Series
Technical Contributions

MINERAL RESOURCES N° 57

METALLOGENIC PORPHYRY COPPER BELTS IN THE ARGENTINE REPUBLIC

Pablo JOHANIS, David SCHÖMWANDT, Martín GOZALVEZ,
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Operations at the Bajo de la Alumbrera porphyry open pit.

ISSN 2618-5032

BUENOS AIRES | 2026

1904 - 2024 SegemAR Servicio Geológico Minero Argentino

Ministry of Economy Argentine Republic

Mining Secretariat

REFERENCE / CITATION

This publication should be cited as:

Johanis P.E., Schömwandt D., Gozalvez M.R., Alvarez M.D., Benítez J., Bruna Novillo J., 2026. Metallogenic porphyry copper belts in the Argentine Republic. Instituto de Geología y Recursos Minerales. Servicio Geológico Minero Argentino. Serie Contribuciones Técnicas Recursos Minerales N° 57, 30 pp. Buenos Aires

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ISSN 2618-5032

1904 - 2024 SegemAR
Servicio Geológico Minero Argentino

Av. General Paz 5445 (Colectora provincia) 1650 - San Martín - Buenos Aires - República Argentina
Edificios 14 y 25 | (11) 5670-0100
www.segemar.gov.ar

SERIES TECHNICAL CONTRIBUTIONS - MINERAL RESOURCES N° 57

METALLOGENIC PORPHYRY COPPER BELTS IN THE ARGENTINE REPUBLIC

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Edition: Daniel Rastelli

ISSN 2618-5032

BUENOS AIRES 2026

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ABSTRACT

Porphyry copper deposits constitute the world's primary source of copper, a metal increasingly critical for the global energy transition and electrification. The delimitation of metallogenic belts is fundamental for assessing and prioritizing national mineral potential. This technical contribution introduces the Porphyry copper metallogenic belts map of the Argentine Republic, an interactive geospatial platform that integrates metallogenic domains, key exploration vectors—such as structural controls, geochemical anomalies, and hydrothermal alteration—and essential land-use planning layers.

Eleven metallogenic belts were defined, corresponding to the evolution of magmatic arcs and backarc environments from the Permian to the Pliocene. Identified copper resources in Argentina currently reach 55 Mt, while estimates of undiscovered resources more than triple this base, projecting a total metal endowment of nearly 240 Mt of Cu. Late Cenozoic magmatism is identified as the most fertile event, characterized by specific geodynamic conditions favorable for tier 1 deposits. Furthermore, the analysis incorporates geospatial intersections with protected areas and the national glacier inventory to evaluate the actual feasibility of exploration targets. This work serves as a strategic tool to guide future exploration, mitigate geological-economic risk, and provide a robust scientific foundation for the sustainable development of Argentina's mineral resources.

Keywords: *Porphyry copper, metallogenic belts, Argentina, resources, exploration*

1. INTRODUCTION AND CONCEPTUAL FRAMEWORK

Porphyry copper (PCu) deposits represent the world's main source of copper (Cu), molybdenum (Mo), and rhenium (Re), as well as being critical and significant by-producers of gold (Au) and silver (Ag). Their genesis is linked to hydrothermal-magmatic systems associated with felsic to intermediate intrusions, located at shallow cortical levels (epizonal) within magmatic arcs of convergent margins. The Andean segment of the Argentine Republic forms part of the Central Andean Volcanic Zone (CAVZ), which extends from Ecuador to Chile and Argentina and contains 39% of the world's copper resources (Hammarstrom 2022). The systematic characterization and delimitation of porphyry copper metallogenic belts are imperative for the evaluation of national mining potential, allowing for the optimization of exploration vectors and the consolidation of a technical basis for the strategic development of mineral resources.

1.1. GLOBAL CONTEXT OF COPPER AND PORPHYRY COPPER DEPOSITS

Copper is an essential metal for the energy transition and global electrification due to its high thermal and electrical conductivity. Approximately 60% of global primary copper production comes from porphyry-type systems (Sinclair 2007). The Andes Mountains constitute the world's most important copper metallogenic province, containing five of the ten largest copper districts in the world currently in operation (Escondida, Collahuasi, and El Teniente in Chile; Cerro Verde and Antamina in Peru), and those with the largest resources (Chuquicamata, El Teniente, Los Bronces, and Escondida in Chile). In this context, the Argentine Republic, with its extensive Andean territory, has exceptional potential, which is currently underexplored compared to its neighbors Chile and Peru. The identification of metallogenic belts, based on regional tectonic-magmatic evolution, is critical to directing exploration efforts toward geologically favorable domains with a high probability of discovery.

1.2. PORPHYRY COPPER DEPOSITS MODEL

A porphyry copper system is defined as an economic concentration of metals, primarily Cu, with Mo and ±Au as critical by-products, frequently with Ag, with Re as a trace element, occasionally with Pb, Zn, and platinum group elements, among others. It is genetically linked to porphyry stocks and dikes of felsic to intermediate composition that intrude plutonites, volcanics, or sedimentary rocks (Kirkham 1971, Sinclair 2007). They are characterized by being large-volume systems (tens to billions of tons) with relatively low grades of 0.3 to 1.5% Cu (Seedorf *et al.* 2005; Sillitoe 2010). Mineralization occurs predominantly as disseminations and in a dense network of veins and stockworks affecting the intrusive rock and surrounding host rock, resulting from hydraulic fracturing processes. Its formation is the result of the evolution of complex magmatic-hydrothermal systems, where the exsolution and partitioning of a saline aqueous fluid phase —under brittle-ductile transition conditions— facilitates the precipitation of sulfides in low-pressure cortical environments.

Within the generalized model of a magmatic-hydrothermal system centered on copper porphyries (Fig. 1), it is possible to identify various models of associated and genetically linked deposits, which are spatially arranged according to their position relative to the center of the system. This configuration allows to find typologies in proximal sectors, such as copper skarns and breccia chimneys, or manifestations in distal environments and shallower cortical levels, such as epithermal deposits (high, medium, or low sulfidation) and polymetallic veins.

1.3. ALTERATION AND MINERALIZATION PATTERNS

Copper porphyry systems exhibit symmetrical hydrothermal and geochemical zoning, resulting from the thermal gradient and chemical evolution of magmatic fluids, which is fundamental for their recognition and exploration. According to classical models and recent reviews (Seedorff *et al.*, 2005; Sillitoe, 2010; Kouzmanov and Pokrovski, 2012), the following domains are defined from the core to the periphery:

- Potassic alteration: high-temperature core (>400-600°C) characterized by the assembly of potassium feldspar-secondary biotite (± magnetite). It hosts the highest grade hypogene mineralization, with a characteristic association of chalcopyrite-bornite and low pyrite contents.
- Phyllic alteration (Quartz-Sericite): moderate to strong hydrolysis domain, in a temperature range of 200º-400ºC, defined by the quartz-sericite-pyrite assemblage. It represents the collapse of the system and usually occurs as a telescopic

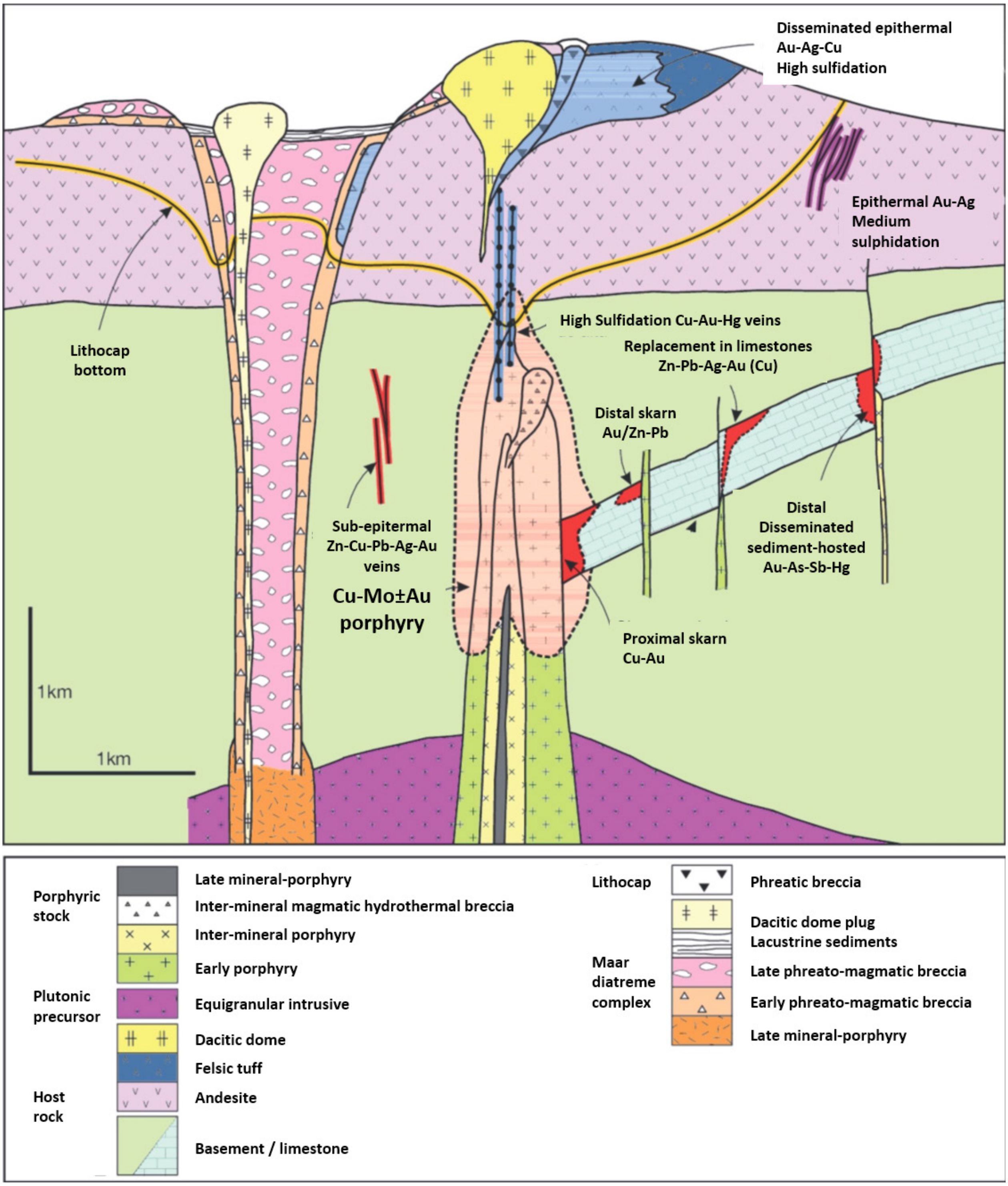


Figure 1. Generalized model of a porphyry copper type system and genetically linked deposits (modified from Sillitoe 2010)

overprint on the potassium core, controlled by the decrease in pH and fluid temperature.

- Advanced Argillic alteration: zone of extreme base leaching under very low pH conditions (<2), with the presence of pyrophyllite, alunite, diaspore, and kaolinite. This domain may form the upper part of the system or be linked to high-sulfidation lithocap.
- Epidote-Chlorite alteration (Propylitization): presents two halos; the inner one with epidote-chlorite and the outer one with epidote + chlorite ± actinolite ± carbonate ± pyrite ± magnetite, representing a more distal zone. These zones surround the Cu-Au mineralized core. The increase in the proportion of epidote relative to chlorite and the appearance of actinolite-magnetite are

vectors that indicate proximity to the potassium core (biotite-K feldspar).

The distribution of metals responds to geochemical fractionation, with Cu±Au concentrated in the potassium core, showing a positive correlation, while molybdenum tends to form high-temperature concentric halos associated with type B veins and phyllic halos.

Other reviews based on case studies of local porphyries (Proffett 2003, Bruna Novillo 2018) develop an applied and practical model that recognizes the ubiquity of sericite, the frequent overlap of intermediate argillic and phyllic (quartz-sericite) alterations that makes it difficult to distinguish between them, and the presence of quartz + magnetite alteration. Thus, the mineralogy and zoning of the alteration facies are defined according to the following sequence:

(1) formation of quartz-magnetite alteration zones in veinlets, and by sectors in massive form, followed by potassic alteration (biotite ± K-feldspar ± magnetite), and epidote-chlorite (epidote-chlorite ± carbonates);
(2) development of ADF (Feldspar-Destructive Alteration), formed by phyllic (quartz-sericite ± pyrite) and intermediate argillic alterations (outward and upward in the upper part),scarce to moderate in sectors, overprinted on the potassic alteration; and
(3) formation of advanced argillic alteration facies in the upper part of the system.

Mineralization is controlled by the network of veinlets, stockwork, and dissemination characteristic of a porphyry-type system, as well as by breccias centered on the volcanic-intrusive complex. These systems show geochemical anomalies of Cu, Au, and Ag in the center, and Mo in the periphery, with potential anomalous contents of Pb, Zn, and Mn.

The conceptual model described here exhibits much more complex manifestations due to the type of emplacement and the structures present. In the central portion of the Argentine-Chilean Andes, hypabyssal bodies or porphyries are emplaced during a compressive phase (resulting from the push of the Nazca Plate against the South American Plate), generating intense North-South trending, high-angle reverse faulting.

Consequently, the intrusive body or bodies (porphyries) are arranged in a tilted or sometimes overturned manner, and at times are truncated by faults. This generates a sequence of alterations that are generally superimposed, repeated, or even missing.

Added to this intrusive style is a structural and magmatic process defined as "telescoping" (Sillitoe, 1994). Sillitoe defines this as a dynamic process of vertical superposition of hydrothermal and metallogenetic environments, caused by rapid exhumation (uplift + erosion) occurring simultaneously with the repeated intrusion of hypabyssal bodies or porphyries within an active magmatic arc, such as the Andes Mountains. This results in a superposition of alterations and mineralizations that, under normal conditions, would be distinctly separated as previously described.

1.4. VEIN CLASSIFICATION

In their classic 1975 work on the El Salvador (Chile) copper porphyry, Gustafson and Hunt developed a classification of A, B, and D quartz vein systems that is of widespread practical application in porphyry and epithermal systems. Quartz veins are typically classified according to their morphology, mineralogy, cross-cutting relationships, and association with hydrothermal alteration. The classification of A, B, D veins (and sometimes others, such as C or M) is common in the geological literature:

Type **A veins** form during the early stages of the hydrothermal system, associated with potassic alteration (K-feldspar, biotite, magnetite). These thick (several centimeters to meters), irregular veins feature diffuse margins. Mineralogy is dominated by quartz + K-feldspar ± biotite ± magnetite, with chalcopyrite and bornite appearing as the primary sulfides. Associated with potassic alteration halos (secondary K-feldspar, green biotite), these features form at high temperatures (>400°C) linked to deep magmatic fluids. Although copper (Cu) and gold (Au) are present, their distribution is typically irregular.

Type **B veins** form after the A type and are associated with phyllic alteration (quartz + sericite ± pyrite). These thin (mm to cm) structures occur as "sheeted veins" (parallel and densely grouped), with a mineralogy consisting of quartz + sericite + pyrite ± chalcopyrite ± molybdenite. Banded textures are occasionally present. Associated with dark halos of sericite + pyrite (phyllic alteration), these veins correspond to medium-to-high formation temperatures (300–400°C). They serve as the primary copper carriers in porphyries; while pyrite is abundant, chalcopyrite is typically concentrated at the vein margins.

Type **D veins** are late-stage veins associated with epidote-chlorite or propylitic alteration (chlorite + epidote + calcite). These irregular veins, sometimes occurring in "stockwork" form, consist of quartz + chlorite ± calcite ± epidote ± pyrite. They contain fewer metallic sulfides than types A and B and are associated with green (chlorite) or whitish (calcite) halos. Formation temperatures are low to medium (<300°C), linked to more dilute and meteoric fluids. While generally poor in mineralization, these veins can contain gold in some systems.

Other classifications incorporate additional vein types (C, M, etcetera). Type **C veins**, in some systems, are defined as late-stage veins with advanced argillic alteration (kaolinite, alunite) linked to acidic fluids. These are common in high-sulfidation epithermal systems. Type **M veins** (Molybdenite) are specialized molybdenite-bearing veins associated with potassic or phyllic alteration, typical of certain Mo-rich porphyries such as at the Portezuelo de Illanes porphyry, within the Upper Miocene-Pliocene back-arc metallogenetic belt in Famatina, La Rioja province (Marcos, 1978).

The **stockwork** is a dense network of veins and microfractures forming an interconnected mesh. In porphyries, it is typically composed of A + B veins forming the stockwork core —characterized by high vein density and Cu-Mo-Au mineralization— and D veins, which infill peripheral fractures or more distal zones of the system.

The paragenetic sequence and cross-cutting relationships indicate that Type A veins form first and are cut by Type B veins. Type B veins cross-cut the A type and are themselves cut by Type D veins. As the latest stage, D veins overprint epidote-chlorite alterations.

In general, Type B veins serve as the primary source of Cu in copper porphyries, whereas Type A veins hold economic importance in gold porphyries. The stockwork (the combination of A, B, and D veins) defines the core ("shell zone") where mineralization is concentrated.

2. BACKGROUND

Open-File Report 2008-1253 entitled “Quantitative Assessment of Copper, Molybdenum, Gold, and Silver Mineral Resources in Undiscovered Porphyry Copper Deposits in the Andes Mountains of South America” (Cunningham *et al.*, 2008) was prepared and published jointly by the geological services of Argentina (SEGEMAR), Chile (SERNAGEOMIN), Colombia (INGEOMINAS), Peru (INGEMMET), and the United States (U.S. Geological Survey - USGS). The main objective of the research was to evaluate mineral resources, delimiting the location of permissive tracts and probabilistically estimating the quantities of copper (Cu), molybdenum (Mo), gold (Au), and silver (Ag) in undiscovered copper porphyry deposits in the Andes Mountains of South America.

In 2015, SEGEMAR published a study on “The copper metallogenic belts of the Argentine Republic” (Cardó *et al.* 2015), based on the analysis of all deposits containing copper, including those where it is a minor component or appears as a trace element, regardless of the type of deposit. That study identified forty-two metallogenic belts, which were grouped into five metallogenic episodes (Pampean, Famatinian, Gondwanan, Jurassic-Cretaceous Andean, and Cenozoic Andean).

Based on this background (Fig. 2), in 2021 SEGEMAR published a report on the mineral resource potential of the continental territory of the Argentine Republic (Zappettini and Gozalvez 2021). This work provides the quantitative assessment methodology and updated figures on resources and undiscovered potential, specifically for PCu-type systems, in the same favorable areas defined by Cunningham *et al.* in 2008.

Figure 2. Covers of previous publications referring to copper porphyry belts in Argentina.

3. METHODOLOGY AND DEFINITIONS

The map of porphyry copper belts in the Argentine Republic accompanying this report was designed as an interactive cartographic platform that combines features of a geographic information system with information analysis tools.

The map covers the portion of Argentine territory located on the American continent, under the WGS84 (World Geodetic System, 1984) geodetic reference system. The scale is not fixed, but a range of 1:25,000,000 to 1:250,000 is recommended for viewing. The smaller scale allows the entire map to be viewed on standard computer screens. Although the map does not limit the possibility of zooming in, the larger scale is related to the resolution of the information provided, which comes from systematic geological and mining-metallogenic surveys carried out by SEGEMAR at a scale of 1:250,000.

The topographic **basemap information** uses layers provided by the National Geographic Institute (IGN). A geochronological layer was also created based on the Geological Map of the Argentine Republic at a scale of 1:2,500,000 (Lizuain Fuentes and Panza, 2018), in which geological units were represented in shades of gray according to their age, with darker shades reserved for older units. This representation facilitates the spatial correlation of the porphyry copper belts with the areas where crystalline basement outcrops and the structures that delimit them.

The remaining information displayed is organized into three themes: metallogenic domains (porphyry copper belts, lithological metallotectons, copper porphyries, other deposits, mining projects); indicative exploration factors (structural clues, copper geochemistry, hydrothermal alteration); land use planning (glacier inventory, protected areas).

The theme of **metallogenic domains** comprises eleven belts as a fundamental element, which are closed polygonal areas. From a metallogenic point of view, the belts are continuous in neighboring countries; however, only the portion of the belts developed in Argentine territory is shown on the map. Most of the belts are defined by a single polygon, while others are composed of several sectors due to their intersection with the international border. They mainly correspond to the location of magmatic arcs during different geological periods, where thermal flow conditions and fluid input were conducive to the genesis of porphyry-type Cu (PCu) deposits.

The map layer called "Porphyry copper deposits" is based on geospatial information from Depósitos de Minerales Metalíferos (Metal-bearing Mineral Deposits) 250k (SIGAM, 2025). It is a point data layer that includes these types of deposits. They correspond to records from the Argentine Republic's Deposit Database belonging to porphyry-type metallogenic models and their subtypes (4a, 4b, 4c, and 4d). Johanis *et al.* (2023) review the complex data model of the Deposit Database, which allows each deposit displayed on the map to have a unique identifier in the database (DEPNO), mining district, name, model, size, upper and lower ages of mineralization, style of mineralization, mineralogical association, hydrothermal alteration, stratigraphic unit of the host rock, lithology of the host rock, upper and lower ages of the host rock, mineral resources, grade, commodity, bibliographic references, and data sheet. Each record has an operational hyperlink to the Mine File in HTML format, hosted on SEGEMAR's servers. This repository ensures the traceability and biannual updating of technical and bibliographic information.

The map includes a data layer called “Other Deposits” that groups together types genetically linked to porphyry systems, such as: high-sulfidation epithermals, copper skarns, breccia pipe deposits, medium- and low-sulfidation epithermal deposits, distal and hot spring-type deposits, polymetallic veins containing copper, both as the main and accessory mineral, and copper mineral veins associated with granitoids.

The aim of integrating a layer of deposits genetically related to porphyry systems is to strengthen exploration vectors through indirect indicators of mineralization. Sedimentary copper and copper sandstone deposits were excluded; although these reflect the presence of the metal on a regional scale, they have little direct link to the magmatic-hydrothermal processes of the arc and the evolution of magmatic fluids typical of porphyries. The tables of associated deposits in this report provide hyperlinks to access the mine file for each deposit mentioned, with complete information.

For both porphyries and other associated deposits, their inclusion in a belt is the result of rigorous scrutiny of the age of the host rock and mineralization, which must coincide or be compatible with the age of the belt. In areas of metallogenic belt overlap or telescoping, there are some deposits of undetermined age, or with a wide potential range of ages, or with recurrent mineralization (Sillitoe and Perelló 2024), which justify their inclusion in more than one belt.

An additional layer of information for each metallogenic PCu belt represented is that of “Mining Projects.” This level of data details, as of the date of publication, the name, operational status (exploration, PEA, PFS, FS), controlling company, and links to technical reports (NI 43-101 standards or similar). This layer encompasses both identified targets and systems with copper by-product potential, optimizing the prospective view of the territory.

From the layer of geological units on the Geological Map of the Argentine Republic at a scale of 1:2,500,000, those that characterize the plutonic and volcanic activity of each metallogenic belt represented were retained, with correspondence in both age and tectonic environment. The display of the lithostratigraphic units representative of each belt helps to delimit its extent and specify its boundaries. Each polygon on the map has associated information such as acronym, name, lithology, upper and lower age, tectonic environment, and units of the 1:250,000 geological sheets that comprise it.

The theme of **Indicative Exploration Factors** is based on three layers of metallogenic favorability: structural controls, copper geochemical anomalies, and hydrothermal alteration zoning.

The structural evidence layer consists of a single polygon, created by superimposing terrain boundaries, structural lines, and faults, to which an area of influence proportional to their extent and attitude was attributed. The main source of information was the structure layer of the Geological Map of the Argentine Republic at a scale of 1:2,500,000. Regional information on structures from Chernicoff *et al.* (2002), Piquer *et al.* (2019), Rubinstein *et al.* (2021), Farrar *et al.* (2023), and Wiemer *et al.* (2023) was also consulted. The alignment of porphyries and other associated deposits, hydrothermal alteration zones, and geochemical anomalies, which can be observed along prominent structures, in areas where parallel and transverse structures intersect the magmatic arc, or following preferential axes linked to lineaments where the magmatic arc progrades, confirms that these structures acted as highly permeable conduits. This underscores their critical role in the ascent of differentiated magmas and the emplacement of large-scale hydrothermal systems, constituting favorable first-order indications for copper porphyry exploration.

The geochemical anomaly layer was created by identifying values that exceed the background threshold of 200 ppm Cu, based on SEGEMAR stream sediment data. The cutoff value was established empirically, after verifying that it discriminates a reasonable number of samples, which show close spatial consistency with the location of porphyry copper (Cu-Mo±Au) deposits and their associated hydrothermal systems. Given that the coverage of regional stream sediment sampling is not continuous, the layer of anomalous copper values was complemented with a layer showing the sampling coverage area, using buffers, allowing for precise differentiation between areas with no geochemical response and those areas lacking sampling.

To provide evidence of hydrothermal alterations and incorporate them into the map, the database of hydrothermal alterations (Koukharsky *et al.*, 1999) published in Mineral Resources of the Argentine

Republic (Zappettini *et al.*, 1999) was digitized as a layer of points with attributes. Of the hydrothermal alteration areas recorded in the database, those located in the belts or close to their boundaries and corresponding to PCu-type or associated deposits were retained. For each hydrothermal alteration area, information is provided on the name, type of alteration, intensity of alteration, associated opaque minerals, type of deposit to which the alteration is linked, age, host rock, surface area, number, references, and observations.

As part of the information related to **land use restrictions and planning**, layers of polygons, protected areas, and elements that make up the glacier inventory were incorporated into the map. This information is essential for assessing the feasibility of projects and legal restrictions that could affect prospecting and eventual mining operations.

The Map of Metallogenic Porphyry Copper Belts in the Argentine Republic displays elements that require precise technical definitions for correct metallogenic and prospective interpretation.

- **Metallogenic belt:** geological units favorable for containing a group of contemporaneous and genetically related deposit models.
- **Permissive tract:** areas where the geology is conducive to the formation of copper porphyries.
- **Metallotecton:** any geological object that contributes to the formation and location of a mineral concentration. The main categories are:
  - Lithological: facies, specific sediments, metamorphic aureoles, magmatic facies, petrographic types.
  - Structural: lineaments, discordances, faults, thrusts, shear zones, mylonitized zones, anticline axes, syncline axes.
  - Paleogeographic: basin margin, karst, paleoslope.
  - Geochemical: quantifiable geochemical anomalies.
  - Mineralogical: hydrothermal alteration, pyrite halos, three-phase inclusions, specific indicator minerals.
  - Geophysical: catalogued anomalies.
- **Mineral deposit:** occurrence of ore of sufficient size and grade that, under favorable circumstances, it is considered to have economic potential.
- **Deposit model:** set of essential attributes of a class of mineral deposits. A model includes descriptive information about geological characteristics and quantitative aspects such as grade and tonnage that characterize the set of deposits considered to belong to the class.
- **Porphyry copper:** deposit model characterized by stockwork, veins, and dissemination of pyrite, chalcopyrite, bornite, magnetite, ± native gold in or adjacent to porphyritic intrusions. Mineralization is spatially and genetically related to hydrothermal alteration affecting the intrusive and host rock. They occur in a tectonic environment of Shoshonitic-type or K-rich calc-alkaline arc or back-arc magmatism, associated with riftogenesis or transtensional basins in cratonic areas, generally rich in LILE and LREE elements and depressed in HFSE. The typical mineralogical association in the ore is chalcopyrite + chalcocite ± native gold + electrum + bornite. The gangue minerals are quartz, potassium feldspar, biotite, magnetite, chlorite, and pyrite. The mineralogy and zoning of the alteration facies correspond to: 1) formation of quartz-magnetite alteration zones in veins, and in massive form in some areas, followed by potassic (Bt±Fk±Mag) and epidote-chlorite (Ep-Chl±Cb) alteration; 2) development of ADF (Alkali-Feldspar Destructive) alteration, consisting of phyllic (Qz-Ser±Py) and intermediate argillic (outward and upward in the upper part) alterations, in sparse to moderate sectors, superimposed on the potassic alteration; and 3) formation of advanced argillic alteration facies in the upper part of the system. Mineralization is controlled by a network of veins, stockworks, and disseminations associated with a porphyry-type system and another associated with breccias centered on the volcanic-intrusive complex. They show geochemical anomalies of Cu, Au, and Ag in the center, and Mo in the periphery. There may be anomalous contents of Pb, Zn, and Mn. Magnetometry usually shows positive anomalies towards the central core linked to the presence of breccias with magnetite, as well as negative magnetic anomalies related to the destruction of magnetite in external pyrite halos.
- **Role of Andean tectonics:** the migration of the continental magmatic arc, linked to the subduction of the Nazca Plate and phenomena such as slab shallowing, controls the temporal and spatial distribution of the belts.
- **Potential assessment methodology:** the potential assessment referred to as background and used as a general model by USGS and SEGEMAR is based on the "Three-Part Form"

method developed by the USGS (Schulz and Briskey 2003). First, permissive tracts are delineated, areas where the geology is conducive to PC formation. Next, grade-tonnage models (such as the USGS general copper porphyry model) are established that contain the statistical distributions of tonnage and grade of globally known deposits. Finally, experts estimate the number of undiscovered deposits in each tract through geological favorability analysis. The estimation of potential resources is performed by probabilistically combining these components.

- **MASH (Melting, Assimilation, Storage, Homogenization):** deep process at the base of the crust (usually at a depth of ~25-40 km) where primary magmas derived from the mantle melt and assimilate rocks from the lower crust, are stored in chambers, and become homogenized. This process is critical for enriching magmas with volatiles (H_2O, S, Cl) and metals (Cu, Au), generating the geochemical "signatures" (high Sr/Y, adakitic) characteristic of the fertile magmas that form large porphyries.
- **LILE (Large-Ion Lithophile Elements):** a group of geochemical elements characterized by having a large ionic radius and a low electric charge (usually +1 or +2). Due to these properties, they are chemically incompatible and preferentially concentrate in molten phases (magma) during partial melting processes of the mantle or Earth's crust, rather than being incorporated into minerals in the crystal lattice. During the evolution of magmatic systems, such as those that generate copper porphyries, LILE are extremely mobile and become enriched in hydrothermal fluid phases. For this reason, they are decisive as geochemical tracers for understanding the processes of melting, crustal contamination, and, especially, hydrothermal alteration associated with mineralization. They include K, Rb, Cs, Ba, Sr, Eu++, Pb++, Th, among others. In the specific context of copper porphyries, the ratios between LILE elements (K/Rb, Ba/Sr) and their patterns of enrichment or depletion are vital tools for identifying and characterizing different types of hydrothermal alteration (such as phyllic, potassic, or argillic), which helps guide the search for the mineralized core.
- **REE (Rare Earth Elements):** group of chemical elements with similar properties, including Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb), and Lutetium (Lu), plus Scandium (Sc) and Yttrium (Y). In geochemistry, they are excellent tracers of petrogenetic processes due to their consistent but slightly different behavior depending on their ionic radius.
- **LREE: (Light Rare Earth Elements):** subgroup of REE that includes elements with atomic numbers from 57 (Lanthanum) to 64 (Gadolinium): La, Ce, Pr, Nd, Pm, Sm, Eu, Gd. Like LILE, they are lithophile and incompatible elements that become enriched in magmas during partial melting. In copper porphyry systems, their behavior is decisive in discriminating between magmatic sources and crustal contamination processes. The fractionation between LREE and HREE (Heavy Rare Earth Elements), as well as Europium (Eu) anomalies, are tools for understanding the degree of melting and the presence of minerals such as feldspar in the source.
- **HFSE (High Field Strength Elements):** a group of geochemical elements characterized by having a small ionic radius and a high electric charge (usually +4 or +5). This combination results in a high charge-to-radius ratio, which is referred to as "high field strength." Due to this property, they are geochemically immobile and incompatible elements, showing strong resistance to incorporation into the crystalline structures of major mantle minerals during partial melting processes. Unlike LILE, HFSE are relatively insoluble in aqueous fluids and vapor phase. Therefore, their distribution is not significantly affected by late hydrothermal processes, making them excellent tracers for identifying the source of magma, the degree of partial melting, and deep crustal contamination processes, as their relative proportion remains virtually unchanged. They include Zr, Hf, Nb, Ta, Ti, Y, Th, and U. In copper porphyry systems, the relative immobility of HFSE during hydrothermal alteration makes them critical for characterizing the original composition of the parent magma. The ratios between HFSE (Nb/Ta, Zr/Hf) are particularly useful for discriminating between different mantle and crustal magmatic sources and understanding the early evolution of the system, prior to mineralization.

4. COPPER POTENTIAL IN ARGENTINA

Porphyry copper deposits account for approximately 98% of total reported national copper resources, with 55 Mt of measured and indicated Cu in September 2025 (National Mining Secretariat 2025), and an equally significant proportion of the total 74 Mt Cu (Zappettini and Gozalvez 2021), which also includes resources from depleted deposits and Cu content below the cut-off grades of feasibility studies.

The development of fertile magmatism for the formation of porphyry deposits is distributed across five major metallogenic epochs, from the Permian to the Pliocene. Among these, the Miocene and Pliocene episodes contain the most voluminous and economically significant systems, which hold the largest proportion of associated copper, molybdenum, and gold reserves.

According to probabilistic estimates made by SEGEMAR and the USGS (Cunningham *et al.*, 2008; Zappettini and Gozalvez, 2021), the potential for undiscovered copper resources in Argentina triples the base of identified resources. This represents a total projected metal endowment of close to 240 Mt of Cu, consolidating the territory as one of the most prospective metallogenic provinces in the Andean arc.

Late Cenozoic (Miocene-Pliocene) magmatism represents the most fertile metallogenic event, characterized by low-angle (flat-slab) subduction geodynamic evolution and transpressive deformation regimes. These processes favored crustal thickening, the consequent fusion by decompression or dehydration in the metasomatized mantle wedge, and the ascent of highly oxidized, hydrated, and volatile-enriched calc-alkaline magmas. These petrogenetic conditions are the key drivers for the formation of giant porphyry systems (Tier-1), allowing efficient partitioning of metals from the melt to the hydrothermal fluid phase.

5. PORPHYRY COPPER BELTS IN ARGENTINA

Information on porphyry copper metallogenic belts in Argentina is summarized in descriptive technical data sheets. Each sheet is headed by the name of the belt as used on the interactive map. The left-hand section includes a map of the belt showing the characteristic lithological metallotectons and the porphyry copper deposits it contains, with their names.

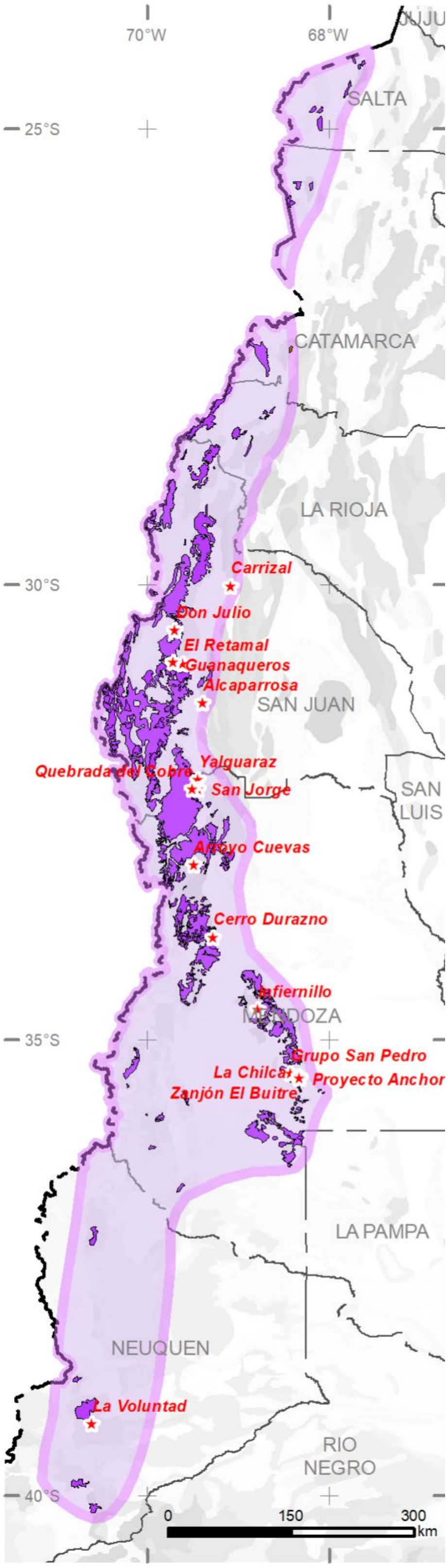
The upper section includes the definition of the belt, given by the tectonic environment, age, and geological provinces it covers; the names and/or equivalents of the belt in the previous publications by Cunningham *et al.* (2008) and Zappettini and Gozalvez (2021); and the area covered by the belt. It is complemented, in the upper right corner, with a detail of the Argentine continental territory with the belt location, providing a representation of its position, size, and provinces in which it extends.

The middle section presents information on lithological metallotectons, providing acronyms and names, lithology, and geological units that make up the lithostratigraphic units represented in the Geological Map of the Argentine Republic at a scale of 1:2,500,000 (Lizuain Fuentes and Panza, 2018).

The porphyry systems that make up the belt are then listed, providing a link to the deposit's mine file in the Argentine Republic Deposit Database, where more complete information on the deposits can be accessed.

The lower section contains, for the belt, a summary of the mineral resources quantified in published reports, details corresponding to each mining project, and potential resources. The potential information is taken from Zappettini and Gozalvez (2021). The area of the belt on which these authors made their estimate is reported, which only considers the sectors of the sub-outcropping belt at a depth of less than 1 km, considering the limitations of PCu exploitability at greater depths. In turn, the value reported may differ from the surface area of the belt in this contribution due to modifications and adjustments made to its perimeter. The section also reports copper resources and associated elements, and a 50% probability estimate of the number of copper porphyries remaining to be discovered in the belt according to the model. With regard to quantified resources, the source is the information published by the operators of the mining projects developed in the belt. A summary of resources for the entire belt is presented, mentioning the reported category and details by project, with its name and status, along with a link to the project information provided by each operator.

5.1. Permo-Triassic belt (≈299 – 201 Ma)



Permo-Triassic magmatic arc in Puna, Cordillera Frontal, Cordillera Principal and Cuenca Neuquina
Other names PamCf; SA16aPC + SA16bPC
Area 250,000 km²

Lithological metallotectons

Name	Lithology	Geological units
PTv Gondwanic extensional arc volcanics	Lavas, breccias, ignimbrite and tuffs of rhyolitic, dacitic and andesitic composition	Laguna de Aracar, Pantanoso, La Cuesta and equivalent formations
PTv Acidic to mesosilicic volcanics. Epiclastic continental sedimentites	Rhyolites, dacites, andesites, ignimbrites, tuffs, breccias, conglomerates	Choiyoi Group, Choique Mahuida, Centinela, Lihuel Calel and equivalent formations
PTγ Gondwanic arc granitoids	Gabbros, granites, granodiorites, diorites, sienites, monzonites, monzodiorites, monzogranites, tonalites	Chuculaqui, Llullaillaco and equivalent plutons
PTγ Granites, granodiorites, tonalites and rhyolitic dykes	Granites, granodiorites, tonalites and rhyolitic dykes	Colangüil batholith, undifferentiated granitoids of Cordillera Frontal and southern La Pampa, Zúñiga formation, del Chachil plutonic complex, Huechulafquen and equivalent formations
Pγ Acidic to mesosilicic plutonites	Granites, aplites, pegmatites	Yuncón granite and equivalents

Porphyry-type deposits in the belt

Carrizal
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3317.html

Don Julio
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp328.html

Guanaqueros
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3190.html

El Retamal
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3194.html

Alcaparrosa
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3205.html

Yalguaraz
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3213.html

San Jorge
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3215.html

Quebrada del Cobre
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24611.html

Arroyo Cuevas
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp5215.html

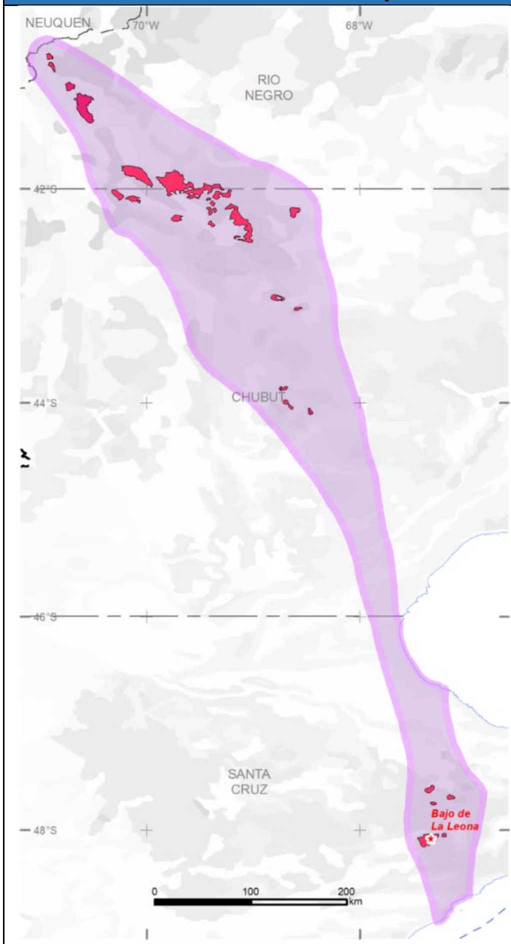
Cerro Durazno
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11012.html

Infiernillo

5.1. Permo-Triassic belt (≈299 – 201 Ma)

	https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3216.html
	Grupo San Pedro https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3231.html
	La Chilca https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3307.html
	Proyecto Anchoris https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3233.html
	Zanjón El Buitre https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3308.html
	La Voluntad https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3337.html
	Reported mineral resources in the belt
	Resources: 1.3 Mt Cu; 1.2 Moz Au (measured and indicated)
	Source: San Jorge, PSJ Cobre Mendocino project ; La Voluntad
	Potential resources in the belt (Zappettini and Gozalvez 2021) Area 91,000 km^2 Resources 20,1 Mt Cu; 460 kt Mo; 510 t Au; 5,8 kt Ag P_{50} porphyry copper yet to be discovered 5
	Mining projects (Cu) in the belt
	PSJ Cobre Mendocino (prefeasibility) Resources 0,9 Mt Cu; 1,2 Moz Au (measured and indicated) https://www.psjcobremendocino.com
	Don Julio (initial exploration) https://sableresources.com/projects/argentina/don-julio/

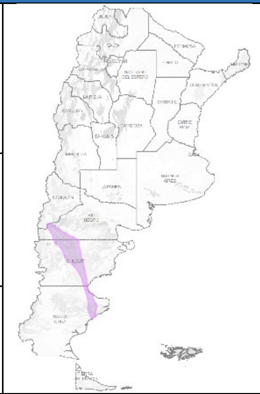
5.2. Triassic-Jurassic belt (≈252-145 Ma)



Triassic-Jurassic magmatic arc in Patagonia extraandina

Other names
TrJamPea; SA19PC

Area
117,000 km²



Lithological metallotectons

Name	Lithology	Geological units
TJγ Granitoids	Granites and granodiorites, porphyries	Lipetrén, Calvo, Flores, Gastre, Curacó, La Leona and equivalents granites
Jv Acidic volcanics and pyroclastites with interbedded continental sedimentites	Acidic ignimbrites and tuffs, rhyolites, shales and tuffites	Bahía Laura group, Marifil formation and equivalents
Jδ Gabbros and basaltic dykes	Gabbros and basaltic dykes	Tecka and equivalent formations., Georgias Islands ophiolites, Malvinas Islands dykes
Jγ Granitoids	Granites, granodiorites, tonalites	Leleque formation, Batolito Subcordillerano granitoids, Malvinas diabase dykes and equivalents

Porphyry-type deposits in the belt

Bajo de La Leona
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3397.html

Reported mineral resources in the belt

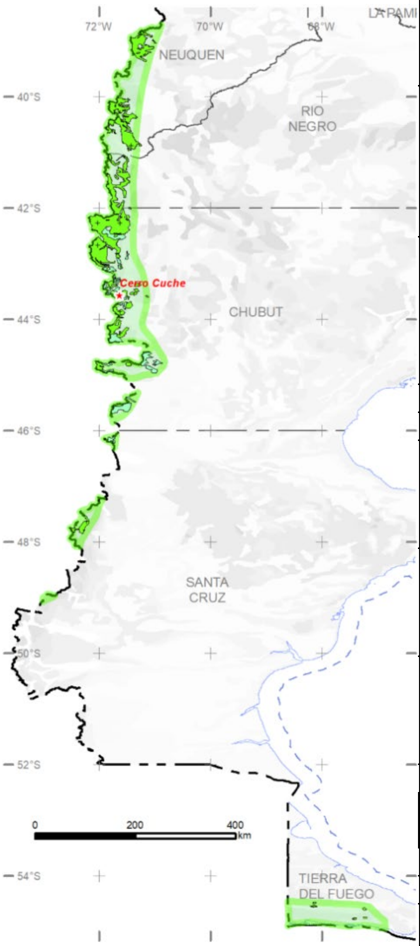
without quantified resources

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 45,600 km²
Resources 5.7 Mt Cu ; 150 kt Mo ; 130 t Au ; 2.0 kt Ag
P_{50} porphyry copper yet to be discovered 2

Mining projects (Cu) in the belt

without PCu-type projects

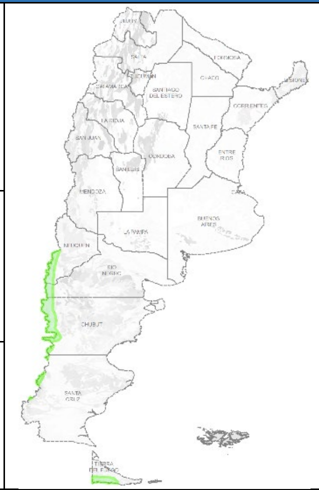
5.3. Cretaceous belt (≈145-66 Ma)



Cretaceous magmatic arc in Cordillera Patagónica

Other names
KamCp; SA20PC

Area
73,000 km²



Lithological metallotectons

Name	Lithology	Geological units
Ky Granitoids from Batolito Andino	Granites, granodiorites, tonalites	La Plata Chico, Aleusco, Sobral, Penitentes, Chacabuco and equivalents granites
K1v Acidic to mesosilicic volcanics	Rhyolites and andesites, tuffs, ignimbrites and tuffites	Divisadero group, Carrenleufú, Payaniyeu and equivalent formations
Ky Granitoids	Granites, granodiorites	Batolito Andino, Plaza Francia diorites and gabbros, Los Machis formation, Paso de Icalma granodiorite

Porphyry-type deposits in the belt

Cerro Cuche
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3364.html

Reported mineral resources in the belt

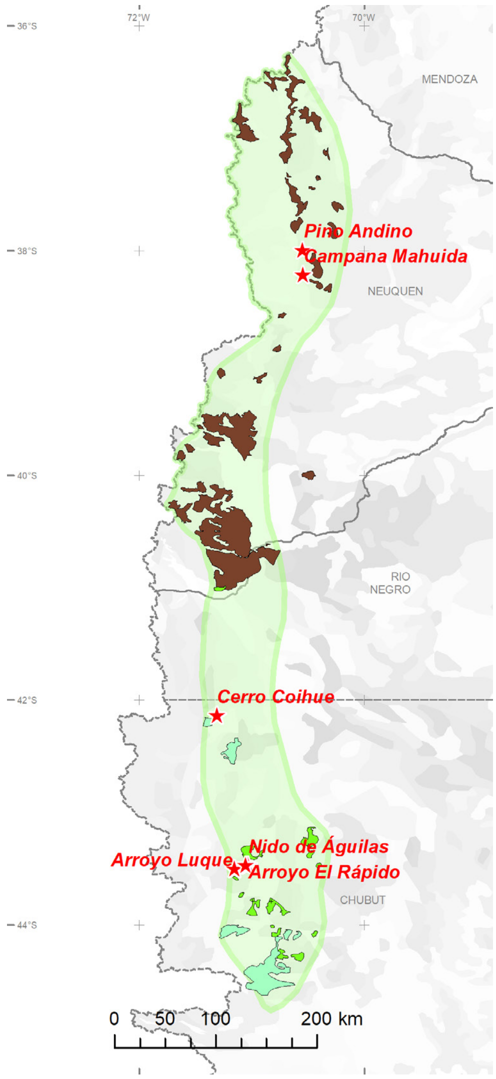
without quantified resources

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 28,000 km²
Resources 4.3 Mt Cu; 110 kt Mo; 110 t Au; 1.4 kt Ag
P_{50} porphyry copper yet to be discovered 1

Mining projects (Cu) in the belt

without PCu-type projects

5.4. Upper Cretaceous-Eocene belt (≈101-34 Ma)



Upper Cretaceous – Eocene magmatic arc in Cuenca Neuquina and northern Cordillera Patagónica

Other names
KPamNCp; SA15PC

Area
100,000 km²

Lithological metallotectons

Name	Lithology	Geological units
Ky Granitoids of Batolito Andino	Granites, granodiorites, tonalites	La Plata Chico, Aleusco, Sobral, Penitentes, Chacabuco and equivalents granites
Ky Granitoids	Granites, granodiorites	Batolito Andino, Plaza Francia diorites and gabbros, Los Machis formation, Paso de Icalma granodiorite
K1v Acidic to mesosilic volcanics	Rhyolites and andesites, tuffs, ignimbrites and tuffites	Divisadero group, Carrenleufú, Payaniyeu and equivalents formations
Ev Volcanics, intrusives, interbedded pyroclastites and sedimentites	Andesites, dacites, ignimbrites, tuffs, andesitic and dacitic porphyries	Doña Ana, Pachón, Vizcachas formations, Naunaco group, Vervaco granodiorite, Huitrera and equivalents formations

Porphyry-type deposits in the belt

Pino Andino
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24829.html

Campana Mahuida
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11194.html

Cerro Coihue
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3359.html

Arroyo Luque
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3363.html

Nido de Águilas
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3361.html

Arroyo El Rápido
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3362.html

Reported mineral resources in the belt

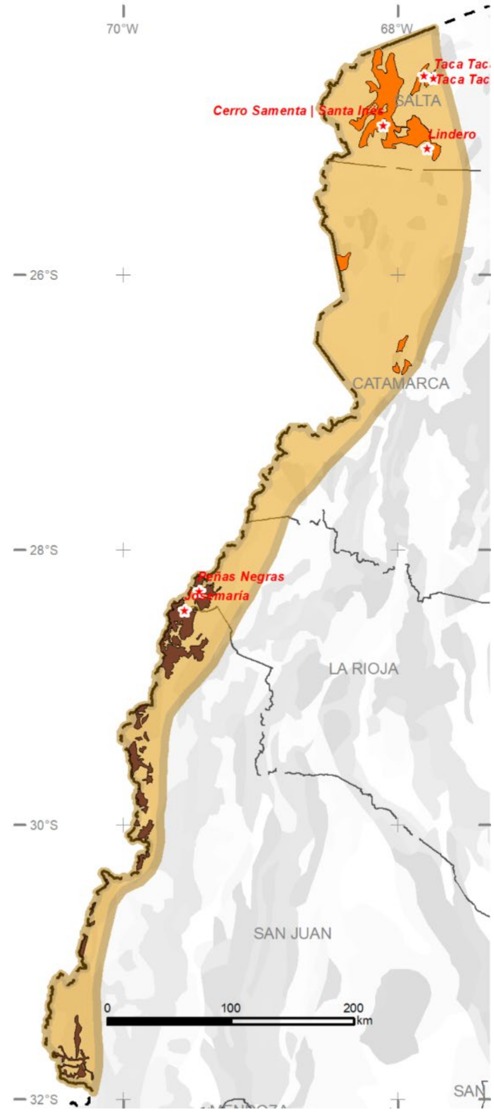
Resources	0.2 Mt Cu (total)
Source	Campana Mahuida

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 83,200 km²
Resources 15.2 Mt Cu; 360 kt Mo; 360 t Au; 4.9 kt Ag
P_{50} porphyry copper yet to be discovered 4

Mining projects (Cu) in the belt

without PCu-type projects

5.5. Oligocene belt (≈34-23 Ma)



Oligocene magmatic arc in Puna and Cordillera Frontal

Other names
OamPCf; SA11PC + SA12PC

Area
50,000 km²

Lithological metallotectons

Name	Lithology	Geological units
Ev Volcanics, Intrusives, interbedded pyroclastics and sediments	Andesites, dacites, ignimbrites, tuffs, andesitic and dacitic porphyries	Doña Ana, Pachón, Vizcachas formations, Naunaco group, Vervaco granodiorite, Huitrera and equivalents formations
Eα Arc volcanics	Dioritic, andesitic and dacitic hypabyssal porphyries	Quebrada del Agua Volcanic Complex and equivalents

Porphyry-type deposits in the belt

Taca Taca Alto
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3061.html

Taca Taca
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3060.html

Cerro Samenta | Santa Inés
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3081.html

Lindero
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3084.html

Peñas Negras
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11205.html

Josemaría
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3158.html

Reported mineral resources in the belt

Resource	13.3 Mt Cu; 15.4 Moz Au (measured and indicated)
Source	Vicuña and Taca Taca

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 13,000 km²
Resources 36.7 Mt Cu; 860 kt Mo; 1,020 t Au; 7.0 kt Ag
P_{50} porphyry copper yet to be discovered 6

Mining projects (Cu) in the belt

Vicuña (preconstruction)
Resources 4.6 Mt Cu; 9.7 Moz Au (measured and indicated)
https://lundinmining.com/news/lundin-mining-announces-vicuna-integrated-technica-123230/

Taca Taca (prefeasibility)
Resources 8.7 Mt Cu; 5.7 Moz Au (measured and indicated)
https://www.first-quantum.com/es/operations/taca-taca/

Santa Inés (advanced exploration)
https://www.powerminerals.com.au/site/pdf/f58b7a9f-8b4d-4926-92b2-b1009e275fbb/Santa-Ines-CopperGold-Project-Update.pdf

Río Salinas (advanced exploration)
Fortescue Ltd.

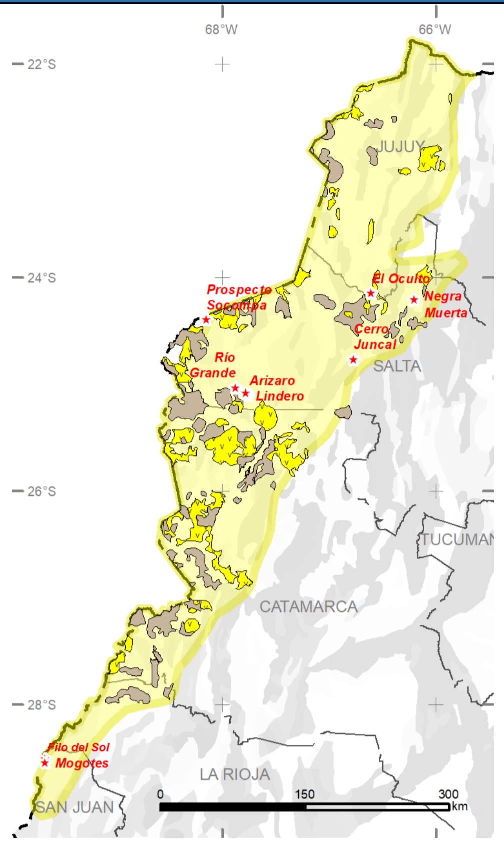
Nivaldo -ex Sillimanita- (initial exploration)
https://riodeorocorp.com/projects/nivaldo-project/

Peñas Negras (initial exploration)
https://senderoresources.com/projects/penas-negras/Overview

La Coipita (initial exploration)
https://www.abrasilver.com/projects/la-coipita/

TMT Toro Malambo Tambo (initial exploration)
https://www.belararox.com.au/site/projects/tmt-argentina

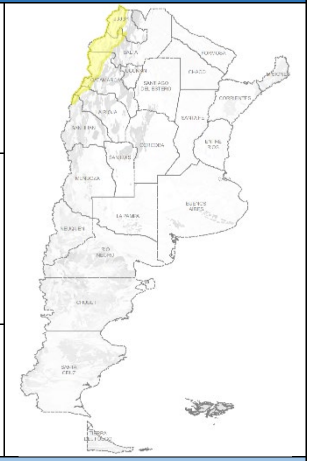
5.6. Middle Miocene belt in Puna and Cordillera Frontal (≈16-11 Ma)



Magmatic arc in Puna and Cordillera Frontal

Other names
MamPCf; SA13aPC

Area
98,000 km²



Lithological metallotectons

Name	Lithology	Geological units
N1α Arc volcanics	Basaltic, dacitic and andesitic lavas, autoclastic andesitic breccias, stratovolcanoes-related block and ash deposits	Abra Grande, Pairique Torona,Coranzuli, Panizo and equivalents volcanic complexes
N2α Arc volcanics	Dacites, andesites, basalts; cinder cones and volcanic *avalanche* deposits	Cerro Tinte, Granada, Zapaleri, Campanario, Poquis, Llullaillaco, Ojos del Salado and equivalents volcanoes

Porphyry-type deposits in the belt

El Oculto
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp15.html

Negra Muerta
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3059.html

Prospecto Socompa
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3082.html

Cerro Juncal
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3094.html

Río Grande
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11297.html

Lindero
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3084.html

Arizaro
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3083.html

Filo del Sol
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24538.html

Mogotes
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3173.html

Reported mineral resources in the belt

Resource	10 Mt Cu; 28.1 Moz Au (total)
Source	Lindero, Arizaro, Río Grande and Vicuña

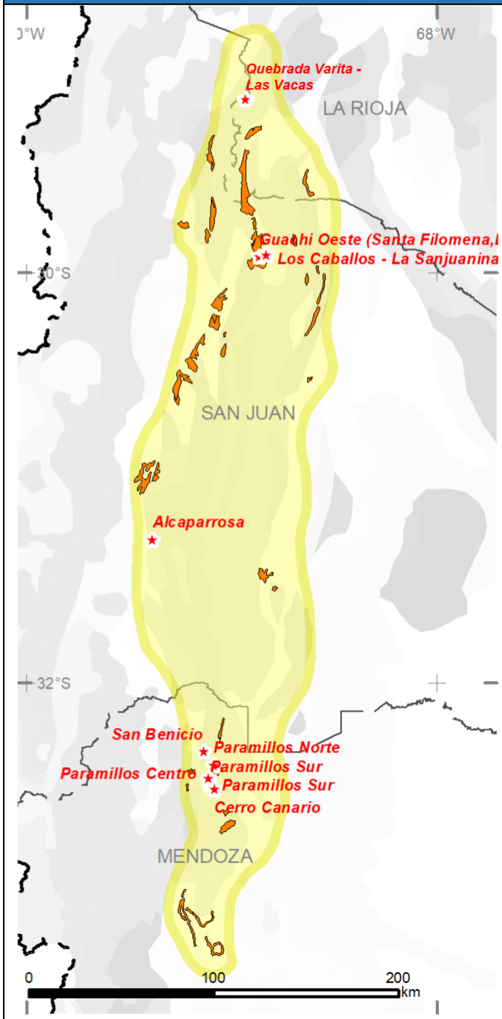
Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 59,500 km²
Resources 36.4 Mt Cu; 860 kt Mo; 1,140 t Au; 17.0 kt Ag
P_{50} porphyry copper yet to be discovered 10

Mining projects (Cu) in the belt

Lindero (production)
Resources 98 kt Cu; 421 koz Au (measured and indicated)
https://fortunamining.com/mine/lindero-mine-argentina/

5.6. Middle Miocene belt in Puna and Cordillera Frontal (≈16-11 Ma)	
	Vicuña (preconstruction) Resources 9.7 Mt Cu; 26.5 Moz Au (measured and indicated) https://lundinmining.com/news/lundin-mining-announces-vicuna-integrated-technica-123230/
	Río Grande (advanced exploration) Resources 213 kt Cu; 822 koz Au (indicated) https://aldebaranresources.com/projects/other-projects/rio-grande/overview/
	Arizaro (advanced exploration) Resources 385 koz Au (inferred) https://fortunamining.com/mine/lindero-mine-argentina/
	Filo Sur (advanced exploration) https://www.mogotesmetals.com/projects/argentina/filo-sur
	La Ortiga (advanced exploration) https://web.sanjuan.gob.ar/ipeem/?page_id=187
	Las Flechas (initial exploration) Link Pan American Silver
	Interceptor (initial exploration) https://ngexminerals.com/projects/valle-ancho/valle-ancho-overview/
	Valle Ancho (initial exploration) https://ngexminerals.com/projects/valle-ancho/valle-ancho-overview/
	Lunahuasi (initial exploration) https://ngexminerals.com/projects/vicuna-district/lunahuasi/lunahuasi-overview/

5.7. Miocene backarc belt in Precordillera (≈23-5 Ma)



Backarc magmatism in Precordillera

Other names
MramP; SA14aPC

Area
39,000 km²

Lithological metallotectons

Name	Lithology	Geological units
Nvc Acidic and mesosilicic volcanics, pyroclastics	Andesites, basandesites, aglomerates, sandstones, tuffs	Molle group, Huincán and equivalents, Cerro Las Tórtolas, Lomas del Campanario, Farellones, Complejo La Ramada and Aconcagua formations, Chachahuen and equivalents Volcanic Complex

Porphyry-type deposits in the belt

Quebrada Las Varitas – Las Vacas | Troya https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp26264.html
Los Caballos | La Sanjuanina https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24545.html
Guachi Oeste https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3176.html
Alcaparrosa https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3205.html
San Benicio https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3218.html
Paramillos Norte https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3211.html
Paramillos Centro https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24612.html
Paramillos Sur https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11224.html
Cerro Canario https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp25794.html

Reported mineral resources in the belt

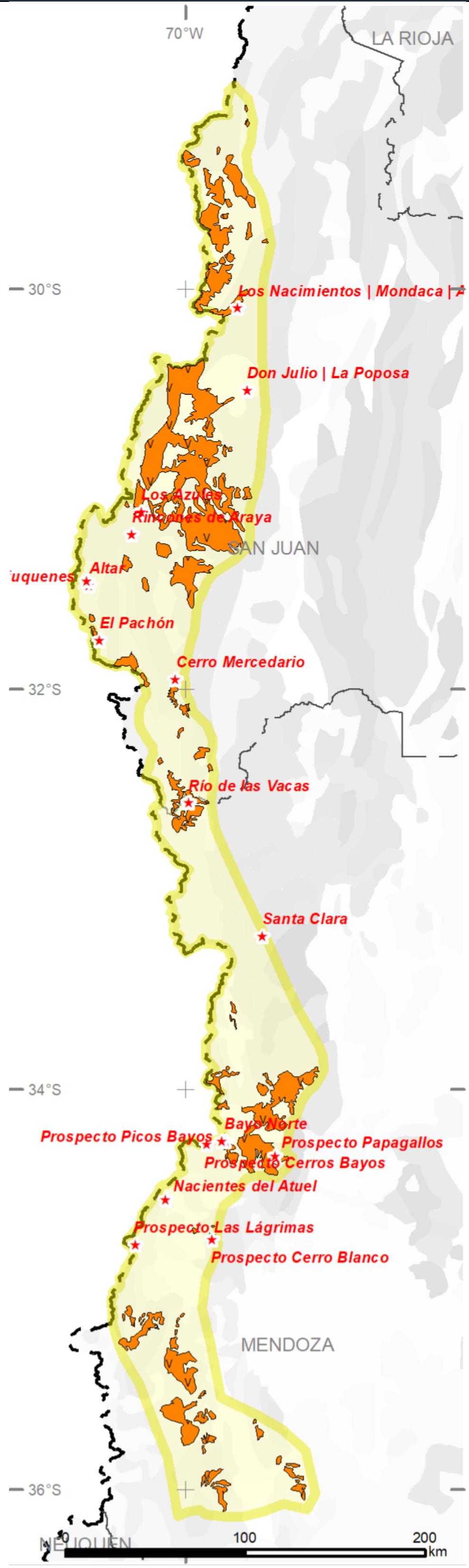
Resources	2.1 Mt Cu (total)
Source	Paramillos Norte and Paramillos Sur

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 21,720 km²
Resources 22.1 Mt Cu; 520 kt Mo; 490 t Au; 6,7 kt Ag
P_{50} porphyry copper yet to be discovered 6

Mining projects (Cu) in the belt

without PCu-type projects

5.8. Upper Miocene belt in Cordillera Frontal and Cordillera Principal (≈12-5 Ma)



Upper Miocene magmatic arc in Cordillera Frontal and Cordillera Principal

Other names
MamCfCp; SA13bPC + SA13cPC

Area
46.000 km²

Lithological metallotectons

Name	Lithology	Geological units
Nvc Acidic and mesosilicic volcanics, pyroclastics	Andesites, basandesites, aglomerates, sandstones, tuffs	Molle group, Huincán and equivalents, Cerro Las Tórtolas, Lomas del Campanario, Farellones, Complejo La Ramada and Aconcagua formations, Chachahuen and equivalents Volcanic Complex

Porphyry-type deposits in the belt

Los Nacimientos | Mondaca https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp331.html
Don Julio | La Poposa https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp328.html
Los Azules https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3196.html
Rincones de Araya https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3200.html
Altar https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp24341.html
El Pachón https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3206.html
Cerro Mercedario https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3208.html
Río de las Vacas https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3298.html
Santa Clara https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3219.html
Bayo Norte https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3257.html
Prospecto Picos Bayos https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3312.html
Prospecto Cerros Bayos https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3313.html
Prospecto Papagallos https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3311.html
Nacientes del Atuel https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3315.html
Piuquenes https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp25906.html
Prospecto Cerro Blanco https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3316.html
Prospecto Las Lágrimas https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3314.html

Reported mineral resources in the belt

Resources	26 Mt Cu; 6.2 Moz Au (measured and indicated)
Source	El Pachón, Los Azules, Altar and Valle de Chita

5.8. Upper Miocene belt in Cordillera Frontal and Cordillera Principal (≈12-5 Ma)

	Potential resources in the belt (Zappettini and Gozalvez 2021) Area 30,000 km^2 Resources 60.2 Mt Cu; 1,130 kt Mo; 894 t Au; 21.2 kt Ag P_{50} porphyry copper yet to be discovered 6
	Mining projects (Cu) in the belt
	El Pachón (feasibility) Resources 10.4 Mt Cu (measured and indicated) https://www.elpachon.com.ar
	Los Azules (preliminary economic assessment) Resources 4.9 Mt Cu; 459 koz Au (measured and indicated) https://www.mcewenmining.com/operations/los-azules/default.aspx
	Valle de Chita (advanced exploration) Resources 470 kt Cu; 665 koz Au (measured and indicated) https://www.minsud.com/our-project/
	Altar (advanced exploration) Resources 10 Mt Cu; 5.1 Moz Au (measured and indicated) https://aldebaranresources.com/projects/altar-copper-gold/overview/
	Río Salinas (advanced exploration) Link Fortescue Ltd.
	Río Cenicero (advanced exploration) https://aldebaranresources.com/projects/altar-copper-gold/location/
	Rincones de Araya (initial exploration) https://wweb.sanjuan.gob.ar/ipeem/?page_id=196
	Piuquenes (initial exploration) https://www.pampametals.com/projects/piuquenes.html
	La Coipita (initial exploration) https://www.abrasilver.com/projects/la-coipita/
	Cerro Amarillo (initial exploration) https://impulsamendoza.com.ar/distrito-minero/
	San Francisco de los Andes (initial exploration) Link Turmalina Metals Corp.
	Don Julio (initial exploration) https://sableresources.com/projects/argentina/don-julio/

5.9. Upper Miocene – Lower Pliocene belt in Cordillera Principal (≈12-3 Ma)

Upper Miocene – Lower Pliocene magmatic arc in Cordillera Principal

Other names
MPamCp; SA14bPC

Area
6,100 km^2

Lithological metallotects

Name	Lithology	Geological units
Nvc Acidic and mesosilicic volcanics, pyroclastics	Andesites, basandesites, aglomerates, sandstones, tuffs	Molle group, Huincán and equivalents, Cerro Las Tórtolas, Lomas del Campanario, Farellones, Complejo La Ramada and Aconcagua formations, Chachahuen and equivalents Volcanic Complex

Porphyry-type deposits in the belt

Yunque
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3207.html

El Indio (Amos Andrés)
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3210.html

Reported mineral resources in the belt

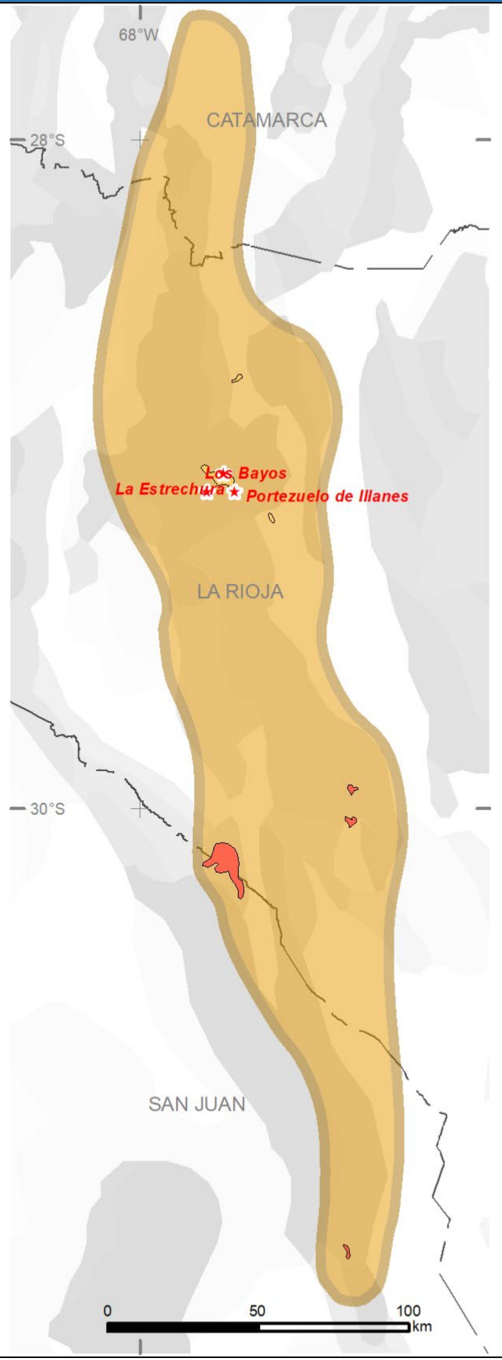
without quantified resources

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 3,800 km^2
Resources 80 Mt Cu; 2,400 kt Mo; 490 t Au; 27 kt Ag
P_{50} porphyry copper yet to be discovered 2

Mining projects (Cu) in the belt

without PCu-type projects

5.10. Upper Miocene – Pliocene backarc belt in Famatina (≈12-2 Ma)



Upper Miocene – Pliocene backarc magmatism in Famatina and Sierra de la Huerta

Other names
MPramF; SA14dPC

Area
23,000 km²

Lithological metallotectons

Name	Lithology	Geological units
Tβ Basic volcanites. Basaltic dykes and lava flows.	Basalts	Los Baldecitos formation, Marayes basalt
Nα Andean volcanics. Arc volcanics	Andesites	Farallón Negro, El Mogote and El Morro complexes

Porphyry-type deposits in the belt

La Estrechura
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11221.html

Los Bayos
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3156.html

Portezuelo de Illanes
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3163.html

Reported mineral resources in the belt

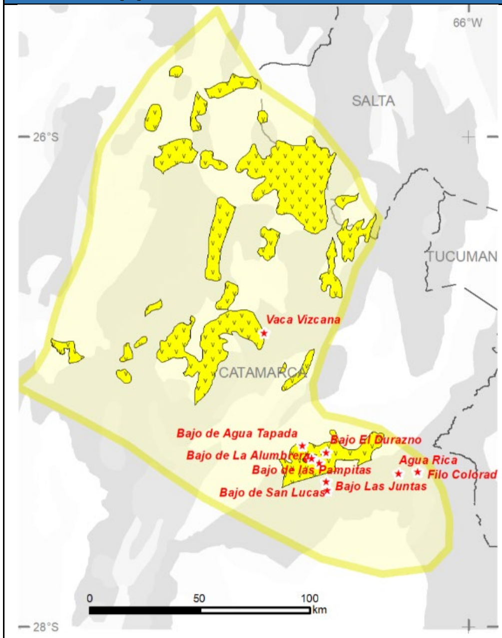
Resources	1.11 Mt Cu (total)
Source	Zappettini and Gozalvez 2021

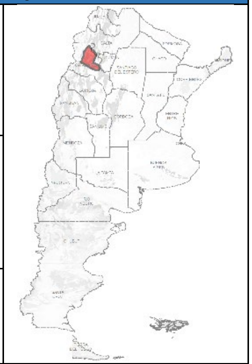
Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 30,000 km²
Resources 13.1 Mt Cu; 410 kt Mo; 308 t Au; 3,8 kt Ag
P_{50} porphyry copper yet to be discovered 4

Mining projects (Cu) in the belt

Famatina
It was an exploration project for the extraction of mainly gold in Cerro Famatina, La Rioja province, linked to the deposits in the La Mejicana district. From 2005 to 2013, the international companies Barrick Mining, Shandong Gold, Osisko Mining, and the local Midais based in Salta, attempted to start the project, but abandoned it due to a lack of social license because of opposition to the projects in the cities of Famatina and Chilecito. As part of this process, the province of La Rioja passed laws prohibiting open-pit mining and the use of cyanide, which it later repealed.

5.11 Upper Miocene – Pliocene backarc belt in Sierras Pampeanas (≈12-2 Ma)





Upper Miocene – Pliocene backarc magmatism in Sierras Pampeanas

Other names
MPramSP; SA14cPC

Area
29,000 km²

Lithological metallotectons

Name	Lithology	Geological units
N1γ Andean granitoids	Granites	Acay Granite
N1α Arc volcanics	Basaltic, dacitic and andesitic lavas, autoclastic andesitic breccias, stratovolcanoes-related block and ash deposits	Abra Grande, Pairique Torona,Coranzuli, Panizo and equivalents volcanic complexes

Porphyry-type deposits in the belt

Vaca Vizcana
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3133.html

Bajo de Agua Tapada
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11218.html

Bajo El Durazno
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11216.html

Bajo de las Pampitas
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3120.html

Bajo de La Alumbrera
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3115.html

Filo Colorado
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3122.html

Agua Rica
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3114.html

Bajo de San Lucas
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp11217.html

Bajo Las Juntas
https://sigam.segemar.gov.ar/segedoc/res/img/sigam_yacimientos/dp3124.html

Reported mineral resources in the belt

Resources	11.6 Mt Cu (total)
Source	Zappettini and Gozalvez 2021

Potential resources in the belt (Zappettini and Gozalvez 2021)
Area 24,050 km²
Resources 28.6 Mt Cu; 1,010 kt Mo; 1,302 t Au; 11.2 kt Ag
P_{50} porphyry copper yet to be discovered 6

Mining projects (Cu) in the belt

MARA (prefeasibility)
Resources 6.1 Mt Cu; 7.8 Moz Au (measured and indicated)
https://proyectomara.com.ar

Cerro Atajo (initial exploration)
https://camyen.catamarca.gob.ar/mineria-2/

6. STRUCTURAL AND GEODYNAMIC CONTROLS

The location of porphyry copper type deposits in the Andean region is not random, but rather responds to structural controls at various scales. The interaction between first-order structures related to subduction and pre-existing cortical structures exerts a fundamental control on the emplacement, ascent, and grouping of deposits.

6.1. REGIONAL TECTONIC SETTING AND METALLOGENESIS

Periods of highest metallogenic productivity, such as the Middle and Upper Miocene, coincide with specific tectonic events such as slab shallowing and the resulting cortical thickening (Rubinstein *et al.*, 2021). These events favor:

- The generation of adakitic magmas (high Sr/Y ratios) through the MASH (Melting, Assimilation, Storage, and Homogenization) process at the crust-mantle interface.
- Compression that generates structures favorable for stock emplacement.
- The possibility of reactivation of ancient crustal weaknesses.

6.2. TRANSVERSE LINEAMENTS (ESE-WNW)

The structures transverse to the Andean arc (direction ~ESE-WNW) are of paramount importance and act as structural guides on a cortical scale. Many of these are deep faults of pre-Andean origin (Lípez, Calama-Olacapato-Toro, Socompa, Archibarca, Culampajá, Ojos del Salado, Calingasta-Uspallata, Bermejo Fault, Tucumán Transfer Zone) that have been reactivated during the Cenozoic. These cortical discontinuities act as highly permeable conduits that facilitate the rapid ascent of water-saturated magmas from the MASH zone to subvolcanic emplacement levels, preventing their stagnation and intermediate fractionation (Yanez *et al.*, 2024). World-class districts such as Taca-Taca and Bajo de La Alumbrera are structurally controlled by intersection with these megastructures (Chernicoff *et al.*, 2002; Piquer *et al.*, 2016; Farrar *et al.*, 2023; Wiemer *et al.*, 2023).

6.3. ARC STRUCTURES (N-S)

Within the magmatic arc, N-S or NNE-SSW faults associated with Andean compression control the location at the district scale (Contreras-Reyes *et al.*, 2021). These intra-arc structures, which include reverse faults and shear zones, facilitate the creation of space for the emplacement of multiphase porphyry stocks and the genesis of stockwork complexes and hydrothermal breccias. The intersection between these arc and transverse structures defines the nodes of maximum permeability, where the highest tonnage and grade deposits are located.

7. PETROLOGICAL AND GEOCHEMICAL INDICATORS

The identification of diagnostic geochemical signatures and mineralogical alteration assemblages is a powerful tool for porphyry exploration. With adequate sampling density, it allows for the identification of zoning and guides the location of the center of the mineralized system.

7.1. FERTILE MAGMAS AND PETROGENESIS

Not all magmas are capable of generating a porphyry copper deposit. Fertile magmas are characterized by being rich in volatiles (H_2O) and oxidized (high fO_2). Geochemically, they tend to have adakitic affinity signatures, with high Sr/Y and La/Yb ratios, indicating garnet stability at the source (Chiaradia 2021). Ratios such as V/Sc > 10 are also reliable indicators of a high redox state of the magma, favorable for copper concentration in exsolved hydrothermal fluids.

7.2. GEOCHRONOLOGY, ISOTOPIC GEOCHEMISTRY, AND FLUID INCLUSION MICROTHERMOMETRY

Understanding of the metallogenic processes of copper porphyries in Argentina has advanced significantly thanks to the application of geochronological, isotopic, and fluid inclusion studies. These analyses make it possible to narrow down the age of magmatic and hydrothermal events, identify the sources of metals and fluids, and characterize the physicochemical conditions during mineralization.

High-resolution geochronology of porphyries in Argentina reveals a temporal distribution that coincides with the main Andean magmatic pulses (Rubinstein *et al.*, 2021). In the Bajo de la Alumbrera district (Sierras Pampeanas), U-Pb ages in zircons from fertile intrusions yield values of ~8.2-7.0 million years (Late Miocene), while the age of mineralization, determined by the Re-Os method in molybdenite, is around ~7.0 million years (Proffett 2003, Buret *et al.* 2016 and 2017). This close temporal relationship between the cooling of the intrusive and the main mineralizing episode is characteristic of porphyry systems. In the Taca Taca project (Puna), the associated intrusions have U-Pb ages between ~39 and 36 million years (Eocene) and Re-Os ages in molybdenite of ~36 million years, indicating a strictly coeval system (Ince *et al.*, 2025). For its part, the San Jorge porphyry (Frontal Cordillera) represents an older episode, with U-Pb ages in zircons of ~290-283 million years (Early Permian) and Ar -Ar ages in hydrothermal biotite of ~286-280 million years (Sillitoe 1977), confirming its genetic affinity with the Choiyoi Magmatic Cycle. These data reinforce the model in which porphyry mineralization occurs shortly after the emplacement of porphyry stocks, within a geologically brief time frame.

Isotopic studies provide key information on the source distribution of magmas and metals. At Bajo de la Alumbrera and Agua Rica, the Sr and Nd isotopic compositions of intrusive rocks indicate a significant contribution from the lower crust. Negative initial εNd values and relatively high initial $^{87}Sr/^{86}Sr$ ratios suggest significant assimilation of mature crust by magmas originating in an enriched mantle in a subduction setting. This supports the MASH (Melting, Assimilation, Storage, and Homogenization) model at the base of the crust as the process generating adakitic or high Sr/Y ratio magmas in the Central Andes (Hildreth and Moorbath 1988).

Sulfur isotopes ($\delta^{34}S$) in sulfides from deposits such as Bajo de la Alumbrera have values close to 0‰ (in a range of -3 to +3‰), which is consistent with a mantle magmatic source for sulfur, with no significant evidence of sedimentary sulfur contribution. On the other hand, studies of oxygen and hydrogen isotopes in fluid inclusions and alteration minerals at San Jorge have determined that the early mineralizing fluids are predominantly magmatic in origin, with $\delta^{18}O$ values of water between +6.5 and +9.5‰ (Garrido *et al.*, 2010). In the late stages of some systems, a minor mixture with meteoric water can be detected, which modifies these signatures.

Microthermometry of fluid inclusions trapped in hydrothermal quartz allows to reconstruct the nature and evolution of the fluids that transported and deposited the metals. In Argentine porphyries (Rubinstein *et al.*, 2021), such as those in the Miocene belt of the Cordillera Frontal (*e. g.*, El Pachón, Los Azules), several types of fluid inclusions are commonly identified that record the evolution of the system:

- Silicate fusion inclusions: These represent trapped magma droplets and are direct evidence of fluid saturation and the partitioning of elements between the silicate melt and the aqueous phase.
- High-salinity fluid inclusions with halite: These are characteristic of the potassic alteration and main mineralization stage. These inclusions, which often contain one or more halite (NaCl) crystals as daughter minerals, record very high salinities (>40% NaCl eq. by weight) and homogenization temperatures that usually exceed 400-500°C. The presence of accidental or captive minerals (chalcopyrite, hematite) evidences their high capacity to transport metals in chloride complexes.
- Low to medium salinity fluid inclusions (vapor and liquid): Associated with phyllic (sericitic) overprinting. Vapor-type inclusions (low density) and low-salinity aqueous inclusions (<10% NaCl eq. by weight) suggest phase separation (boiling) of the fluid, a crucial mechanism for the destabilization of copper-bearing chlorine complexes and the subsequent precipitation of chalcopyrite due to increased pH and loss of H_2S.
- CO_2 inclusions: Present in several districts, they indicate an early volatile phase that affects the saturation depth of the magma.

In the San Jorge porphyry, fluid inclusion studies have identified the presence of high-salinity, high-temperature fluids, as well as evidence of boiling (Garrido *et al.*, 2010), reinforcing the model of a magmatic-hydrothermal system typical of copper porphyry. Fluid inclusion data from Agua Rica show a complex evolution, where telescoping allowed events of lower temperature and salinity, associated with the overprinting of a high-sulfidation system, to enrich the porphyry core.

Together, these tools define that Argentine porphyries derive from deep magmatic reservoirs with strong cortical interaction, where the exsolution of hypersaline fluids and their subsequent thermodynamic destabilization (by boiling or mixing) were the fundamental controls for the genesis of these metallic anomalies.

8. LAND USE RESTRICTIONS

The assessment of metallogenic potential must be carried out within the framework of sustainable development, taking into account legal and environmental restrictions. The geospatial intersection of metallogenic porphyry copper belts with layers of Protected Areas and the National Glacier Inventory (ING) is a critical input for territorial planning and investment risk analysis. This integration of information allows decision-makers, companies, and civil society to identify early on the restrictions imposed by land use planning on the use of land, balancing economic development with the preservation of natural heritage and compliance with current legislation.

With regard to protected areas, in National Parks, National Reserves, and Protected Natural Areas under national jurisdiction, National Law No. 22,351 (Article 10) strictly prohibits prospecting, exploration, and mining, with the exception of duly authorized aggregates for internal infrastructure.

There is no direct prohibition in protected areas under provincial jurisdiction, although each province sets environmental and protection standards that must be met, and mining companies are therefore required to include this item in their Environmental Impact Report (IIA by its initials in spanish). The provincial authority issues a ruling called an Environmental Impact Statement (DIA by its initials in spanish) in which it approves or rejects the IIA report.

The information layer from the National Glacier Inventory included in the map corresponds to National Law No. 26,639 (Basic Requirements Regime for the Preservation of Glaciers), which in Article 6, paragraph c, prohibits mining activity in glacial landforms. It is imperative to note that this restriction extends to the periglacial environment, technically defined as the area with frozen soils (permafrost) that acts as a water regulator, which represents a **highly complex technical and legal challenge** for high-mountain porphyry projects.

The analysis of the potential of copper porphyry belts, through the identification of metallogenic controls (structural, magmatic, and lithostratigraphic), deposit associations, and hydrothermal alteration signatures, must be complemented by mapping land use restrictions to determine the actual feasibility of exploration targets.

9. CONCLUSIONS AND PERSPECTIVES

This analysis of the porphyry copper metallogenic belts in Argentina, based on the integration of geological, structural, geochemical, and land use planning information, provides an overview of the country's copper resources and prospects. The conclusions confirm significant potential and establish guidelines for greenfield and brownfield exploration, highlighting the usefulness of the resulting cartography as a geospatial intelligence platform for decision-making and land management.

10. SUMMARY AND GUIDELINES

10.1. COPPER RESOURCES SUMMARY

Argentina's copper resources are predominantly concentrated in copper porphyries, which account for more than 98% of total metal resources. The distribution of these resources is not homogeneous over time, but rather concentrated in specific metallogenic episodes. Although eleven belts are analyzed, the Miocene-Pliocene magmatic-hydrothermal events have generated the largest metal accumulations per kilometer of arc, notably the Bajo de la Alumbrera district and the world-class clusters of the Cordillera Frontal (El Pachón, Los Azules). The Eocene-Oligocene also represents a notable episode, with large-tonnage deposits such as Taca Taca and Josemaría.

10.2. STRATEGIC EXPLORATION GUIDELINES

The potential for undiscovered resources in Argentina exceeds known resources by a ratio of 3:1. Exploration strategies should prioritize:

- Deep and undercover exploration: The search for “blind” or under covered porphyries in the most promising belts, such as the Upper Miocene in the Frontal and Main Cordillera, the Oligocene in Puna and Frontal Cordillera, and the Miocene-Pliocene in the Sierras Pampeanas.
- Evaluation of underexplored belts: Belts such as the Miocene-Pliocene in Cordillera Principal and the Triassic-Jurassic in Patagonia have fewer discoveries but a permissive geological setting, requiring new conceptual models and

exploration efforts to identify favorable erosion windows.
- Comprehensive district analysis: The use of tools such as spectral alteration maps, geophysics, and mineral system modeling to guide the location of fertile porphyries in large known districts.

10.3. PURPOSE OF THE MAP

It is expected that this map of metallogenic belts, together with its layers of critical information, will transcend cartographic representation to become an analytical tool that provides a solid scientific basis for:

Future exploration focus: By defining prospective areas through the superimposition of favorability criteria.

Long-term land use planning: Integrating mining prospectivity with the cadastre of environmental and cryospheric restrictions.

Mitigation of geological-economic risk: By providing a scientific basis that reduces uncertainty in the early stages of the mining life cycle.

Applied geoscientific research: Synthesizing the tectonic-magmatic evolution of the Andes to guide the next generation of discoveries.

11. ACKNOWLEDGMENTS

The authors would like to thank Eduardo Zappettini and Julio Ríos Gómez for their valuable comments and suggestions, which helped improve the manuscript and validate its content.

12. REFERENCES

Buret, Y., von Quadt, A., Heinrich, C., Selby, D., Wälle, M., & Peytcheva, I. 2016. From a long-lived upper-crustal magma chamber to rapid porphyry copper emplacement: Reading the geochemistry of zircon crystals at Bajo de la Alumbrera (NW Argentina). Earth and Planetary Science Letters, 450, 120-131.

Buret, Y., Wotzlaw, J. F., Roozen, S., Guillong, M., von Quadt, A., & Heinrich, C. A. 2017. Zircon petrochronological evidence for a plutonic-volcanic connection in porphyry copper deposits. Geology, 45(7), 623-626.

Bruna Novillo, Julio M. 2018. Geología y Génesis del Pórfido de Au-Cu de Bajo El Durazno, Provincia de Catamarca, República Argentina. Tesis Doctoral. Facultad de Tecnología y Ciencias Aplicadas, Dpto. Geología, UNCA. Co-directores: Márquez Zavalía, María Florencia; Heinrich, Christoph A. pp 1-257. https://riaa-tecno.unca.edu.ar/handle/123456789/673.

Camus, F. 2002. The Andean porphyry systems. Giant Ore Deposits: Characterisitics, genesis and exploration; in Porter T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective, PGC Publishing, Adelaide, v. 1, pp 45-63.

Cardó, R., Godeas, M. C., Márquez, M. J., Ramallo, E. E., & Zanettini, J. C. M. 2015. Las Fajas Metalogenéticas Cupríferas de la República Argentina. https://repositorio.segemar.gov.ar/handle/308849217/2841

Chernicoff, C. J., Richards, J. P., & Zappettini, E. O. 2002. Crustal lineament control on magmatism and mineralization in northwestern Argentina: geological, geophysical, and remote sensing evidence. Ore Geology Reviews, 21(3-4), 127-155.

Chiaradia, M., 2021. Magmatic Controls on Metal Endowments of Porphyry Cu-Au Deposits. In: Tectonomagmatic Influences on Metallogeny and Hydrothermal Ore Deposits: A Tribute to Jeremy P. Richards (Volume I). Sholeh, A. & Wang, R. (Ed.). Society of Economic Geologists, 1–16. doi: 10.5382/SP.24.01

Contreras-Reyes E., Díaz D., Bello-González J.P., Slezak K., Potin B., Comte D., Maksymowicz A., Ruiz J.A., Osses A. and Ruiz S., 2021. Subduction zone fluids and arc magmas conducted by lithospheric deformed regions beneath the central Andes. Scientific Reports 11:23078. https://doi.org/10.1038/s41598-021-02430-9

Cunningham, C.G., Zappettini, E.O., Vivallo S., Waldo, Celada, C.M., Quispe, Jorge, Singer, D.A., Briskey, J.A, Sutphin, D.M., Gajardo M., Mariano, Diaz, Alejandro, Portigliati, Carlos, Berger, V.I., Carrasco, Rodrigo, and Schulz, K.J. 2008, Quantitative mineral resource assessment of copper, molybdenum, gold, and silver in undiscovered porphyry copper deposits in the Andes Mountains of South America: U.S. Geological Survey Open-File Report 2008-1253, 282 p. Available on CD-ROM and online at https://pubs.usgs.gov/of/2008/1253/.

Farrar, A. D., Cooke, D. R., Hronsky, J. M. A., Wood, D. G., Benavides, S., Cracknell, M. J., Banyard, J. F., Gigola, S., Ireland, T., Jones, S. M., and Piquer, J. 2023. A Model for the lithospheric architecture of the Central Andes and the localization of giant porphyry copper deposit clusters, Economic Geology, 118, 1235–1259. https://doi.org/10.5382/econgeo.5010, 2023.

Garrido M.M., Gómez M.C., Fernández M.L., Lambrecht S. 2010. Brecha de Turmalina del pórfido de Cu-Au San Jorge, Mendoza: alteración, mineralización y origen de los fluidos. Rev. Asoc. Geol. Argentina 67 (1), 47-57.

Gustafson, L. B., & Hunt, J. P. 1975. The porphyry copper deposit at El Salvador, Chile. Economic geology, 70(5), 857-912.Hammarstrom, J. M. (2022). Porphyry copper: Revisiting mineral resource assessment predictions for the Andes. Minerals, 12(7), 856.

Hildreth, W., & Moorbath, S. 1988. Crustal contributions to arc magmatism in the Andes of central Chile. Contributions to Mineralogy and Petrology, 98(4), 455–489. https://doi.org/10.1007/bf00372365

Ince, M. A., Hagemann, S. G., Rubinstein, N. A., Fiorentini, M. L., Kemp, A. I., Fisher, C. M., ... & Gigola, S. 2025. Insights Into the Magma Source and Evolution of the Taca Taca Bajo Porphyry Deposit: Implications for the Metallogeny and Cu Fertility of the Central Andean Retro Arc. Economic Geology, 120(4), 819-845.

Johanis, P. E., Larcher, N., Varas, R., Rodríguez, D., Carrizo, N., Cecenarro, F. J., Hernando, I., Ferpozzi, F., García, C., Turra, J.M. 2023. Base de datos de yacimientos de la República Argentina. Informe anual 2023. 80 pp. Buenos Aires, Servicio Geológico Minero Argentino. Instituto de Geología y Recursos Minerales. https://repositorio.segemar.gov.ar/handle/308849217/4373

Kirkham, R.V. 1971. Intermineral Intrusions and Their Bearing on the Origin of Porphyry Copper and Molybdenum Deposits. Economic Geology and the Bulletin of the Society of Economic Geologists (December 1971) 66 (8): 1244-1249.

Koukharsky, M., M.C. Godeas y N. Pezutti (1999). Las áreas de alteración hidrotermal en Argentina. En. Recursos Minerales de la República Argentina (Ed. E.O. Zappettini), Instituto de Geología y Recursos Minerales SEGEMAR, Anales 35: 107-147, Buenos Aires.

Kouzmanov, K., & Pokrovski, G.S. 2012. Hydrothermal Controls on Metal Distribution in Porphyry Cu (-Mo-Au) Systems.

Lizuain Fuentes, A. y Panza, José L. A. 2018. Mapa Geológico del Sector Continental e Insular Americano de la República Argentina - Mapa Geológico del Sector Antártico Argentino. Buenos Aires, Servicio Geológico Minero Argentino. Instituto de Geología y Recursos Minerales https://repositorio.segemar.gov.ar/handle/308849217/3184

Marcos, O. R., 1978. Area de Reserva N°1. Perforación N°19 Zona La Mejicana. Plan La Rioja. 22p. Buenos Aires, Ministerio de Industria y Minería. https://repositorio.segemar.gov.ar/handle/308849217/3214

Márquez, M., Ramallo, E. y Zanettini, J. C. 2015. Las Fajas Metalogenéticas Cupríferas de la República Argentina. Anales N° LIII. 158pp. Buenos Aires

McCuaig, T. C., & Hronsky, J. M. 2014. The mineral system concept: the key to exploration targeting.

Muñoz, M., Charrier, R., Fanning, C. M., Maksaev, V., & Deckart, K. 2012. Zircon trace element and O–Hf isotope analyses of mineralized intrusions from El Teniente ore deposit, Chilean Andes: constraints on the source and magmatic evolution of porphyry Cu–Mo related magmas. Journal of Petrology, 53(6), 1091-1122.

Piquer, J., Yáñez, G., Rivera, O., and Cooke, D. R. 2019. Longlived damage zones associated with fault intersections in the Andes of Central Chile, Andean Geol., 46, 223–239. https://doi.org/10.5027/andgeoV46n2-3106.

Proffett, J. M. 2003. Geology of the Bajo de la Alumbrera porphyry copper-gold deposit, Argentina. Economic Geology, 98(8), 1535-1574.

Rubinstein, N.A., Zappettini, E.O., Gómez, A.L.R. (2021). Porphyry CU deposits in the Central Andes of Argentina: An overview. Journal of South American Earth Sciences, Volume 112, Part 1. https://doi.org/10.1016/j.jsames.2021.103543.

Schulz K.J., Briskey J.A. 2003. The Global Mineral Resource Assessment Project. U.S. Geological Survey Fact Sheet 053-03, http://pubs. usgs. gov/fs/fs053-03

Secretaría de Minería de la Nación 2025. Recursos y Reservas minerales en Argentina. Análisis septiembre 2025. https://www.argentina.gob.ar/sites/default/files/recursos_y_reservas_minerales_en_argentina_sep_2025_0.pdf

Seedorf, E., Dilles, J., Proffett, J., Einaudi, M., Zurcher, L., Stavast, W., Johnson, D., & Barton, M. 2005. Porphyry Deposits: Characteristics and Origin of Hypogene Features. In: Hedenquist, J., Thompson, J., Goldfarb, R., & Richards, J. P. (Eds.) Economic Geology 100th Anniversary Volume. Society of Economic Geologists, 251–299.

SIGAM. Depósitos metalíferos 250k 2025. Catálogo de datos abiertos geoespaciales. SEGEMAR. https://sigam.segemar.gov.ar/geoserver217/wfs?request=GetFeature&request=GetFeature&service=WFS&typename=sigam:e250K.DepositMetalif&outputFormat=CSV&version=1.0.0

Sillitoe, R.H. 1977. Permo-Carboniferous, Upper Cretaceous, and Miocene porphyry-copper-type mineralization in the Argentinian Andes. Economic Geology v.72 pp 99-103.

Sillitoe, R.H. (1994). Erosion and collapse of volcanoes: Causes of telescoping in intrusion-centered ore deposits. Geology, 22(10), 945-948.

Sillitoe, R. H. 2010. Porphyry copper systems. Economic Geology, 105(1): 3-41.

Sillitoe, R. H., & Perelló, J. 2024. Porphyry copper recurrence in the Andes of Chile and Argentina. Economic Geology, 119(5), 995-1003.

Sinclair, W.D. 2007 Porphyry Deposits. In: Goodfellow, W.D., Ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, The Evolution of Geological Provinces, and Exploration Methods, Geological Association of Canada, 223-243.

Villela, D., & Cantallopts, J. 2016. Franjas metalogénicas de los Andes Centrales: blancos clave para la exploración minera. Informe Comisión Chilena Cobre (Chile). Dirección de Estudios y políticas públicas.

Wiemer D, Hagemann SG, Hayward N, Begg GC, Hronsky J, Thébaud N, Kemp AIS and Villanes C 2023, Cryptic trans-lithospheric fault systems at the western margin of South America: implications for the formation and localization of gold-rich deposit superclusters. Frontier Earth Science 11:1159430. doi: 10.3389/feart.2023.1159430

Yanez G.C., Piquer J.R. and Rivera O.H. 2024. On the role of trans-lithospheric faults in the long-term seismotectonic segmentation of active margins: a case study in the Andes. Solid Earth, 15, 1319–1342. https://doi.org/10.5194/se-15-1319-2024

Zappettini, E. O.; Segal, S. J.; Godeas, M. C.; Brodtkorb, M. K. de y Schalamuk, I. A. 1999. Recursos Minerales de la República Argentina. Anales;XXXV. Buenos Aires, Subsecretaría de Minería de la Nación. Servicio Geológico Minero Argentino. Instituto de Geología y Recursos Minerales. https://repositorio.segemar.gov.ar/handle/308849217/2746

Zappettini, E. O.; Gozalvez, M. R. 2021. Potencial en recursos minerales del territorio continental de la República Argentina. (Cu, Mo, Pb, Zn, Au, Ag, Li, K, B). Serie Contribuciones Técnicas. Recursos Minerales N°47, 101 p. Buenos Aires, Servicio Geológico Minero Argentino. Instituto de Geología y Recursos Minerales.