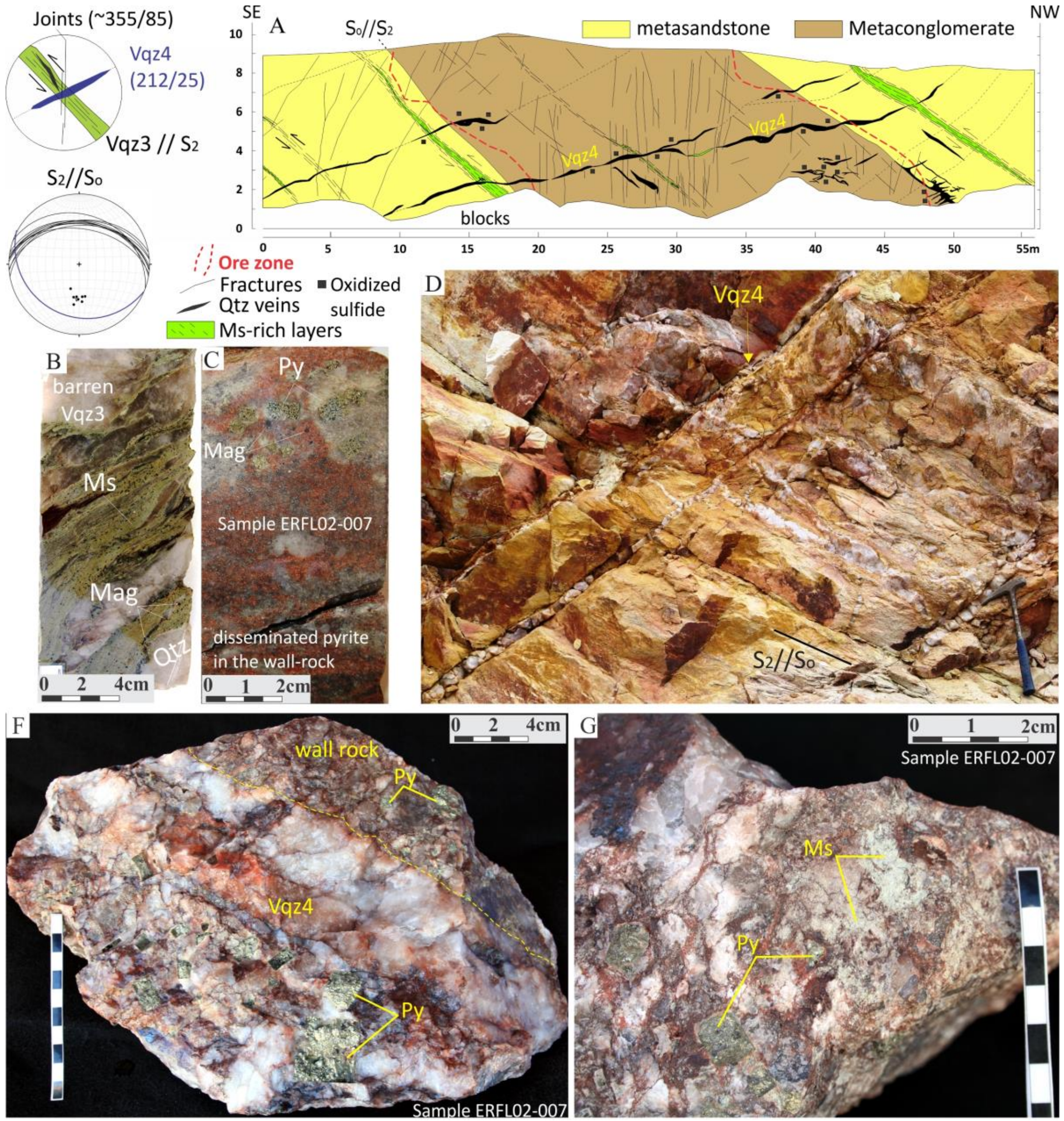

Veining and hydrothermal mineralogy

Veining and hydrothermal alteration

Ernesto (intermediate level)

- **Ore:** zone of gold-rich quartz veins and veinlets as well, the silicified wall rock, with disseminated coarse-grained pyrite;
- **Mineralization style**: stratabound, disseminated and vein-type ores;
- **Veining:** slightly deformed veins along WNW-striking fracture system, composed of milky quartz. Typically pyrite-bearing, centimeter scale in width, although form meter-wide pods of difuse quartz hosted by silicified wall rock.
- **Hydrothermal gangue phases** includes: Fe-Ti oxides (magnetite; rutile and ilmenite) and muscovite.

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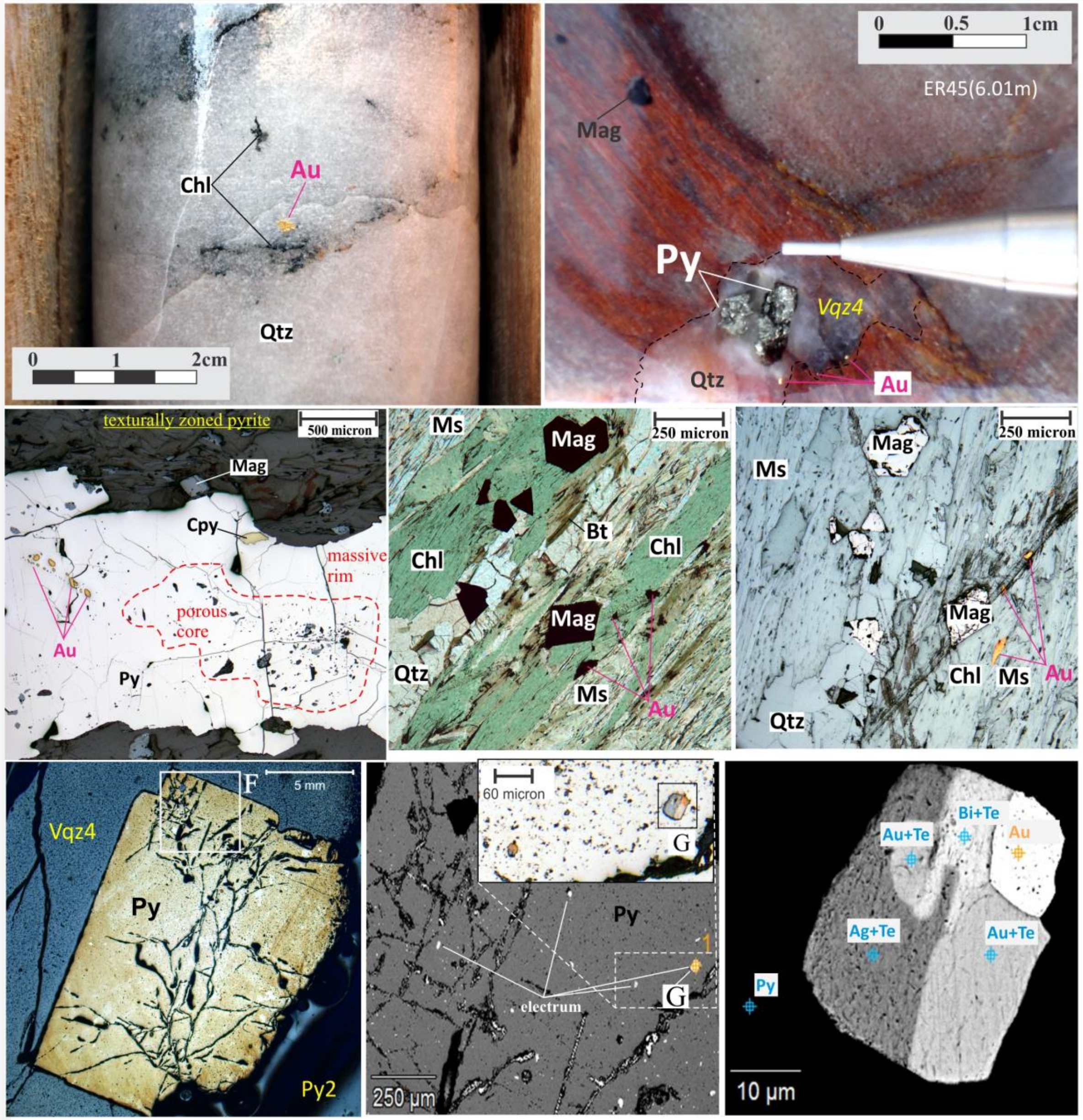
Ore-related mineralogy



Ore-related mineralogy

❖ **Gold:**

- **Microinclusions** of native gold or in association with Te, Ag and Bi in pyrite porphyroblasts;
- Grains of visible gold are in quartz veins or in association with muscovite and chlorite;

❖ **Sulfide**: **Pyrite**

-Very minor **chalcopyrite** and lesser **galena** (mainly on Pau a Pique) as inclusions or in fractures of pyrite;

As – Co – Mo – Cu are the main elevated trace elements;

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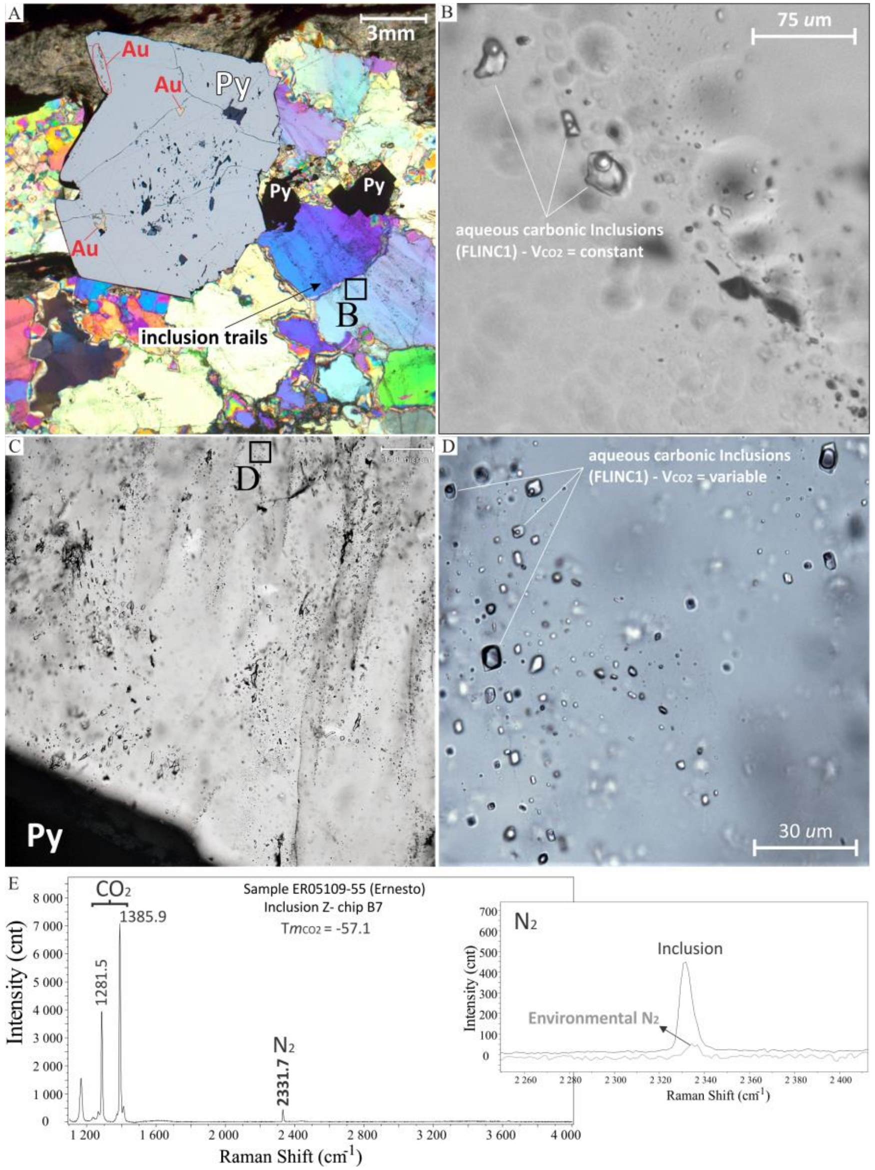
Metalogenesis

Fluid inclusions



Photos of trails of aqueous-carbonic fluid inclusions in ore bearing quartz surrounding gold-bearing pyrite crystals and Laser spectroscopy showing volatiles composition

Assemblages are in trails of secondary inclusions

Three types:

- **FLINC1:** interpreted to **represent the mineralizing fluid** due to its close relationship with gold and gold-bearing pyrite;
- low salinity, aqueous carbonic inclusions (H_2O + CO_2 + N_2 + NaCl + minor KCl, $NaHCO_3$ and $NaSO_4$)
  - *Pau a Pique*: nearly constant VCO_2 (~20 vol %)
  - *Ernesto*: strongly variable VCO_2 (10-70 vol %) – trapping of heterogeneous fluid due to immiscibility
- **FLINC2:** High density, low salinity aqueous Inclusions (H_2O + NaCl)
- **FLINC3:** High salinity (13-17 wt % NaCl equiv) aqueous inclusions (H_2O + NaCl) – only in Pau a Pique

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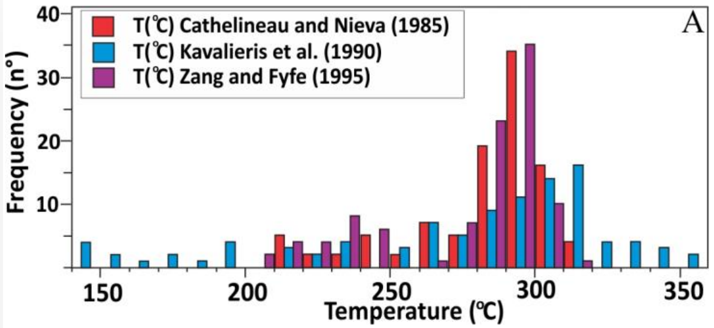
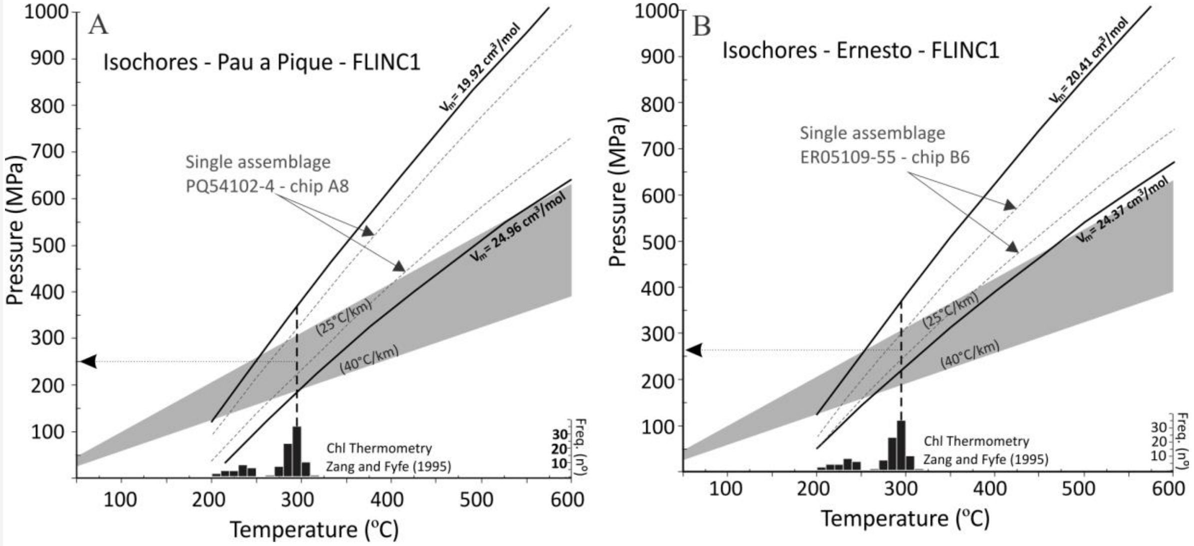




Chlorite geothermometry and calculates isochores for FLINC1

Metalogenesis

Fluid inclusions and geothermometry

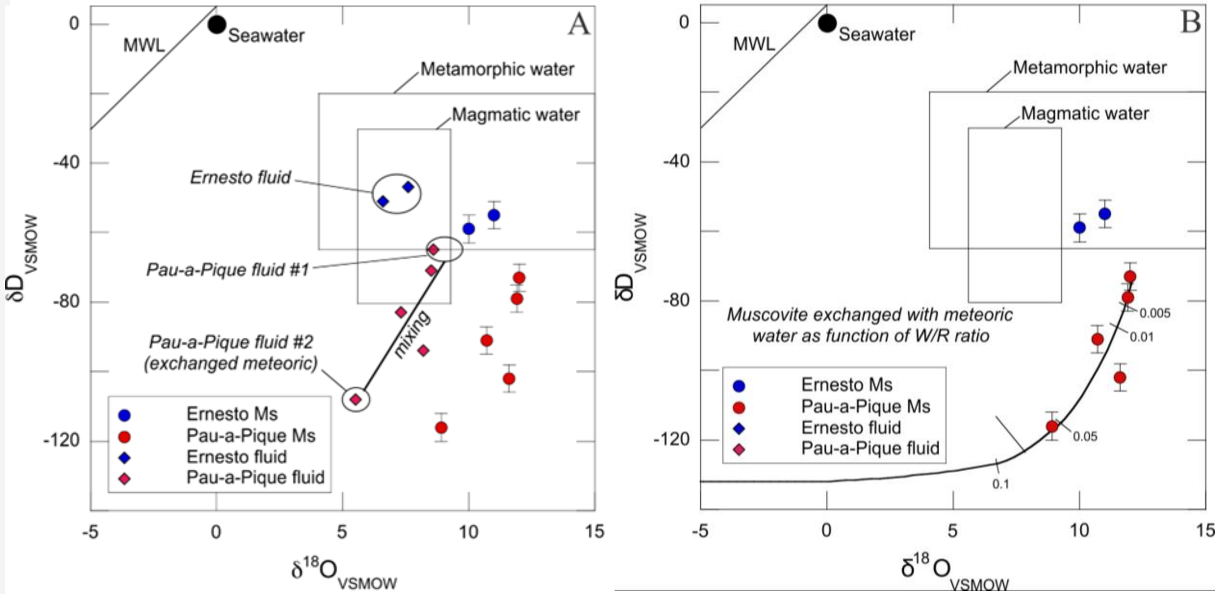
- **Crystallization temperature of hydrothermal chlorite** range between **280 and 310 °C**– obtained from three empirical calibrations

Isochore calculations:

- **Molar volume** varied from **20 to 25 cm³/mol** in both deposits
- Projection of the average Chlorite crystallization temperature against calculated isochores gives an estimated trapping **pressure of ~2.5 Kbar**, which correspond to **8 to 10 Km** at lithostatic pressure.

Summary of Hydrogen and Oxygen isotope data

	Quartz	Muscovite	Albite	Chlotite
$\delta^{18}O_{Mineral}$	8.4 to 13‰	**8.9 to 12‰**	11.5 to 11.6‰	
$\delta^{18}O_{Fluid\ (300°C)}$	1.5 to 6.1‰	5.5 to 8.6‰	7.1 to 7.2‰	
$\delta D_{Mineral}$		**-116 to -55‰**		-85 to -56‰
$\delta^{18}D_{Fluid\ (300°C)}$		-108 to -47‰		



δD vs δ18O plots showing measured values for hydrothermal muscovite (circles) and two possible interpretations of the data. (A) Calculated values for H2O in the hydrothermal fluid (diamonds: equilibration T assumed to be 300°C) fall in the magmatic and metamorphic fields of Taylor (1997) for the Ernesto deposit but extend lower in δD for the Pau-a-Pique deposit, which is consistent with mixing between magmatic/metamorphic fluids and exchanged meteoric fluids during ore formation. (B) The arcuate shape of the Pau-a-Pique data is consistent with small amounts of isotope exchange between muscovite and meteoric water during post-gold exhumation of the deposit (open-system exchange model indicates water-to-rock mass ratios ≤0.05).

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Metalogenesis

Stable isotopes

- **Relatively homogeneous fluid** precipitating ore-related quartz (less susceptible to reset).
- Calculated fluid (300°C) from quartz veins Within orogenic gold;
- **δD** show exceptionally broad range (-108 to -47‰). Orogenic gold deposits are rarely bellow -80‰ (only when methane is involved). Two scenarios:

-(A) Influx of surface water and mixing (linear array);

-(B) Exchange between hydrothermal muscovite and surface water during exhumation (arcuate array).

- **Pyrite $\delta^{34}S$ isotope**: -1.2 to +5.3‰
- Within the range of orogenic gold deposits worldwide (broad range of $\delta^{34}S$) – **crustal source**

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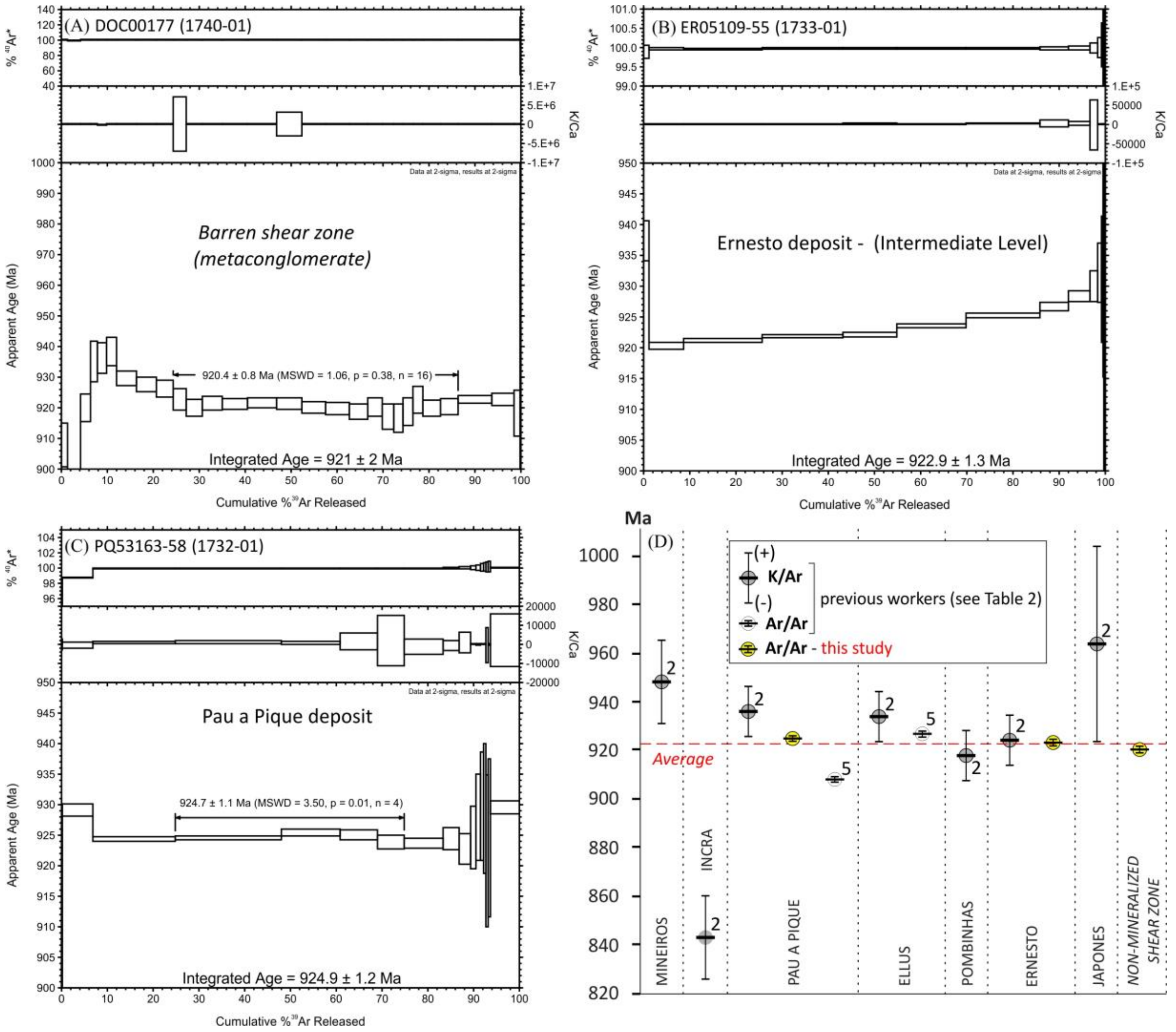


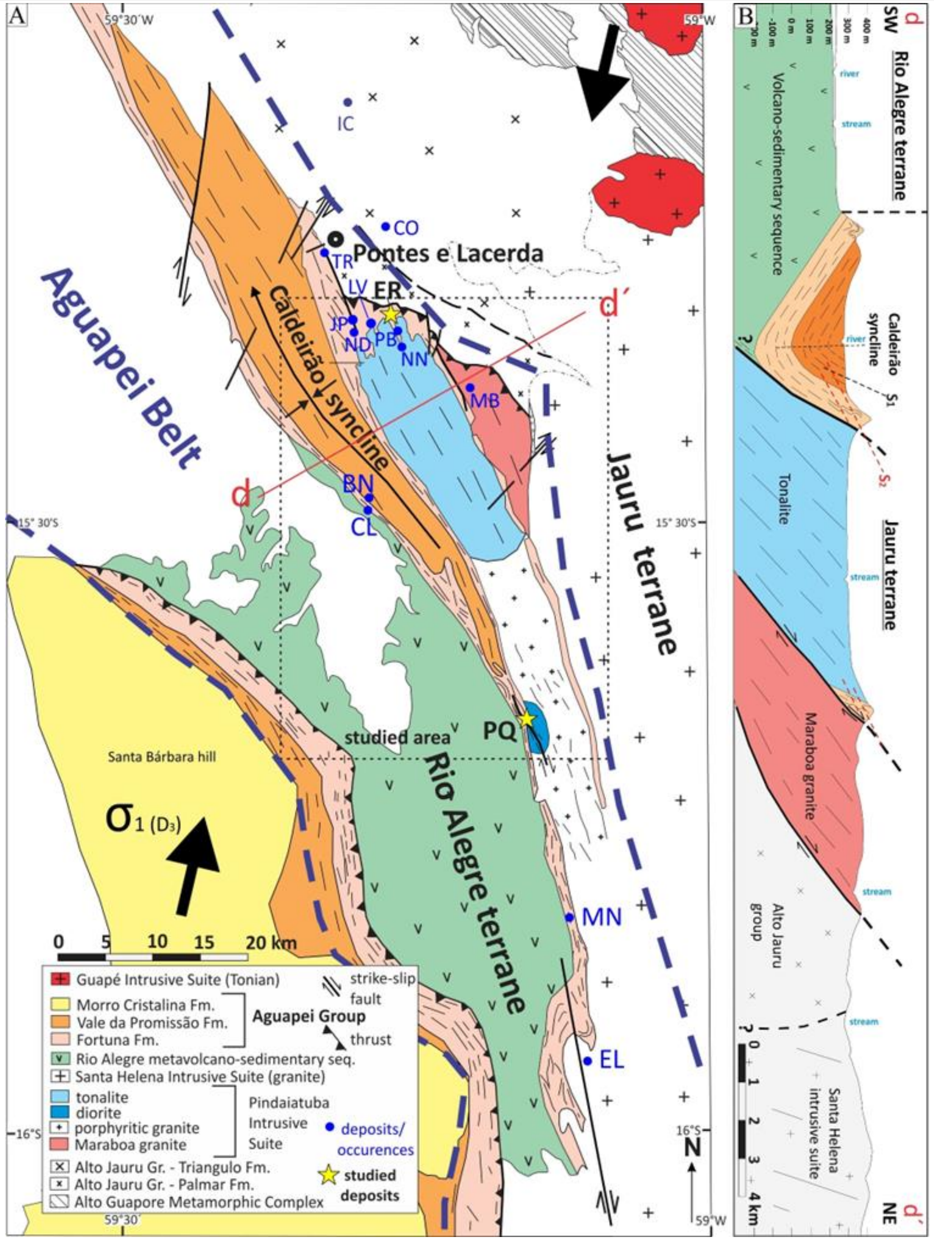
$^{40}Ar/^{39}Ar$ ages of hydrothermal muscovites. (A) Plateau age of 920.4 ± 0.8 Ma of barren shear zone within metaconglomerate of the Fortuna Formation. (B) Integrated age of 922.9 ± 1.3 Ma of ore-bearing quartz vein (Vqz4) of the Ernesto deposit. (C) 40Ar/39Ar plateau age of 924.7 ± 1.1 Ma of muscovite-rich mylonitic zone from high-grade ore of the Pau-a-Pique deposit. (D) Diagram comparing previous 40Ar/39Ar and K/Ar ages from former workers with the new ages published in this study (dashed red line), favoring a much more restricted interval for the hydrothermal system.

Metalogenesis

Age of the hydrothermal event

- Muscovite and sericite is present in almost all reported mineralized veins systems of the studied province;
- It is spatially and genetically related to the gold.
- It is interpreted as being formed during fluid circulation along the shear zones, presumably during the transpressional reactivation (D_3);

- $^{40}Ar/^{39}Ar$ data **(920.4 – 924.9 Ma)** combined with existing data gives an estimate interval between 920 and 928 Ma for the hydrothermal event, favoring a more restrict age interval, which is **consistent with** the relatively short **interval of less than 10 m.y. of activity for orogenic gold** systems associated with evolutions of many metamorphic belts.



Metalogenesis

Fluid and metal source

- Stable isotope data suggest a metamorphic fluid source from devolatilization of crustal sequences;
- Devolatiziation of underlying basement rocks is not a feasible model because these are upper greenchsit to granulite facies rocks that record Mesoproterozoic (1320 – 1380 Ma) Ar/Ar and K/Ar ages of hornblende and biotite (e.g., Tohver et al., 2006);
- Metamorphism of fine grained sedimentary rocks (Vale da Promissão Fm.) is the most likely event leading fluid and metal release to form the gold deposits;

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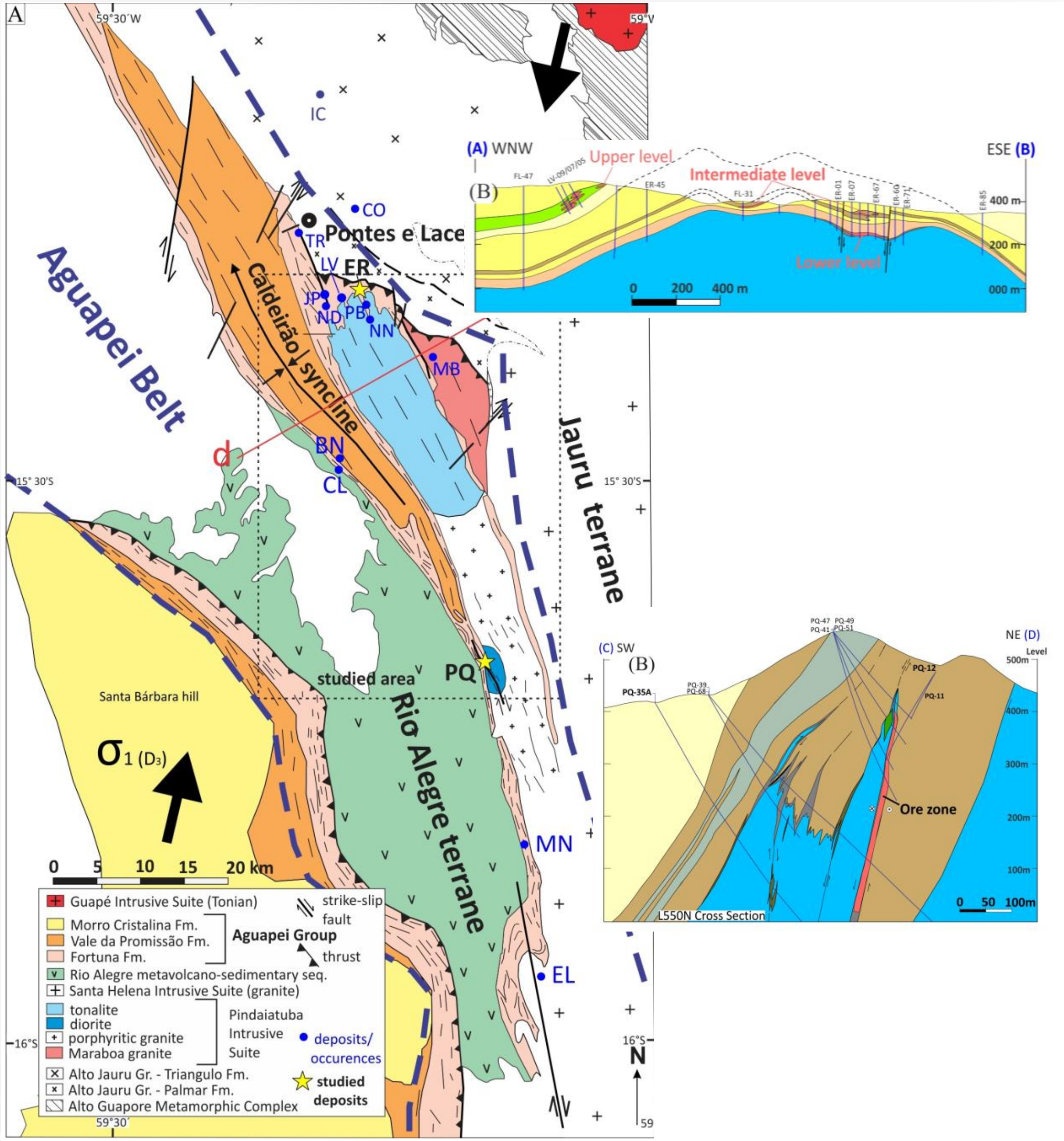

Structural control on location of the largest AGGP deposits

- **Structural geometry on location of province's largest deposits are very similar to what is reported in orogenic gold provinces worldwide (e.g., Groves et al., 2018)**
- **(1) Both Pau a Pique and Ernesto** (~40km apart) are both located on jogs of a first-order structure;
- The belt has a system of late, ~70°, cross accommodation faults that rotate the more rigid component that probably generate dilatational zones in the earlier (S_2) structures:
- Both, **Pau a Pique** and the **Ernesto (inferior level),** are located in the sheared margins between rigid pre-ore granitoids and more ductile metasedimentary sequences, and which heterogeneous stress must have been generated due to variations in geometry of the igneous rock;
- In **Ernesto (intermediate level):** a discordant to bedding parallel fracture system filled with ore-bearing veins represents the low minimum stress zone formed within highly competent layer of conglomerate where the sequences bend around competent tonalite

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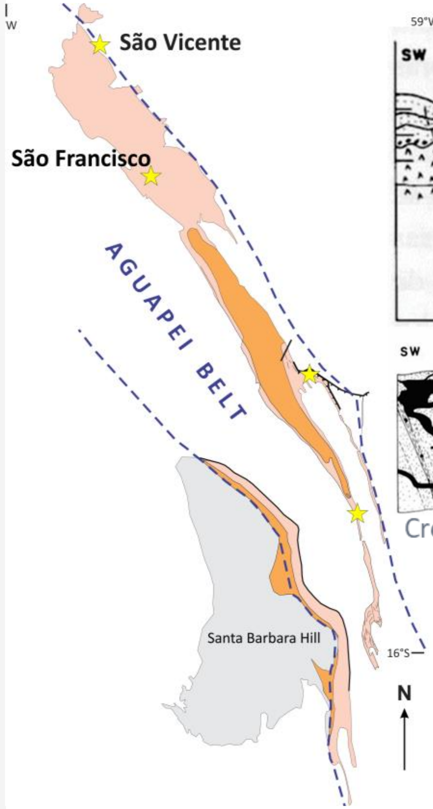
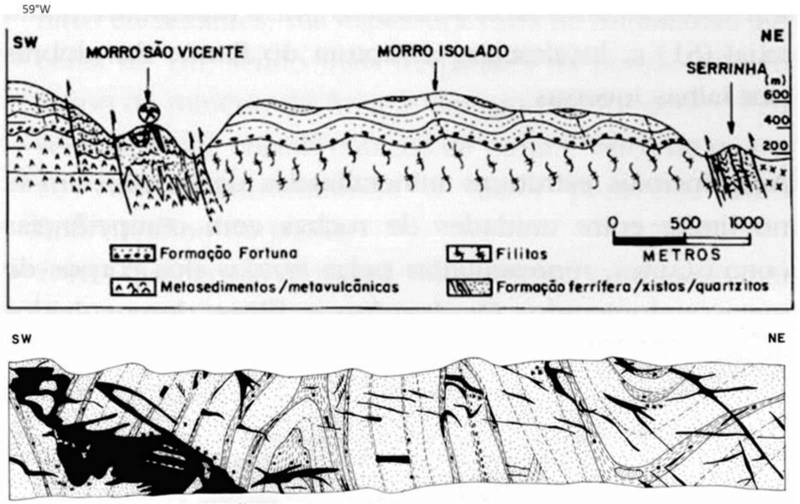
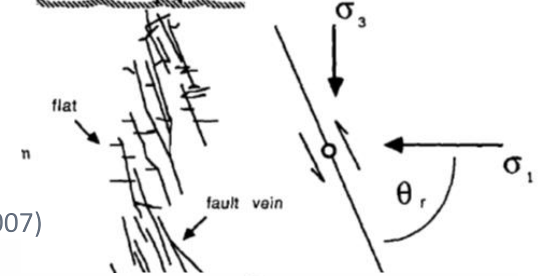


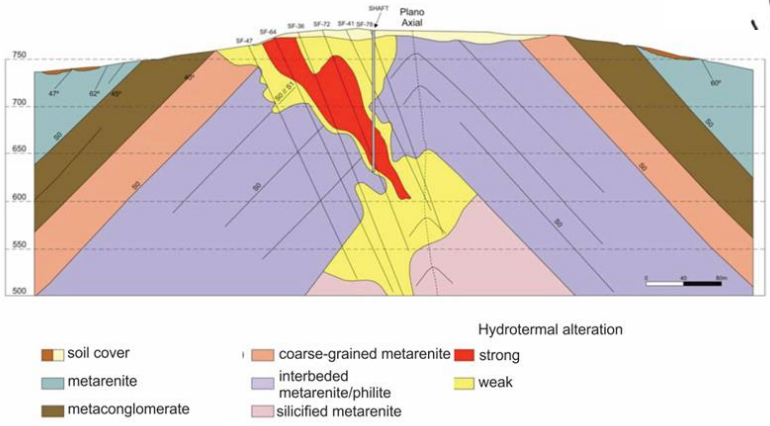


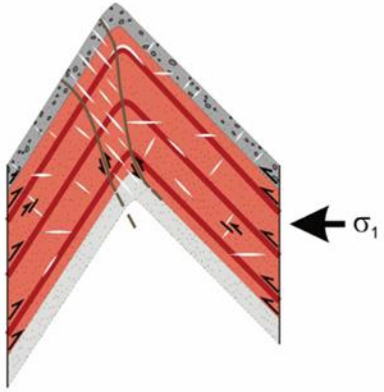
Cross sections of São Vicente deposit (Scabora and Duarte, 1998)

Sibson and Poulsen (1998)



Cross-sections of São Francisco deposit (Alvim, 2007)





Structural control on location of the largest AGGP deposits

- ✓ In **São Vicente deposit** mineralized veins are:

-Suhorizontal extensional veins that truncated isoclinaly folded layers of metarenite and the deposits is located in the center of 1-km wide zone of tightly folded rocks formed by high angle reverse faults

- ✓ In **São Francisco deposit** mineralized veins are:

-NE-dipping and subhorizontal occuring within the hinge zone of an anticline and veining is controlled by fracturing and high-angle reverse faulting suggesting an overprint within the earlier flexural folding as critical ore-related mechanism.

- ✓ **Largest deposits are repetitive, distant 35-40 km apart;**

Exploration implications

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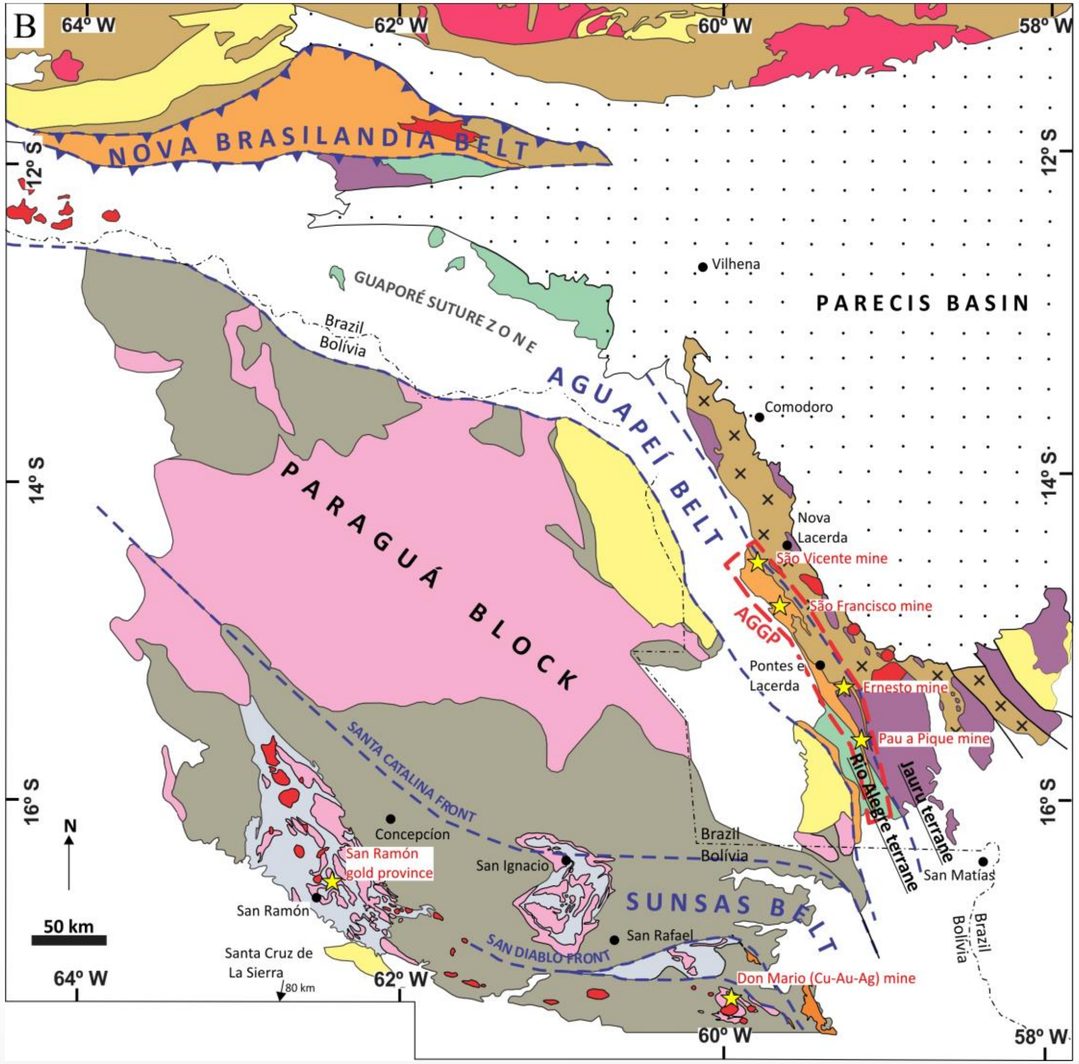

- Exploration works should be focused on structurally favorable areas:
  - -**regional anticlines;**
  - -**sheared margins** between more ductile metasediments and the more rigid pre-ore igneous rocks or volcanosedimentary sequences;

- There are also **long segments of the belt** (> 40km) with no reported deposits → e.g., between Pau a Pique and Dom Mario deposit in Bolivia;

- This study dealt with only one branch of the **much wider Western Amazon belt**.

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Early Neoproterozoic Gold Deposits of the Alto Guaporé Province, Southwestern Amazon Craton, Western Brazil

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Obrigado!

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