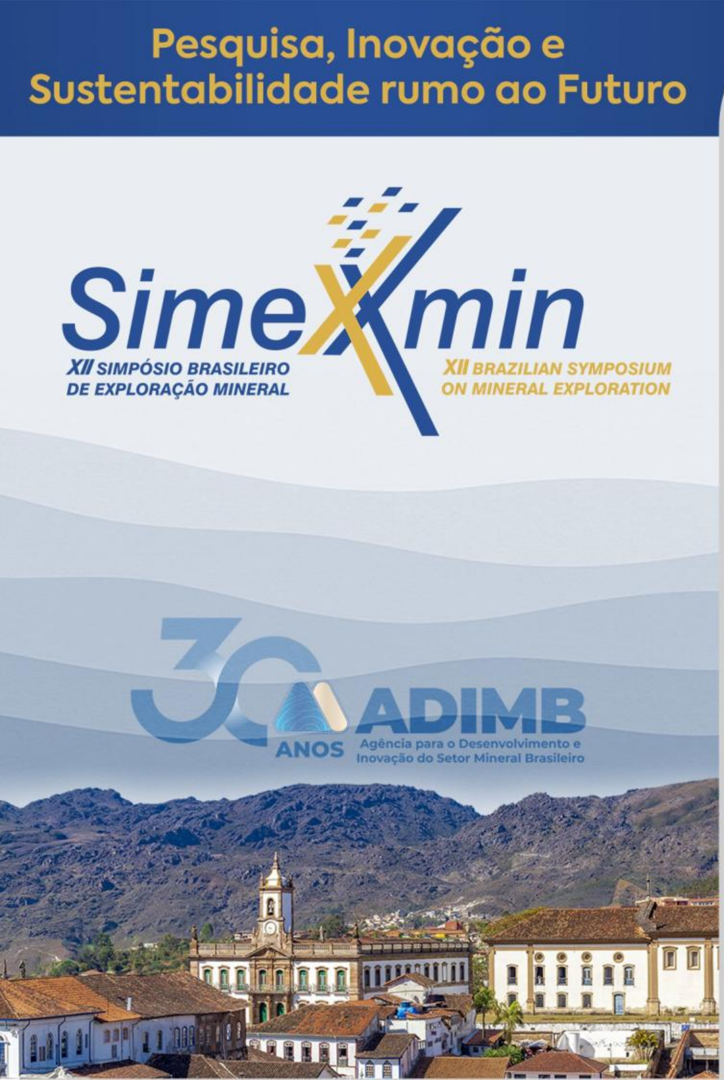

Camaquã Mines (Cu-Pb-Zn) and Bojuru (Ti) Deposit: implications for mineral prospecting and the geological H_2 potential in southern Brazil.

Minas do Camaquã (Cu-Pb-Zn) e Bojuru (Ti): implicações para a prospecção mineral e o potencial de H_2 geológico no sul do Brasil

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Universidade do Vale do Rio dos Sinos (UNISINOS)

Ouro Preto, 17 a 20 de maio de 2026
Ouro Preto, May 17 – 20, 2026

Pesquisa, Inovação e Sustentabilidade rumo ao Futuro

SimeXmin

XII SIMPÓSIO BRASILEIRO DE EXPLORAÇÃO MINERAL

XII BRAZILIAN SYMPOSIUM ON MINERAL EXPLORATION

30 ANOS ADIMB Agência para o Desenvolvimento e Inovação do Setor Mineral Brasileiro

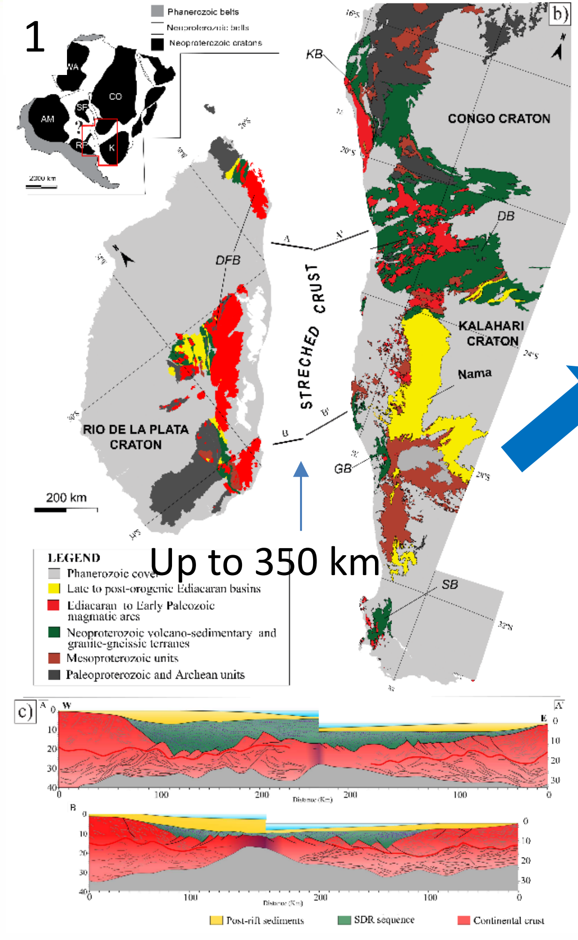
NGA

Topics

1. *Tectonic Setting of Southernmost Brazil*
2. Camaquã Mines (Cu-Pb-Zn)
3. Heavy Mineral Deposit of the Bojuru Region (Ti)
4. Potential of Natural Hydrogen in Southern Brazil

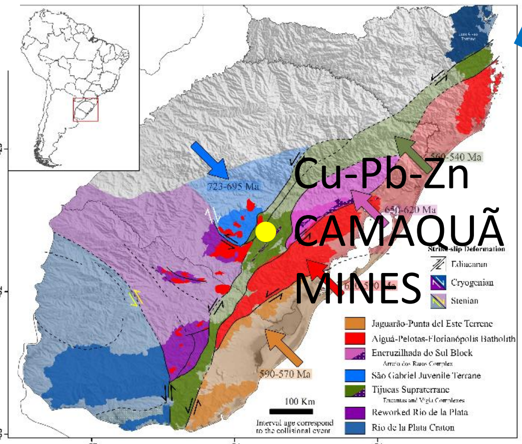
Tectonic Setting of Southernmost Brazil

1



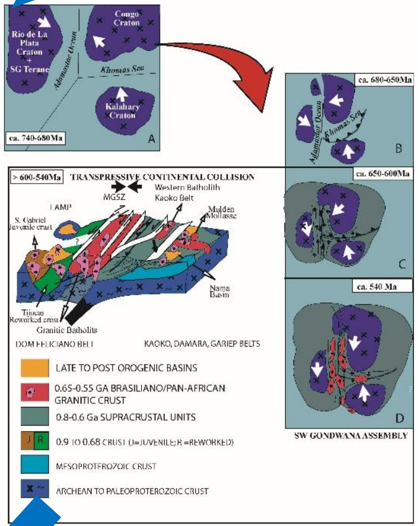
Teixeira et al., 2025a

2



Teixeira et al., 2025b

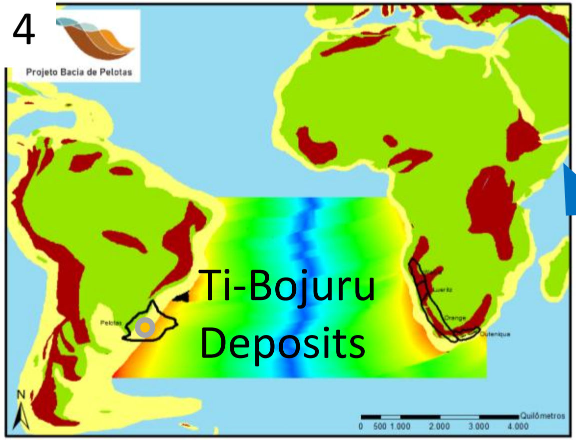
3



Chemale et al., 2012

1. Pan-African-Brasiliano Belts
2. Dom Feliciano Belt (1.1 Ga to 500Ma) W Gondwana Terrane Accretion

4



Chemale et al., 2022

3. Collision of Congo/SF-Kahalari-Rio de la Plata Paleoplates (Cratons)
4. Mesocenozoic break-up and separation of South America and Africa Plates

Camaquã Mining District

Main Deposits

• Camaquã Mines (Cu-Au): **~30 Mt @ 1.05% Cu**

- Minerals: chalcopyrite, bornite, chalcosite
- History: 1865-1996

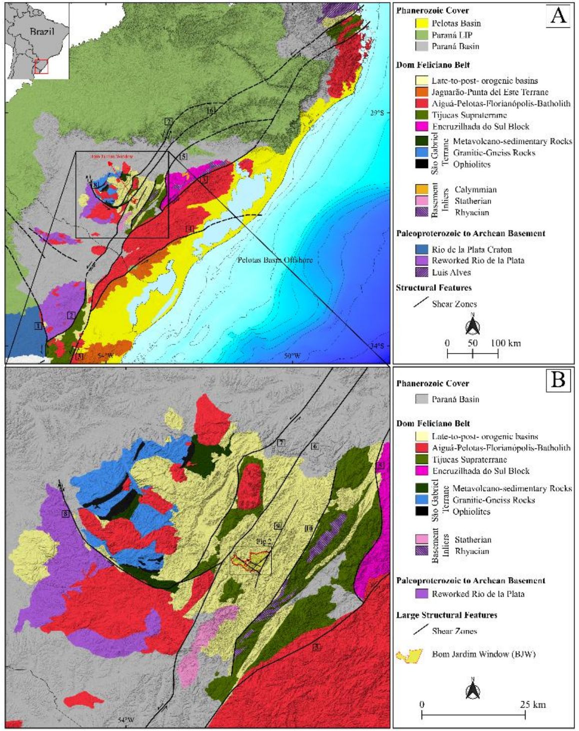
• Santa Maria Deposit (Pb-Zn-Cu-Ag): **~33 Mt @ 1.44% Pb, 1.06% Zn**

- Minerals: galena, sphalerite, chalcopyrite, bornite, chalcosite, Beteknetite
- Discovered in 1978

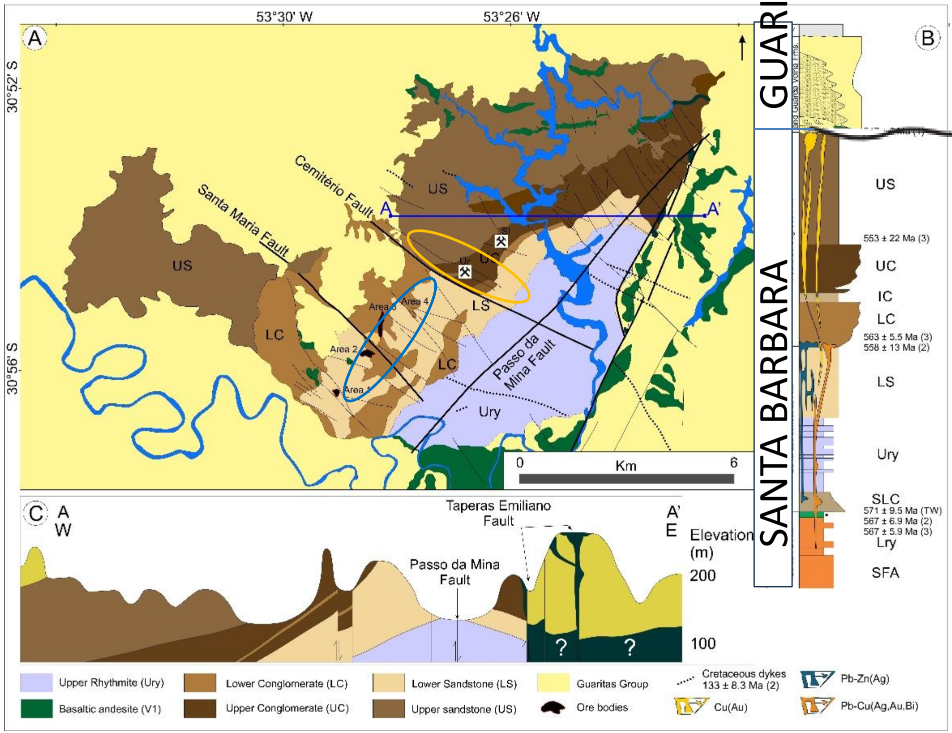
Camaquã Mining District

Tectonic enviroment, stratigraphy and mineralization

Main geotectonic units of the Sul-Rio-Grandense Shield (mod. after Teixeira et al., 2025a).



A) Geologic map of the Bom Jardim Window (BJW). C) BJW section (mod. after Bicca et al., 2013).



Alluvial-fluvial and aeolian system

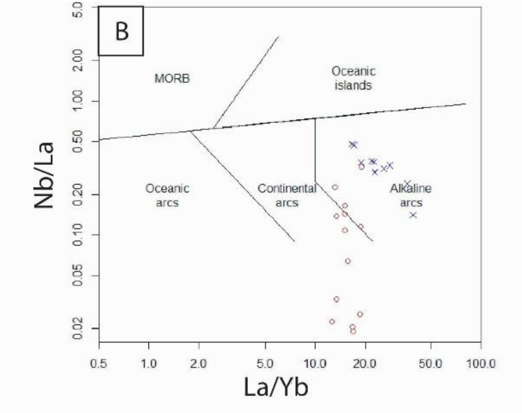
U

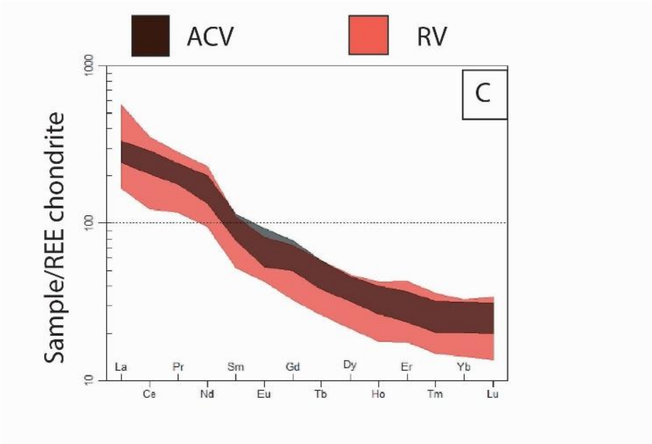
Depositional pattern with axial fluvial and fan-delta systems

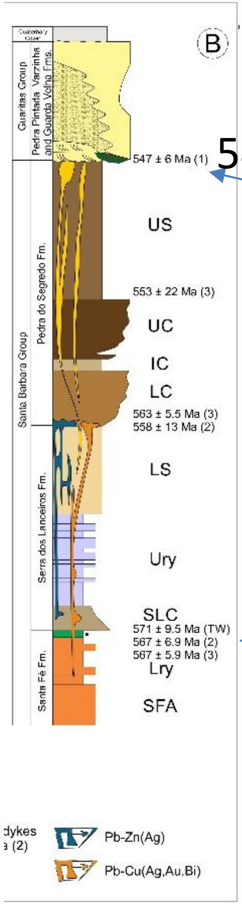
Cu(Au) mineralization: Ur= Uruguai Mine, SL = São Luis Mine;

Pb-Zn-Cu (Ag,Au) mineralization: Areas 1, 2, 3, and 4 (Santa Maria Deposit)

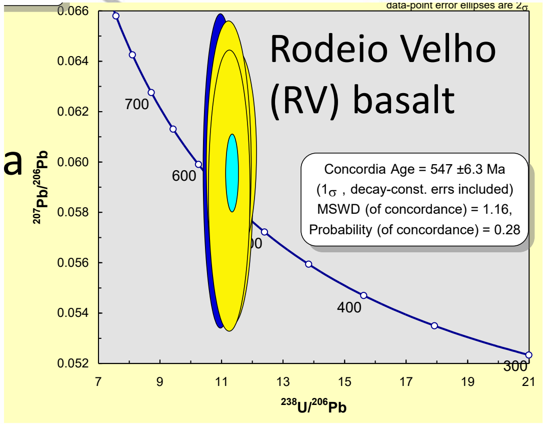
Age constraints for the mineralization



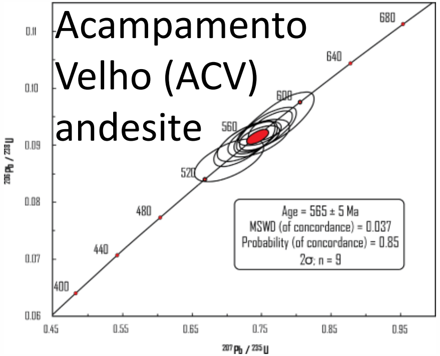




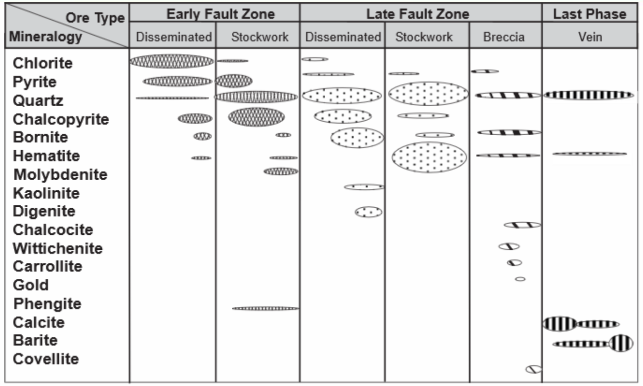
RV
547±6.3 Ma



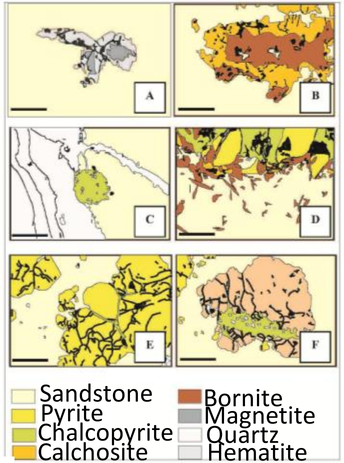
ACV
565±5 Ma



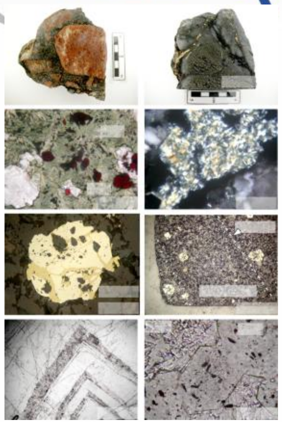
Paragenesis and textural aspects of the mineralization



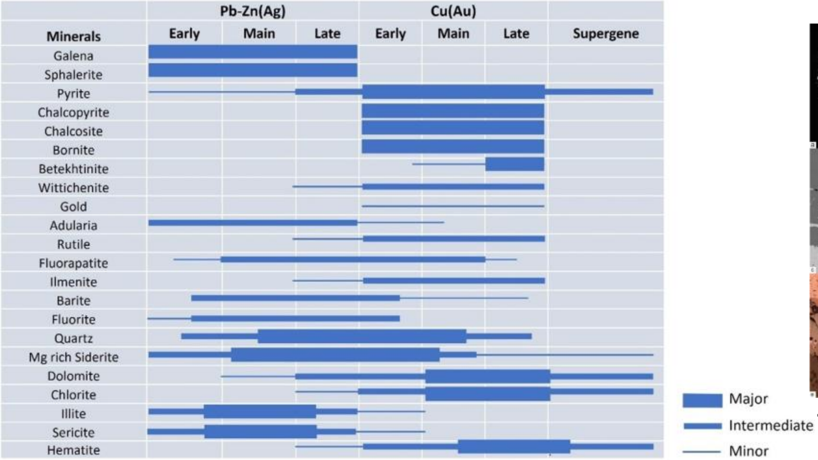
Paragenesis of the Uruguai mine (Laux et al., 2005)



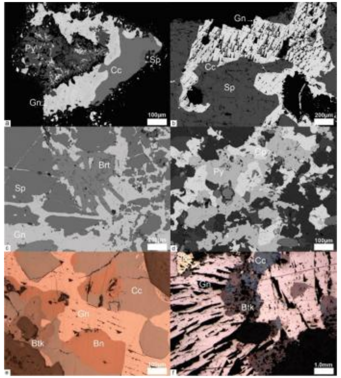
Main textures observed in the Cu ore from the Uruguay mine (Ronchi et al., 2000)



Renac et al., 2014



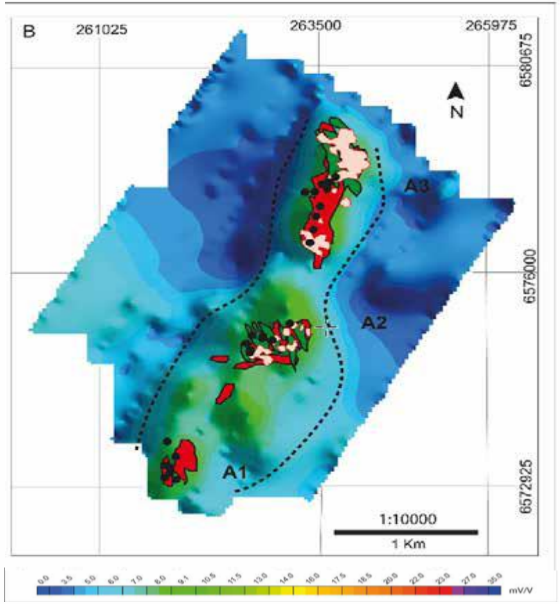
Paragenesis of the Santa Maria deposit



Textures of Santa Maria (Goulart et al., in prep.)

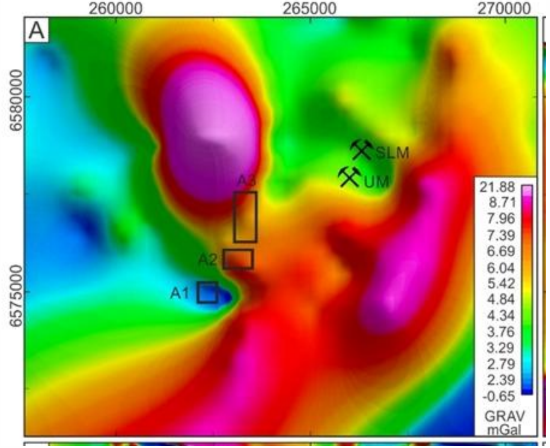
Zn-Pb and Cu- mineralizations (Araújo et al., 2021)

Geophysical Signature in the Camaquã District

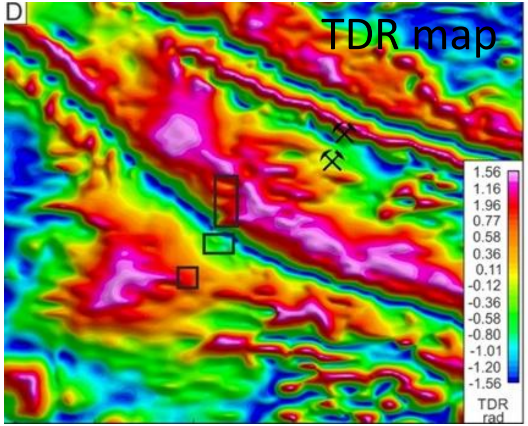


Chargeability map
Araújo et al., 2021

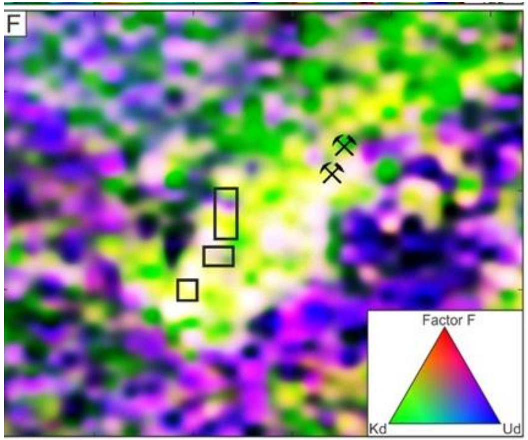
Bouguer Anomaly



TDR map



F ternary image

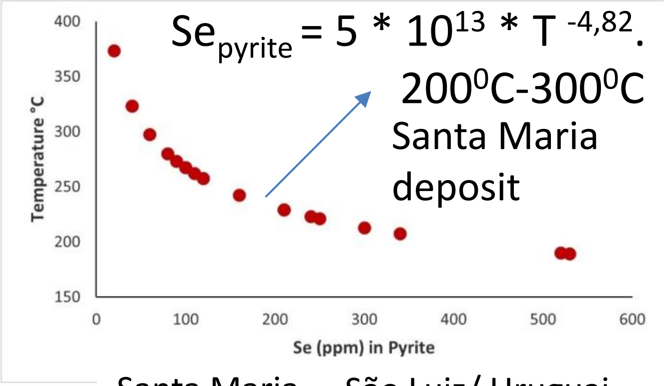


1. Bouguer map
2. TDR map
3. F Ternary Image

Goulart et al., in prep.

Isopope Signature and Mineralization Temperature

SimeXmin – XII Simpósio Brasileiro de Exploração Mineral – XII Brazilian Symposium on Mineral Exploration



$Se_{pyrite} = 5 * 10^{13} * T^{-4,82}$.

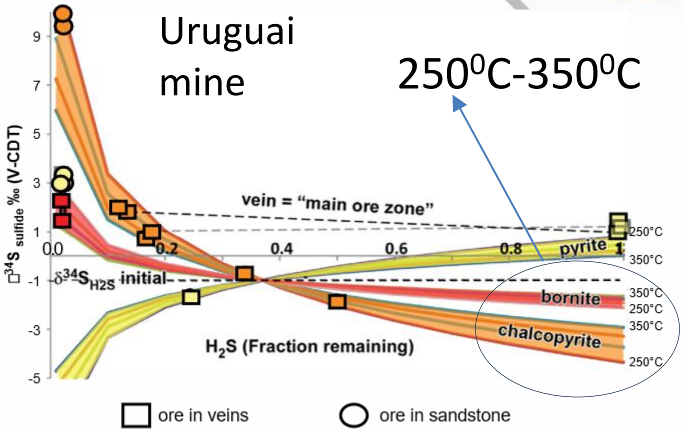
200^0C-300^0C

Santa Maria deposit

Diagram showing the relationship between Se concentration in pyrite (ppm) and formation temperature

Uruguai mine

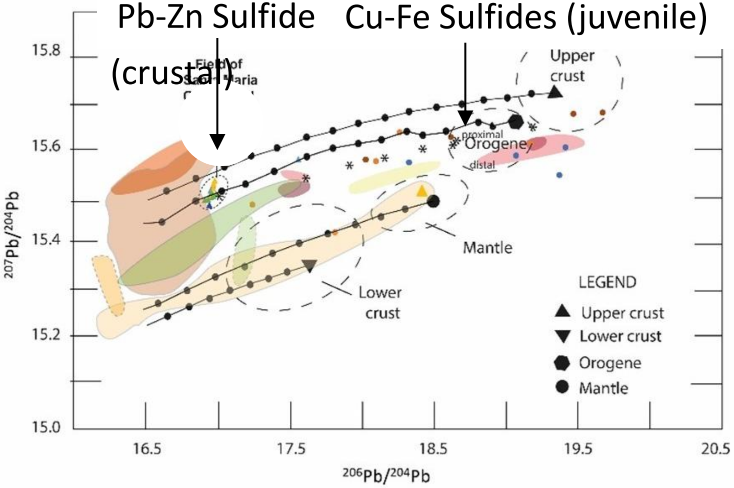
250^0C-350^0C



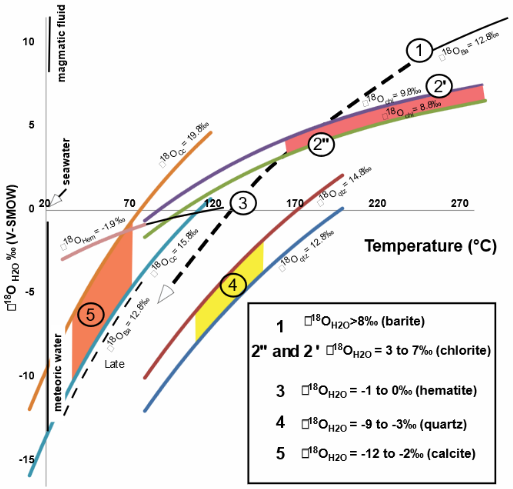
Changes in the δ^{34} of pyrite, chalcopyrite and bornite precipitaded due change in the H_2 (Renac et al., 2014)

Santa Maria Pb-Zn Sulfide (crustal)

São Luiz/ Uruguai Cu-Fe Sulfides (juvenile)

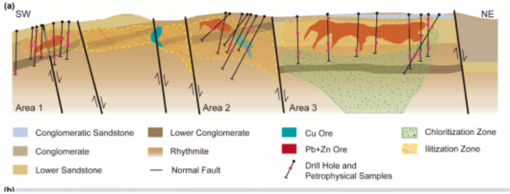


Goulart et al., in prep.

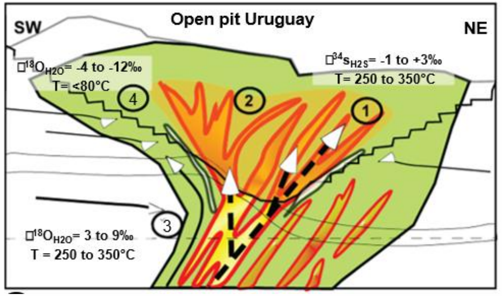


Temperature vs calculated $\delta^{18}O_{H20}$ values from Barite, chlorite, quartz, hematite and calcite analyzed In the Uruguai Mine (Renac et al., 2014)

Genetic Model for Camaquã District



Geological section (SW–NE) across N20E trending Pb-Zb-Cu (Ag-Au) Santa Maria Deposit. Araujo et al., 2021

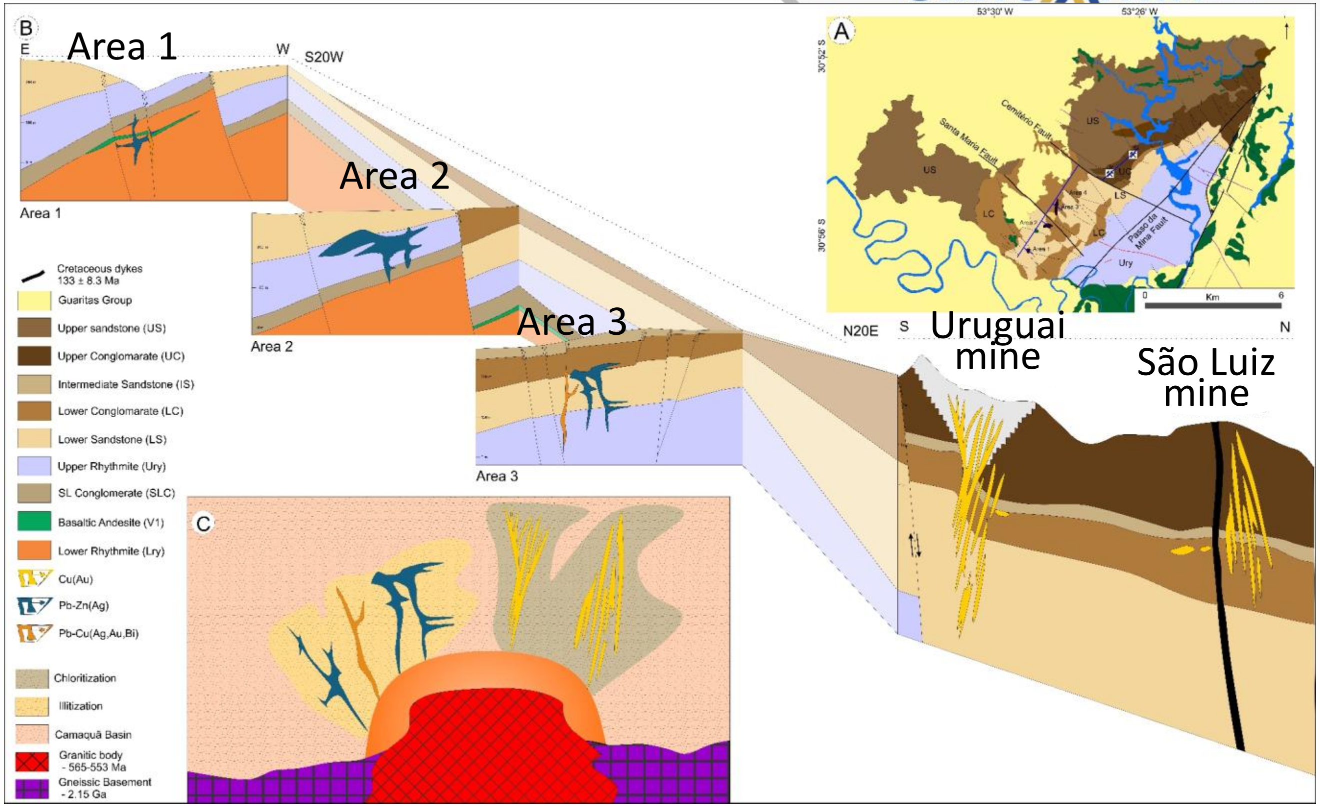


1 FeS_2, Cu S_2, Cu_5S S Magmatic Source (low O fugacity)

2 Increasing oxygen fugacity

3 Si, Mg, Fe, Al-SiO_2 with H_2O magmatic to meteoric signature

4 SiO2 and CaCO3 dominant meteoric fluid circulation (Renac et al., 2014)



A) Geological map with location of sections. B.Cross section along with the São Luis and Uruguai Mines (north of the Cemitério Fault) and the Santa Maria deposits (south of the Cemitério Fault). C. Conceptual model

Camaquã Mining District Highlights

Geological Setting: Hosted in the transtensional Santa Bárbara Basin (late Brasiliano Cycle), with mineralization dated to **565–543 Ma**.

Two Hydrothermal Systems:

- **Cu (Au):** Associated with the N60°W trending Cemitério Fault; formed at **250–300 °C**; chloritic alteration halos.
- **Pb–Zn (Ag):** Formed at 200-250 °C, later cut by lower-temperature **Pb–Cu (Ag, Au, Bi)** mineralization along N20°E treding faults. At Santa Maria, early Pb–Zn transitions to later Cu, with sericitic to chloritic alteration.

Mineralization Style: Structurally controlled, **epithermal** system.

Metal Sources (Pb isotopes):

- **Pb–Zn (Ag):** Paleoproterozoic crustal source.
- **Cu (Au):** Mixed crustal + mantle contributions. Fluids likely from Ediacaran hypabyssal to plutonic intrusions.

Exploration Implications: Geophysical data suggest fault-controlled system linked to a **deep plutonic source**, revealing new targets under the sub horizontal layers of the Guaritas Group units

Ti Bojoru Deposit

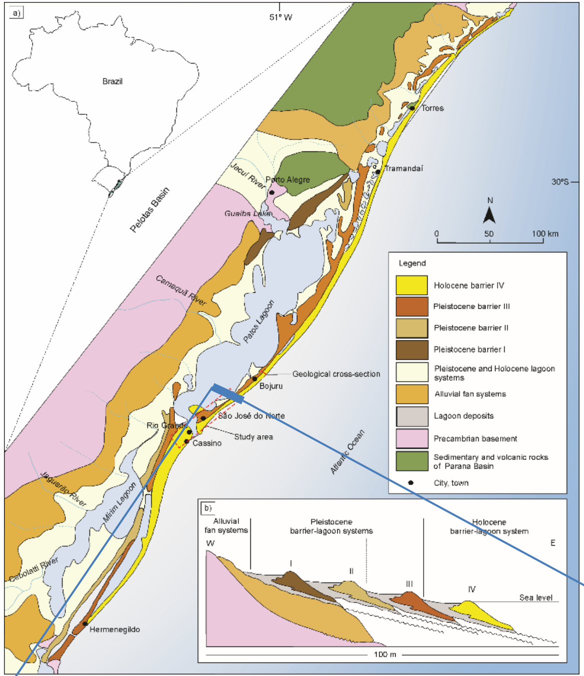
- **Mining Rights:** Rio Grande Mineração S.A. (RGM).
- **Production:** annual production potential of 323,000 tons of HM concentra-tes: 275,000 tons of ilmenite, 38,000 tons of zircon, and 10,000 tons of rutile.
- **Economic Use:** The ilmenite is used for producing titanium dioxide (\(TiO_{2}\)) pigments for industries such as paints, plastics, and ceramics.
- **Location:** The deposits are found from the frontal dunes to the transgressive dune fields that anchor to the shore of the Lagoa dos Patos.

Key Characteristics of Bojuru Ilmenite Deposits:
Geological Setting: The heavy minerals are concentrated within eolian (wind-blown) dune deposits of "Barrier System IV," which is the youngest barrier system in the Rio Grande do Sul Coastal Plain, dating from 8 ka to present.

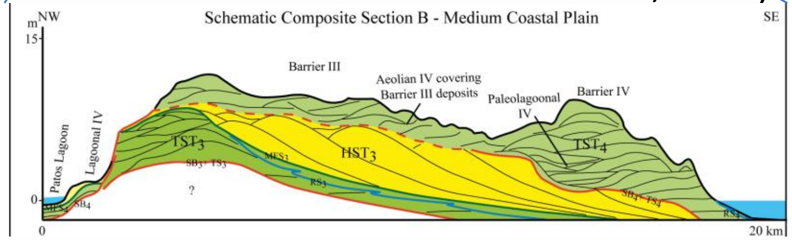
Reserves: 531.2 million tons of ore reserves and ca. 17 million tons of heavy minerals (ilmenite, rutile, and zircon; COMERGS, 2018).

Geology and mineral deposits

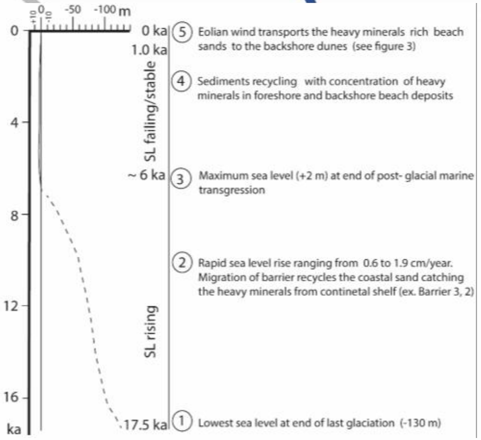
Simplified geological map of Rio Grande do Sul Coastal Plain (Wust et al., 2024)

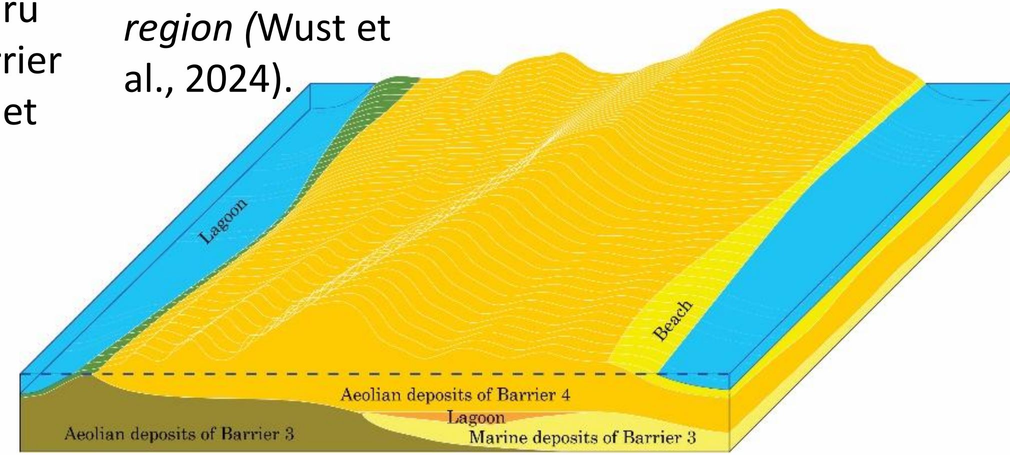


Schematic section along the São José do Norte - Bojuru region with Barrier III and IV (Rosa et al., 2017)

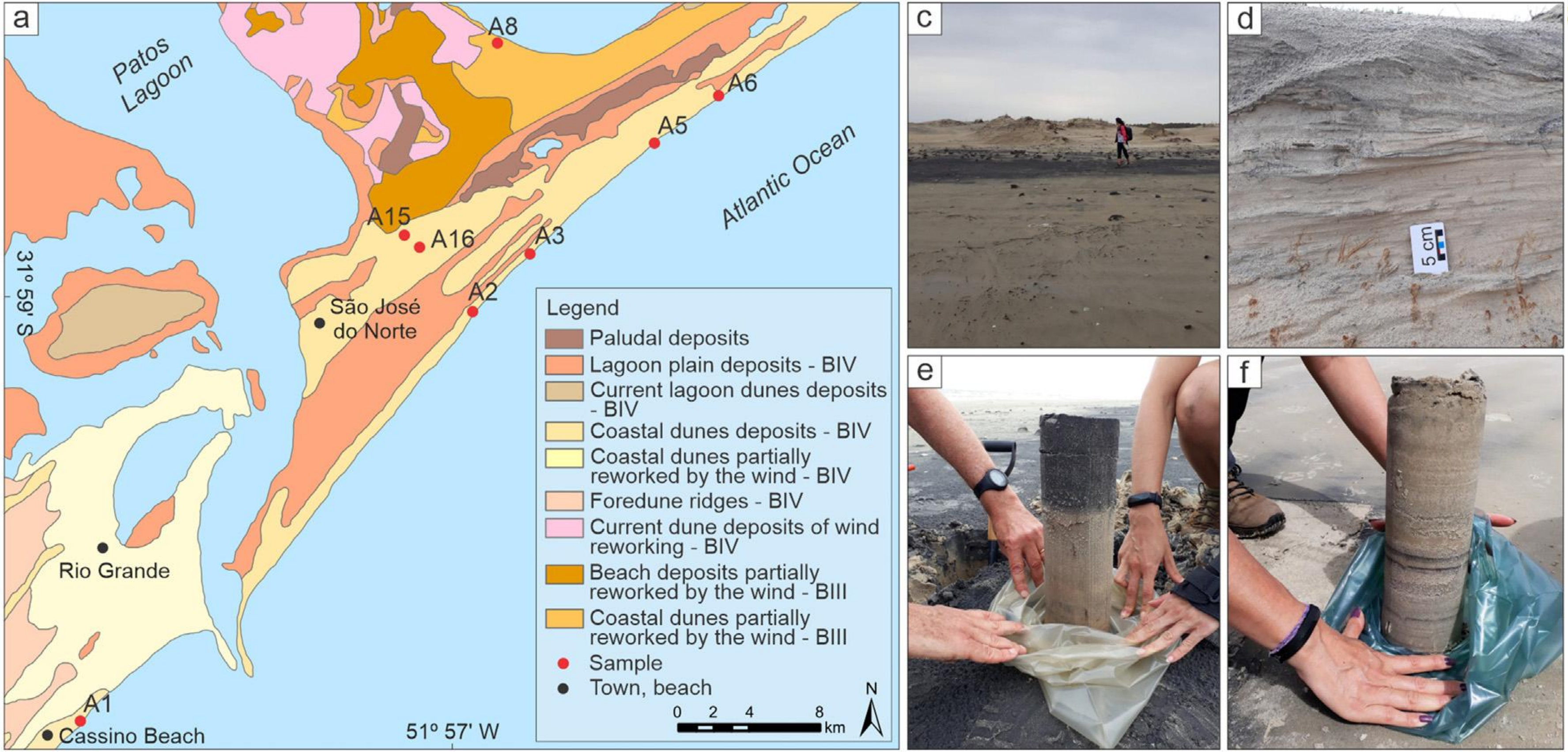


Block diagram of the region with titanium deposits in the São José do Norte–Bojuru region (Wust et al., 2024).





Heavy Mineral (HM) of the Bojuru Region



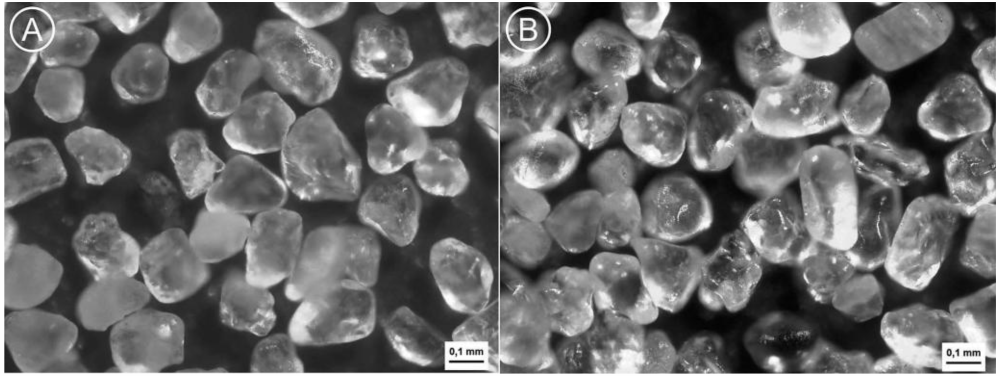
1-Location map; 2-Backshore sampling;3- HM-enriched layer in eolian deposit; 4 and 5- Sampling (Rizzi et al., 2022)

HM assemblage

Rizzi et al., 2022

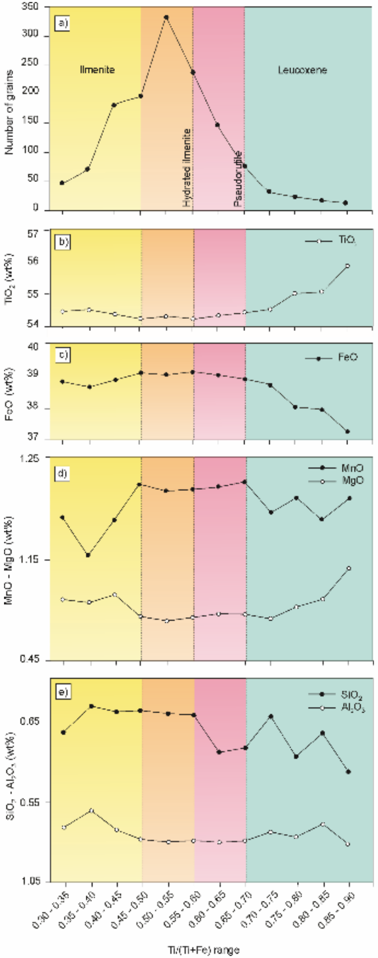
Minerals	Bujuru	North Bujuru	Average
Ilmenite	59.3	57.9	58.6
Zircon	8.5	8.3	8.4
Epidote	7.5	8.5	8
Tourmaline	5.6	7	6.3
Magnetite	5.6	5	5.3
Staurolite	5.1	5	5
Rutile	2.5	2.5	2.5
Kyanite	2.1	2.1	2.1
Leucoxene	2	2.2	2.1
Garnet	0.7	0.6	0.7
Perovskite	0.4	0.6	0.5
Chromite	0.4	0.2	0.3
Others	0.3	0.1	0.2

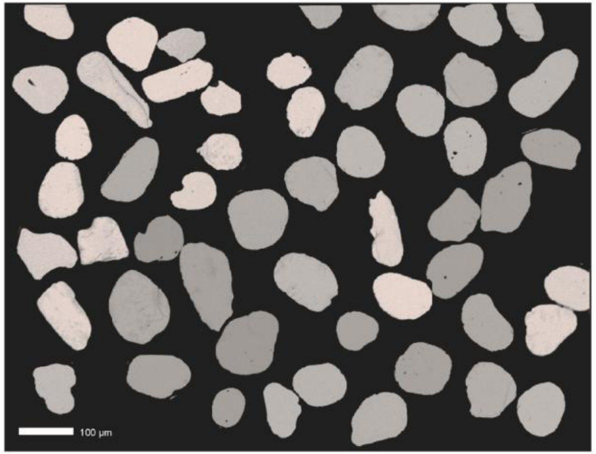
Source:Munaro, 1991



Aspects of sediments from barriers I, II, III, and IV. (A) Marine sediments from barrier I; (B) aeolian sediments from barrier IV (Carassai et al., 2018)

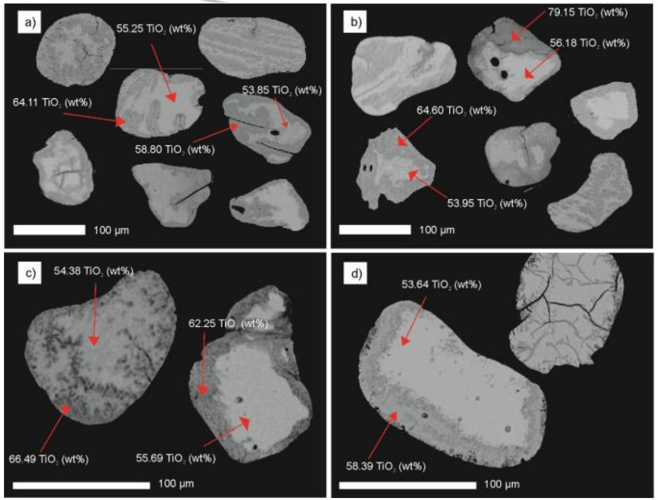
Images and Chemistry of Ti-minerals



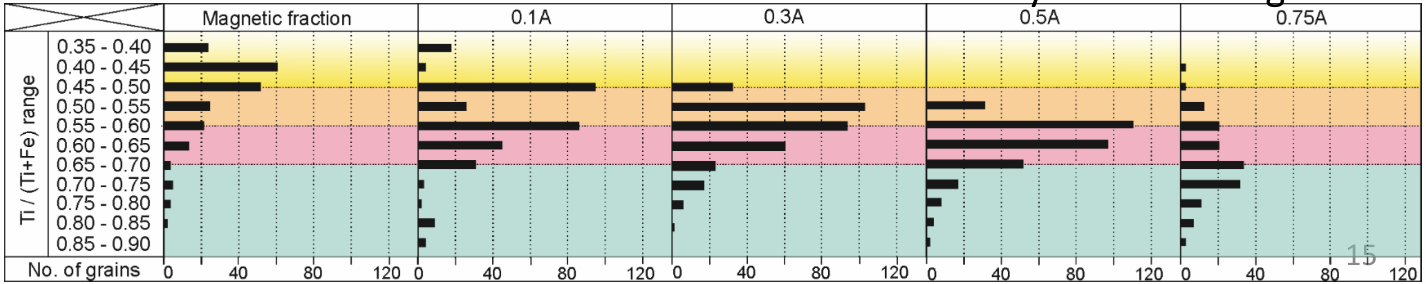


Wust et al. 2024

(BSE) of ilmenite grains from heavy mineral layers of the São José do Norte placer deposit.

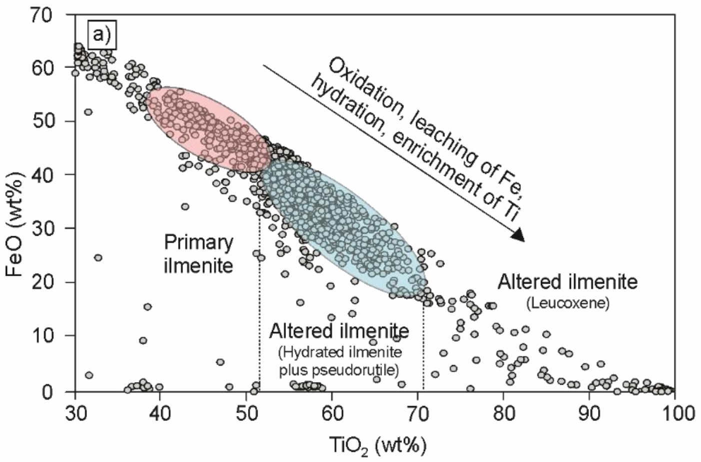


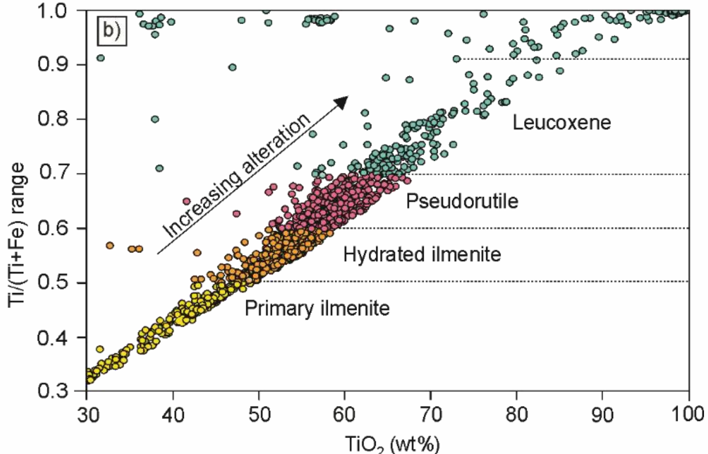
Representative of different styles of alteration observed in the analyzed ilmenite grains.

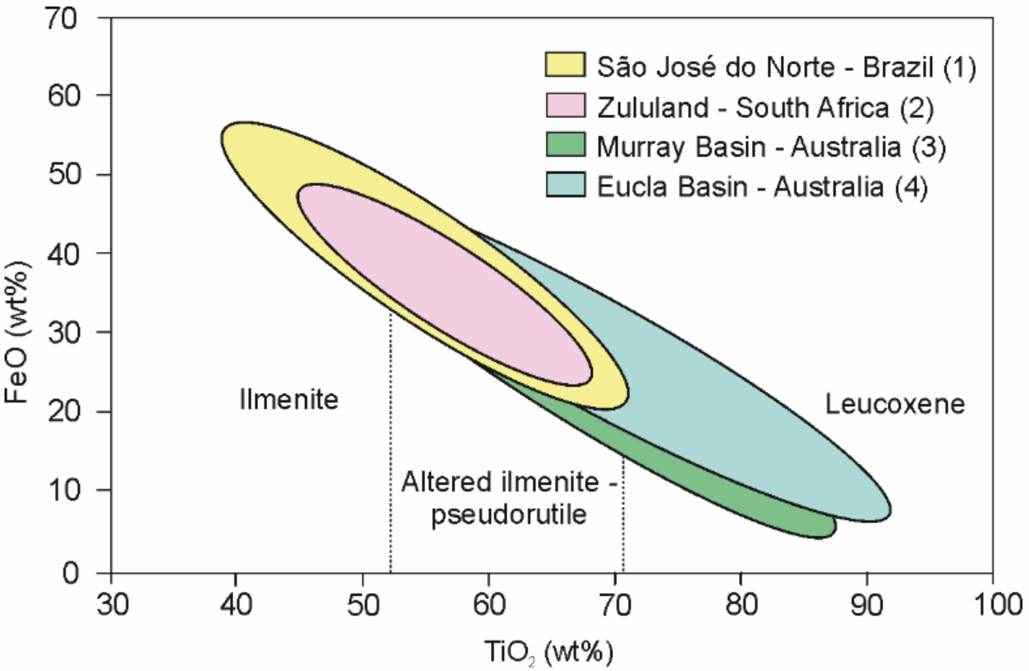


Chemistry of Ti-minerals of Bojuru deposits

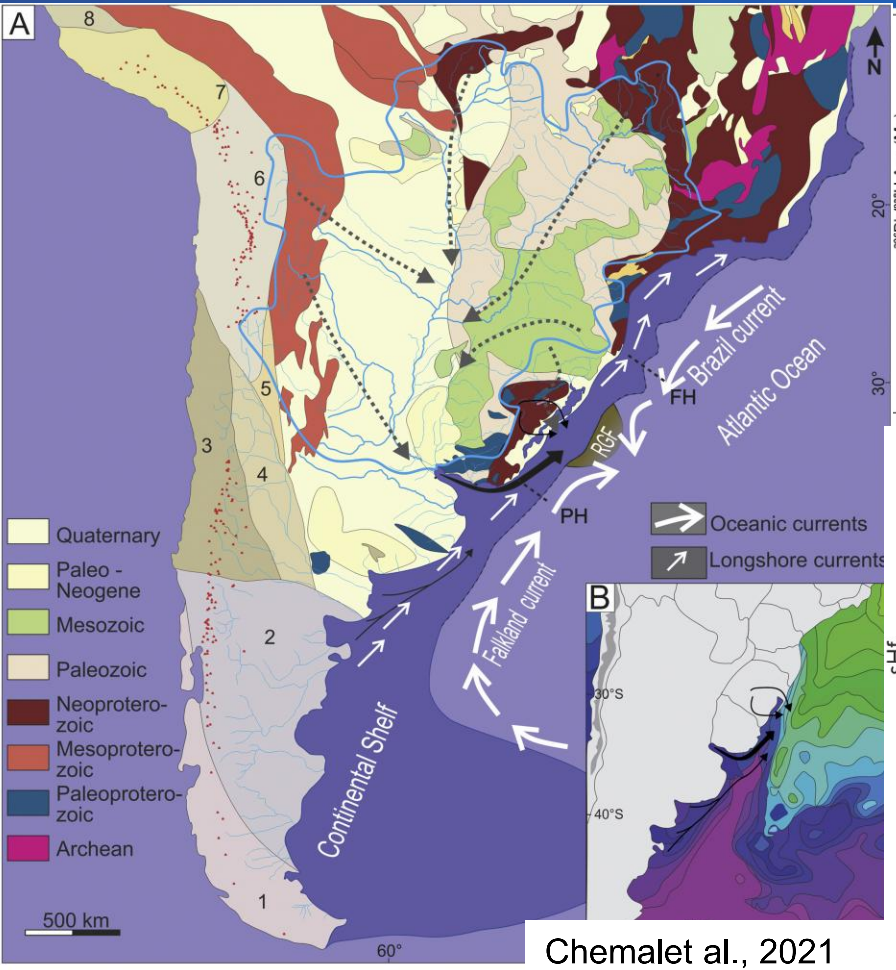
Wust et al. 2024



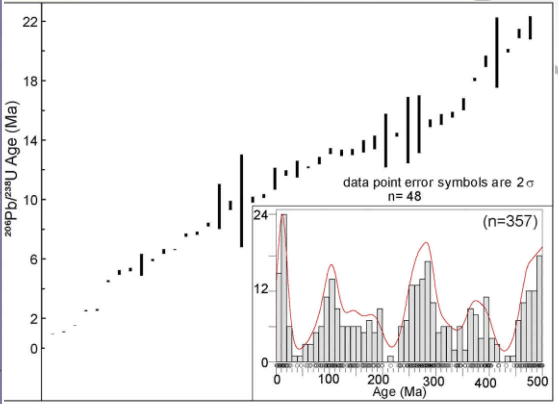




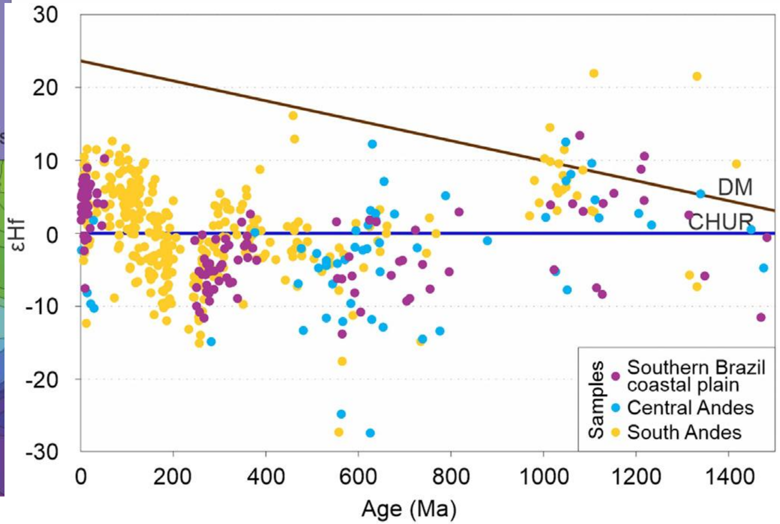
Provenance of HM



Chemalet al., 2021



Detrital zircons with Andean Signature in The Barriers I,II,III and IV (Chemale et al., 2021)



Andean Signature for the Bojuru region (Rizzi et al., 2022)

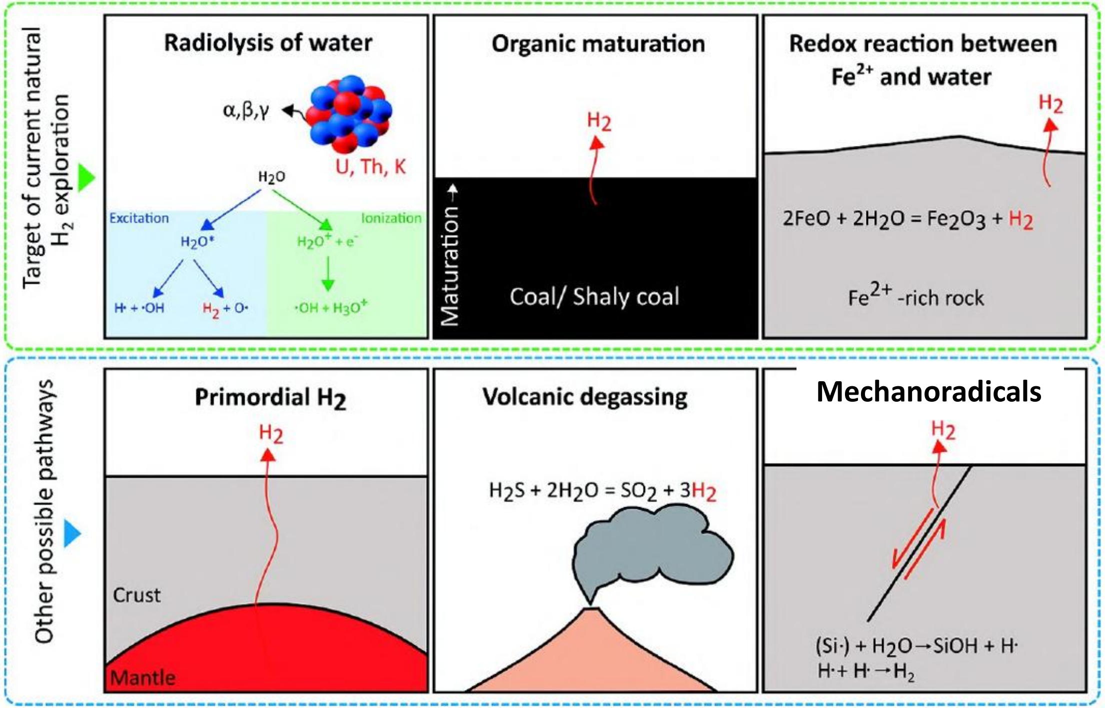
Enrichement factors for HM Bojuru deposits

1. Marine deposits are richer in heavy minerals compared to the eolian sediments (Barrier I,II, III, and IV).
2. In the Bojuru region the HM deposits are in the eolian sediment of the Barrier IV
3. Two keypoints one is that the eolian sediments are mainly product of the erosion from the Barrrier III: (a) So this área are juxtaposed northern to São Gonçalo channel (set up during the Barrier III), (b) Since the marine sediments are mostly carried out by the north driving litoral drift, the first factor of the enchrichment of HM in the Bojuru region is direct connected to the energy diminishing due to action of Sao Goncalo Channnel interaction with the lateral current.

4. The second process is thus connected to action of eolian wind that transport much more transluced minerals than opaque ones (heavier)

Potential of Natural Hydrogen in Southern Brazil

Why geological H_2 is a solution for energetic transition?



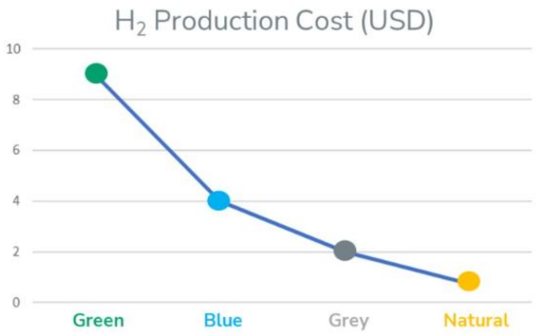
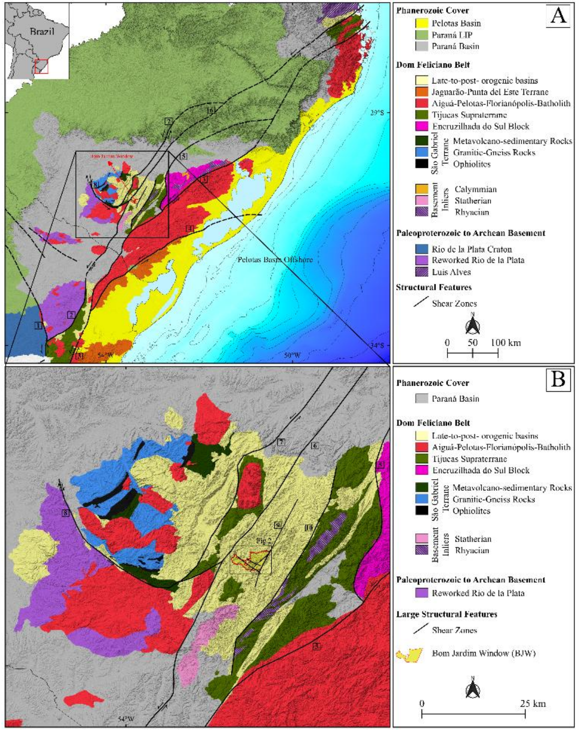


Figure 2: Current production costs for different types of hydrogen (without any subsidies). Data from[3] .

Why is a solution?

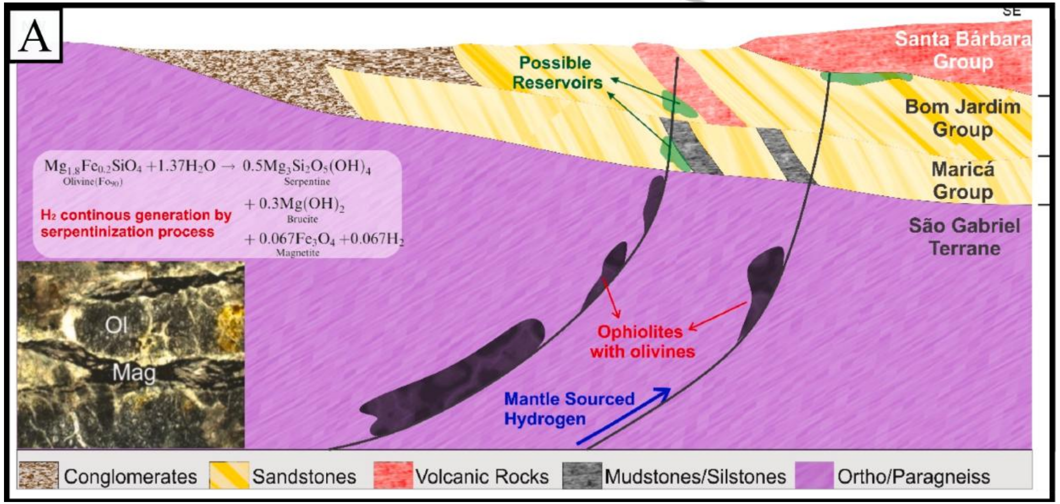
It is a solution because it could be cheaper!!!

Natural H_2 in Southern Brazil - Ultramafic rocks



$$6[(Mg_{1.5}FeO_{0.5})SiO_4] + 7H_2O = 3[Mg_3Si_2O_5(OH)_4] + Fe_3O_4 + H_2$$

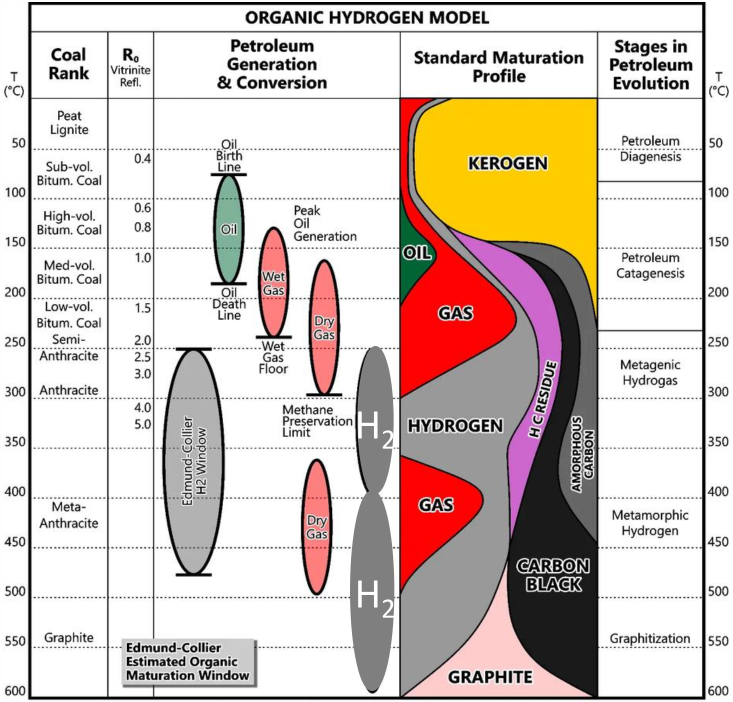
olivine, serpentine, magnetite, hydrogen



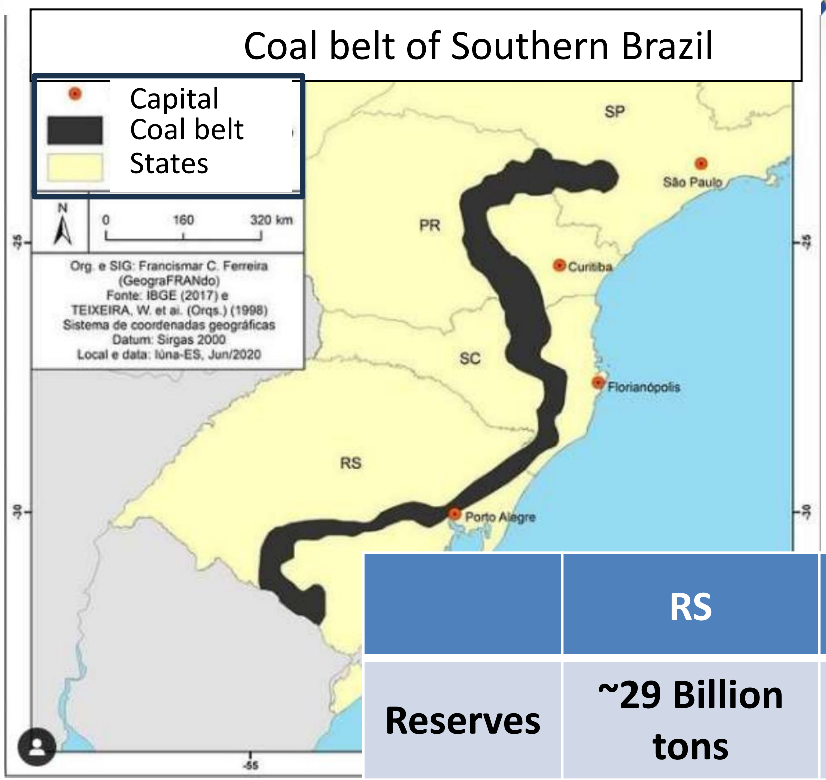
Schematic model for possible H2 sources in the Camaquã Basin region. The sources are related to core and mantle sources H2 and by serpentinization process. Suture zones and crustal-scale faults could act as paths for continuous H2 migration. Volcanic and thin-grained rocks of the Camaquã Basin could act as a seal for the H2 Geological System.

Serrat et al. (2024)

Natural H_2 in Southern Brazil – Organic rocks



From Hanseon, J & Hanson, H 2023, Hydrogen Organic Genesis

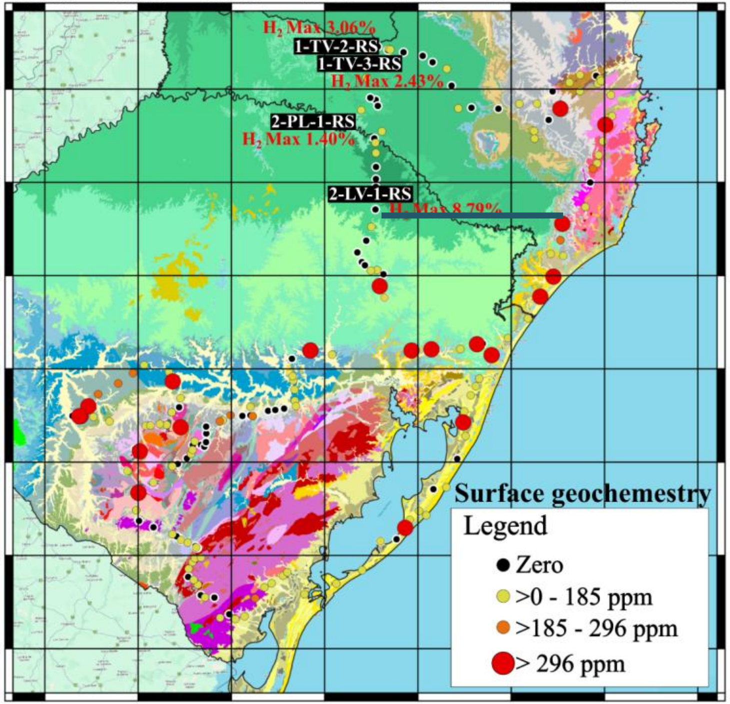


	RS	SC
Reserves	**~29 Billion tons**	**3,3 billion tons**
Coal Rank	**Sub-bituminous coal**	**Bituminous coal**

The thermal evolution of organic matter generates traditional hydrocarbons, but upon reaching deeper maturation windows, thermal cracking favors the production of natural H2.

Natural H_2 in Southern Brazil – Organic rocks

A



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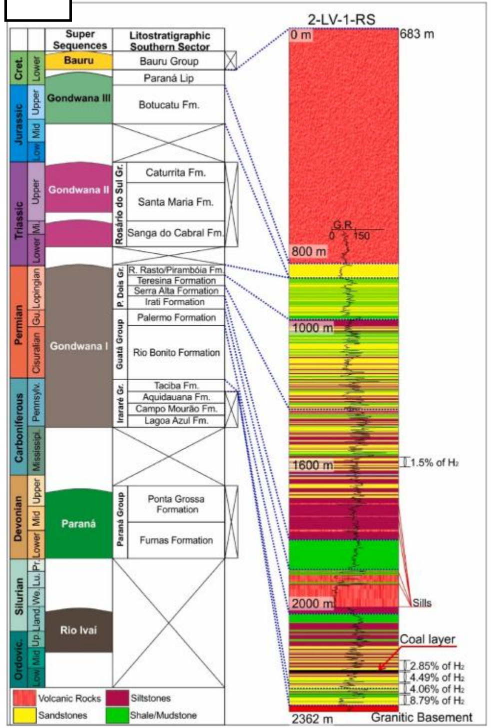
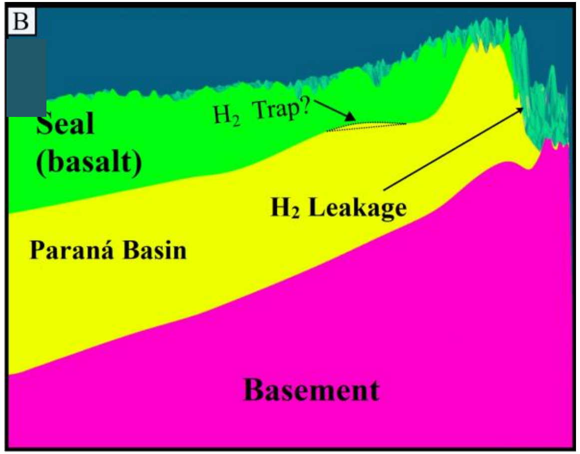


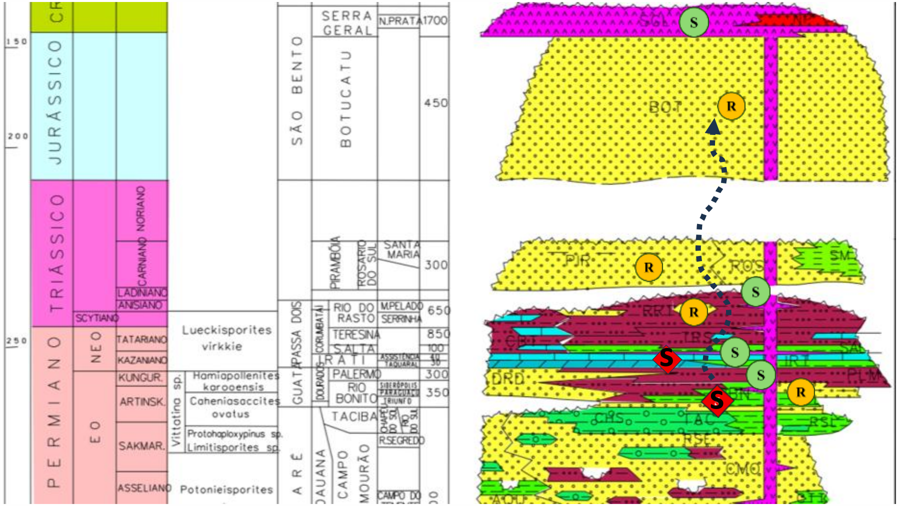


Conceptual model for H_2 leakage produced from the Paraná Basin or subsurface and suggestion of H_2 reservoir(Serrat al. ,em prep.)

A: Map with measurement of H_2 in surface (NGA, Unisinos, 2026)

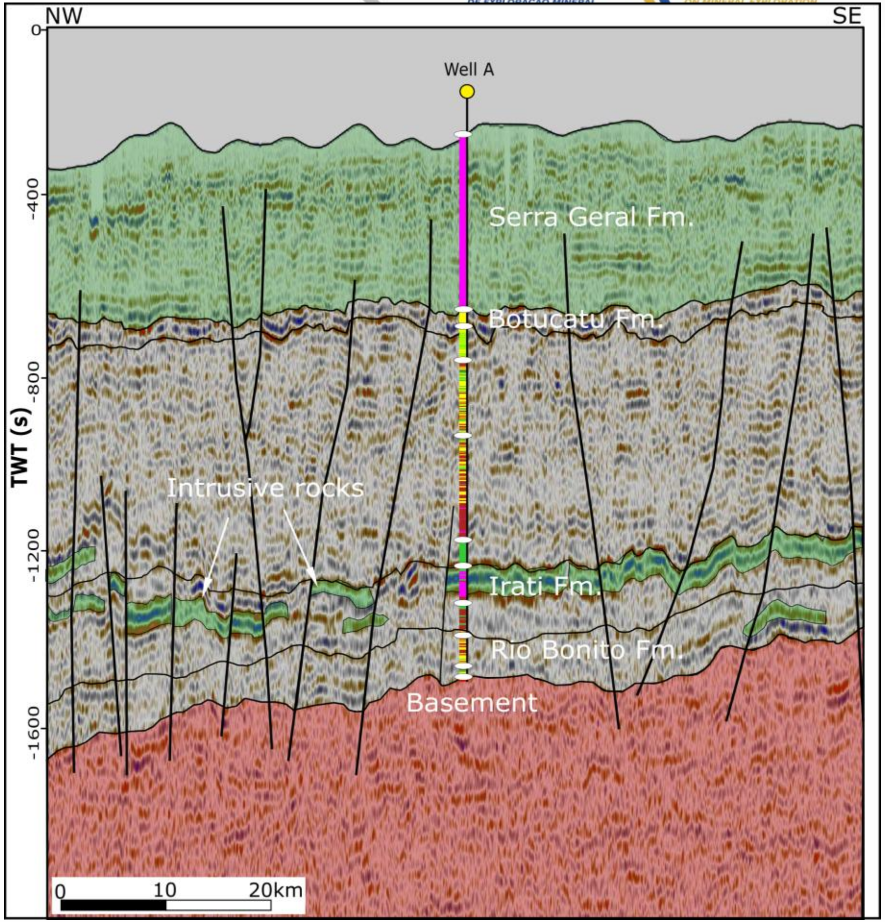
B: Drill hole with measurement of H_2 up to 8.79 % of H2(data from ANP-BEDEP, Serrat et al., 2024)

Basic elements for H2 system



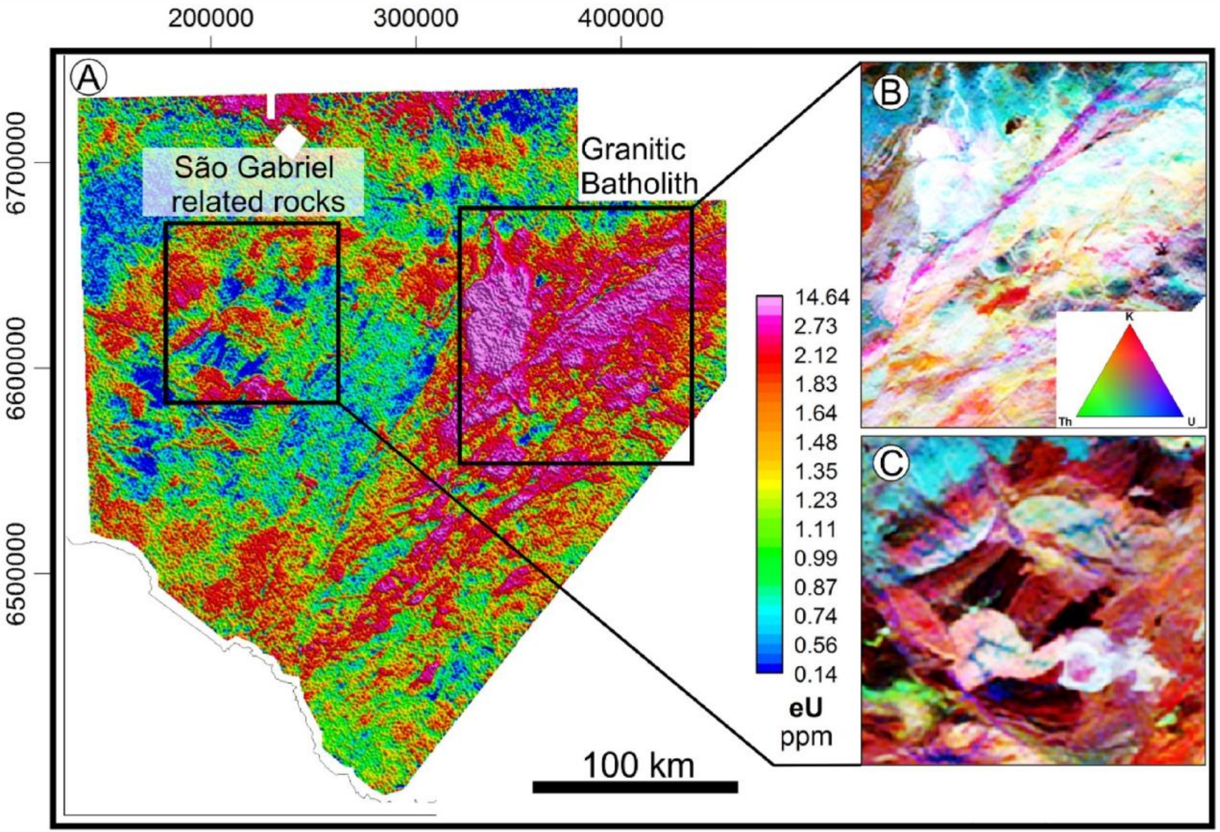
S R S

Seal Reservoir Source



(NGA-UNISINOS, 2026)

Natural H_2 in Southern Brazil – Radyolises



Uranium channel gamma-ray spectrometry map of Sul-Riograndense Shield. Potential target areas are those portions of the basement hidden beneath the Paraná Basin sedimentary rocks and linked to faulting to produce H2 through the radiolysis process (Serrat et al., 2024).

Final remarks on the H2 potential in Southern Brazil

Hydrogen Detection: H_2 gas linked to natural gas was detected in four legacy wells in the Paraná Basin (Rio Grande do Sul & Santa Catarina states), with concentrations ranging from **0.14% to 8.79%**. Source rocks include coals of the Rio Bonito Formation.

Potential from Irati Formation: Bituminous shales of the Irati Formation are prospective for H_2 generation, as they were intruded by mafic sills and dykes during the **Paraná LIP event**, reaching overmaturation temperatures capable of generating H_2.

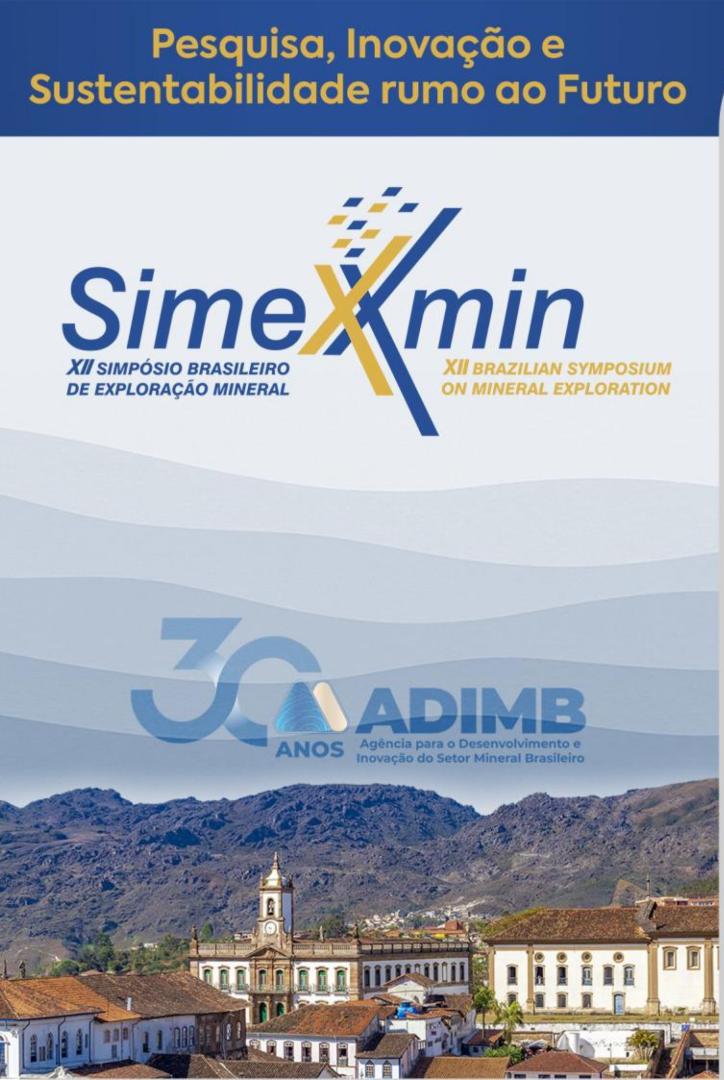
Reservoir and Seal Analogy (Mali analogy): The Paraná lavas and fine-grained sediments of the Paraná Basin may act as effective seals and reservoirs, similar to the natural H_2 accumulation in **Mali, Africa**.

Mafic–Ultramafic Rocks: H_2 may also be produced from mafic to ultramafic rocks, such as Neoproteozoic ophiolites cover by Ediacaran Camaquã and Paleozoic Paraná basins.

Granitic Rocks and Faulting: Granitic rocks associated with fault systems offer high potential for H_2 generation via **radiolysis**.

Orange H_2 Potential: Injection of CO_2 into subsurface coal beds could generate H_2 (Orange H_2), representing an additional anthropogenic-geologic hybrid pathway.

Key Challenges for Future Research: Identification of fairy circles (surface expression);Isotopic signature characterization (e.g., He isotopes);Microbiological studies; Understanding the **Hydrogen System** as a complete analogy to the **Petroleum System** (source, reservoir, seal, gas migration, trapping, etc.)



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UNISINOS
DESAFIE O AMANHÃ.

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