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Introduction to Journal of South American Earth Sciences special issue on
“Magmatism of southernmost South America”

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1. Foreword

The southernmost region of South America has an extremely rich and complex magmatic history due to the occurrence of multiple large-scale geological processes that include mantle plumes impingements, slab windows opening, collisional episodes, normal and flat subduction events, mantle transition zone-derived melts ascent, slab break-off events, etc. (e.g., Mpodozis and Kay, 1992; Gorrington et al., 1997; Riley et al., 2001; Pankhurst et al., 2006; Kay et al., 2007; Ramos, 2008; Breitsprecher and Thorkerlson, 2009; Aragón et al., 2013; Gianni et al., 2018; Navarrete et al., 2019; 2020; Iannelli et al., 2020). Although this magmatic history began during the Neoproterozoic, the igneous activity of the last 300 Myr has been remarkably intense and voluminous, constituting one of the most distinctive geological features of this region. So much so that three Phanerozoic Large Igneous Provinces (LIPs) have been proposed (Kay et al., 1989; Pankhurst et al., 1998; Kay et al., 2007; Bastías-Mercado et al. 2020 – this special issue). The first of them linked to the Permian-Triassic

subduction events (Choiyoi SLIP - Bastías-Mercado et al. this especial issue, and references therein; Oliveros et al., 2019), although there are also proposals that have suggested an origin related to slab-breakoff episodes (e.g., Mpodozis and Kay, 1992; Pankhurst et al., 2006). The second would have been generated by the Jurassic Karoo mantle plume impingement added to the paleo-pacific subduction during the beginning of the Gondwana breakup (Chon Aike SLIP - e.g., Kay et al., 1989; Pankhurst et al., 1998), whereas the origin of the Oligocene-Miocene third province (Somuncura LIP – Kay et al., 2007) is still under discussion. There are proposals that invoke a mantle plume impingement (Kay et al., 2007), a lithospheric delamination event (Remesal et al., 2012), as well as the mantle transition zone-derived melts ascent due to the Farallon slab stagnation (Navarrete et al., 2020), between others. In this special issue, most of the articles are linked to these Permian-Triassic, Jurassic and mid-Cenozoic LIPs (Fig. 1), although multiple subduction-related magmatic events are also included, such as the formation of the Patagonian Batholith (e.g., Pankhurst et al., 1999) and the eruption of the volcanic products linked to the magmatism of the Andean subduction zone (e.g., Rapela et al., 1984; 1988).

From the economic point of view, the socio-economic development of Chile and Argentina was marked by the magmatism of the southernmost South American region. In this sense, the Jurassic magmatism of Patagonia gave rise to numerous precious metals hydro-thermal large mineral deposits (e.g., Schalamuk et al., 1997; Echavarría et al., 2005; Guido and Campbell, 2011; Permuy Vidal et al., 2016; Tassara et al., 2017), whereas the Cenozoic intraplate magmatism of Patagonia favored the hydrocarbon maturation in Patagonian oil and gas producing Mesozoic basins (e.g., Rodriguez and Littke, 2001; Spacapan et al., 2018). Also, giant porphyry copper deposits were

produced by the Meso-Cenozoic subduction-related magmatism in the Andean region (e.g., Mpodozis and Cornejo, 2012; Lee and Tang, 2020).

Therefore, new contributions that improve the comprehension of the large magmatic episodes of southernmost South America are highly relevant for the general geological knowledge of this region, and their interest exceeds that of the academic geological community.

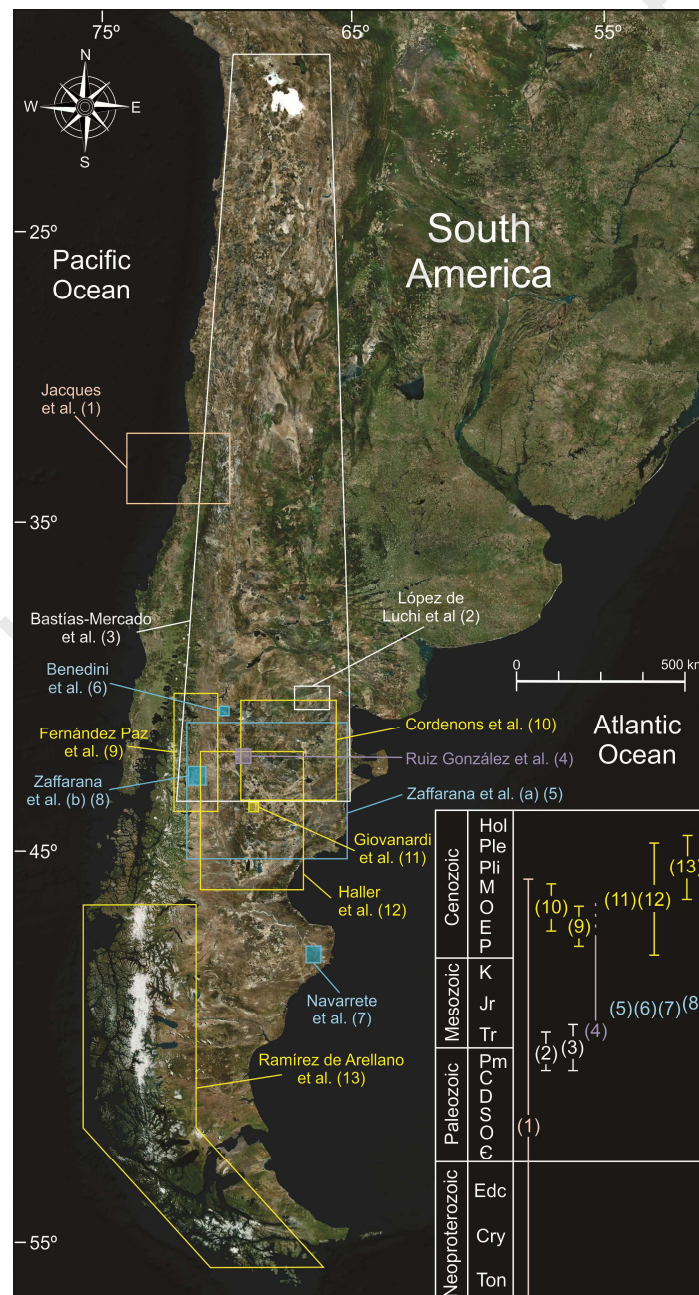


Figure 1. Locations of the studied areas of the articles included in this special issue. The filled and unfilled areas correspond to local and regional articles, respectively.

2. Content of the volume

The articles of this special issue cover several aspects of the above cited magmatic records of southern South America. Some articles have a regional scope and review the magmatic products occurring at certain time windows, together with providing new data (Jacques et al., Bastias-Mercado et al., Zaffarana et al. (a), Cordenons et al., Fernández Paz et al., Haller et al., Ramírez de Arellano et al., this volume), whereas other articles have a more local scope and are related to specific issues of the tectonic and magmatic evolution of the studied areas (López de Luchi et al., Ruiz González et al., Benedini et al., Zaffarana et al. (b), Navarrete et al., Giovanardi et al., this volume). These regional and local scopes are also highlighted in Fig. 1. In the following paragraphs, the articles are briefly described. The descriptions of the articles are ordered following the stratigraphic sequence of the units involved in each of them.

The paper from *Jacques et al.* titled “Sr-Nd-Pb-Hf-O Isotopic Constraints on the Neoproterozoic to Miocene Upper and Mid Crust in central Chile and western Argentina and Trench Sediments (33°-35°S)” characterizes the mid to upper crustal lithologies of the Andean basement in central Chile and western Argentina through the acquisition of a complete dataset of new trace element and Sr-Nd-Hf-Pb-O isotope data. The studied rocks are of Neoproterozoic to Phanerozoic age. This paper also studies the isotopic signature of trench sediment data which are being subducted offshore the northern segment of the Southern Volcanic Zone in Chile (33°-33.3° S). The comprehensive study of magma sources constrains the geochemical composition of the Chilenia terrane. The authors concluded that the samples from the Guargaráz Complex

in Argentina represent part of the collisional zone between the Chilenia and Cuyania microcontinents. The rocks of the Guarguaraz Complex in Argentina are restricted to a narrow range of Sr, Nd, Hf and O isotopic compositions suggesting that the Chilenia block basement would have a Mesoproterozoic crustal residence time. The authors found two geochemical endmembers in the pre-Andean Chilenia terrane: (1) a component with unradiogenic Pb isotopes, similar to the Proterozoic Cuyania basement, and (2) a more radiogenic Pb component similar to metasedimentary and igneous rocks in Chile (represented by the Coastal Batholith and the Choiyoi province). In turn, Sr-Nd-O data from trench sediments suggest a relatively homogeneous material input along the Southern Volcanic Zone, even though there are subtle differences in REE and Pb isotopic compositions attributed to different source materials. However, based on Nd-Hf isotopes, trench sediments from offshore Chile are distinct from sediments from offshore Peru, reflecting input material differences. Positive ϵ_{Nd} and ϵ_{Hf} values suggest derivation from mafic protholiths such as the present volcanic arc in the Northern Southern Volcanic Zone (NSVZ).

The paper from *López de Luchi et al.* titled “The Permian to early Triassic granitoids of the Nahuel Niyeu – Yaminué area, northern Patagonia: igneous stratigraphy, geochemistry and emplacement conditions” presents a multidisciplinary study of the late Paleozoic – early Mesozoic magmatism in northeastern North Patagonian Massif (Fig. 1). This magmatism was separated into the Early Permian Granitoids (EPG - >270 Ma) and the Late Permian-Early Triassic Granitoids (LPETG - 260-245 Ma), which present geochemical and isotopic major differences between them. The EPG display typical mantle-derived geochemical and isotopic features, whereas the LPETG show crustal-derived characteristics. Therefore, a major change in the magmatic source from

rather more primitive to a reworked crustal source is envisaged at ca. 260 Ma. Likewise, the emplacement conditions (pressure) and the deformational history is also addressed by this article, which indicates the existence of a contractional ductile deformation event between 261 and 250 Ma possibly related to a flat subduction event.

The article by *Bastías-Mercado et al.* titled “Volumetric and compositional estimation of the Choiyoi Magmatic Province and its comparison with other Silicic Large Igneous Provinces” provides an exhaustive review about the Permian-Triassic magmatism of the Andes, La Pampa Permian-Triassic Magmatic Corridor (CMPT-LP) and North Patagonia (Fig. 1). According to the compilation made by the authors, the Choiyoi Magmatic Province was built by ~39 Myr (286-247 Ma) of igneous activity, covering an area of about 909,250 km² and reaching an estimated volume of 947,553 km³, which allows it to be classified as a Silicic Large Igneous Province (SLIP). The volcanic products of this SLIP are composed of 51% rhyolite, 26% dacite, 22% andesite and 1% basalts, whereas the plutonic rocks are dominated by granites (~65%) and granodiorites (~30%), although the early stages were dominated by andesites, granodiorites, tonalites and diorites.

The paper from *Ruiz González et al.* titled “Paleomagnetic evidence of the brittle deformation of the Central Patagonian Batholith at Gastre area (Chubut Province, Argentina)” is about post emplacement deformation of the Central Patagonian Batholith, a set of Late Triassic granitoids emplaced in the Gastre area in Central Patagonia (Fig. 1). This post-emplacement deformation was characterized by paleomagnetism, a method which is useful to detect the presence of tectonic rotations on vertical axes. The authors obtained a paleomagnetic pole for the magmatic and solid-

state deformed rocks which comprise the Central Patagonian Batholith; a pole that does not coincide with the other Late Triassic poles of stable South America. However, if the tectonic block containing the granites is tilted $\sim 11^\circ$ towards the NE, then the paleomagnetic pole of the Late Triassic granites of the Central Patagonian Batholith coincides with the other paleomagnetic poles of coeval rocks which form part of the Apparent Polar Wander Path. The tilting was probably aided by the NW-SE subvertical structures that affect the area and which form part of the Gastre Fault System. The paleomagnetic results of this work suggest that the magmatic and solid-state deformation of the Late Triassic granites from Gastre was constrained to its emplacement in Late Triassic times, whereas the tilting occurred later during the Andean Orogeny.

The paper from *Zaffarana et al. (a)* titled “Petrogenetic study of the Lonco Trapial volcanism and its comparison with the Early-Middle Jurassic magmatic units from northern Patagonia” comprises new whole rock geochemical, isotopic and geochronological data from the Early Jurassic Lonco Trapial Formation in Central Patagonia (Fig. 1). The article also establishes a comparison between coeval units from the eastern and western domains of northern Patagonia, given by, respectively, the Marifil Complex and the Lago La Plata/Ibañez formations. These units form part of the Chon Aike large igneous province developed in western Gondwana during its breakup stage. The comparative study shows that all Early-Middle Jurassic igneous rocks from this area have mixed characteristics between slab-derived subduction-related settings and intraplate magmas. A mixed source between crustal and mantle magmas is envisaged for Lonco Trapial volcanic rocks. The relationship between the intermediate and felsic rocks of Lonco Trapial Formation is explained by the ascent to shallow crustal levels

with subsequent low-pressure differentiation followed by assimilation. The authors explain the arc signature of Lonco Trapial magmas as resulting from decompression melting of mantle enriched by previous subduction events.

The article of *Benedini et al.* titled “Lower Jurassic felsic diatreme volcanism recognized in central Patagonia as evidence of along-strike rift segmentation” provides a detailed study of the Jurassic volcanic and sedimentary rocks at western North Patagonian Massif (Fig. 1). The stratigraphic data of this work allow proposing the existence of two felsic diatreme volcanic edifices developed in an asymmetrical basin related to an E-W regional transfer fault system developed in continuity to a major strike-slip structure. Also, a new geochronological data was obtained (188 ± 3 Ma), reinforcing the stratigraphic correlation of the studied rocks with the Garamilla and Lonco Trapial formations.

The paper of *Navarrete et al.* titled “An early Jurassic graben caldera of the Chon Aike Silicic LIP at the southernmost massif of the world: The Deseado caldera, Patagonia, Argentina” focused on an eastern area of the Deseado Massif (Fig. 1), where the authors carried out an exhaustive study on the Jurassic volcanic rocks of the Bahía Laura Volcanic Complex. From their analyses on lavic, volcanoclastic and sedimentary lithofacies, added to structural study and a U/Pb geochronological data, the authors were able to identify the a large NW-rhyolitic fissure-type caldera (graben caldera), which would have registered two extensional piecemeal-type collapses during the early Jurassic ($>178.7\pm 1.9$ Ma), in correspondence with the extensional tectonic regime that affected the southwestern Gondwana. During both collapse events, sustained low pyroclastic fountaining (boil over) explosive eruptions were generated through multiple

fissure conduits, which would have given rise to a large volume of moderate-to extremely high-grade pyroclastic facies. Sedimentary rocks deposited in lagoons, lahars and alluvial fans mark the two post-collapse periods.

The paper from *Zaffarana et al. (b)* titled “Magmatic and tectonic fabrics in the Upper Jurassic La Hoya Pluton, North Patagonian Batholith (~43°S. Fig. 1) as a record of the early stages of the Andean deformation” is based on the structural study of the La Hoya Pluton, a shallow intrusive body located in the Esquel Range in the North Patagonian Andes. The anisotropy of magnetic susceptibility (AMS) and microstructural study of the pluton has shown that the original subhorizontal magmatic fabrics were overprinted by subvertical solid-state deformation fabrics. The original magmatic fabrics were interpreted as emplacement ones, which were acquired during the Late Jurassic. The compressive deformation of the La Hoya Pluton was temporally constrained by the 42.15 ± 0.40 Ma ^{40}Ar - ^{39}Ar age in plagioclase of the basaltic dikes intruding the pluton. These dikes are devoid of tectonic deformation, and their geochemical features suggest that they are transitional temporally and geochemically between the Pilcaniyeu (~57.8-42 Ma) and the El Maitén (~37-19 Ma) belts. The fact that the dated plagioclase may contain excess argon suggests that these dikes would represent the early stages of the El Maitén Belt in the Esquel area.

The paper of *Fernández Paz et al.* titled “The late Eocene–early Miocene El Maitén Belt evolution: magmatic response to the changing subduction zone geodynamics” provides new field and isotopic data of this Cenozoic magmatic belt of northwestern Patagonia (Fig. 1), that together with lithological, geochronological and geochemical data compilations, suggest significant changes in the nature and location of magmatic

sources. The evolution of the El Maitén belt could be summarized in three stages: i) incipient arc magmatism, with a tholeiitic basaltic-basaltic andesitic composition and scarce contributions of the subducted slab components; ii) mature arc, characterized by calc-alkaline andesitic-dacitic associations with important fluid, sediment and crustal intake in the magma source; iii) late Oligocene-early Miocene juvenile, tholeiitic basaltic volcanism interbedded with marine deposits, interpreted as the result of a westward arc migration and the development of an extensional tectonic regime in the back-arc. Finally, the authors evaluate the slab dynamics within a petrological framework that can reproduce the geochemical-geochronological characteristics of this belt.

The paper from *Cordenons et al.* titled “Temporal and spatial evolution of the Somún Curá Magmatic Province, Northern Extra-Andean Patagonia, Argentina” is a review paper about the broad basaltic plateau covering the North Patagonian Massif (Fig. 1) in a back-arc to intraplate environment. The paper compiles updated geochronological data and provides new stratigraphic information. The authors, therefore, identify seven discrete periods of volcanic emissions between late Eocene and late Miocene times (~38-37 Ma, ~32.5-31 Ma, ~29.5-28 Ma, ~26-24 Ma, ~21-18.5, ~18-15 Ma and ~10.5 Ma), together with four pulses of effusion of flood basalts, represented by the Somún Curá Formation (~32 Ma, ~27-26 Ma, ~26-25 Ma, and ~21.5 Ma). The authors revise and do not support the application of an extrusion scheme consisting of “pre-plateau”, “plateau” and “post-plateau” lavas proposed by Kay et al. (2007); instead, they propose a classification consisting of seven stages. The periods of highest magma extrusion were the late Oligocene-early Miocene, coinciding with periods of slower convergence rate which involved the relaxation of the stress fields. Their temporal and spatial analysis

also permitted to define a counter-clockwise evolution of the effusive centers of the magmatism, which started in the southwest. Pre-existing structural corridors would have controlled the extrusion of lavas. According to this paper, kinematic changes in the convergence between the South American and the oceanic plates at the time of the consumption of the Aluk plate and the break-up of the Farallon plate would have triggered magma generation.

The paper from *Giovanardi et al.* titled “Mantle heterogeneities produced by open-system melting and melt/rock reactions in Patagonian extra-Andean backarc mantle (Paso de Indios, Argentina)” deals with ultramafic mantle xenoliths carried by the Eocene basaltic intrusions from the Paso de Indios area in the Chubut Province (Fig. 1), Argentina. The authors characterize the xenoliths as harzburgites and lherzolites with subordinated pyroxenites, and their equilibrium temperatures range from 853 ± 15 °C to 1057 ± 32 °C, and pressures are within the spinel stability field. The xenoliths are the evidence of the complex magmatic history of the mantle column below the Paso de Indios area, where meter-scaled mantle heterogeneities can be inferred. Melt/rock reactions can be summarized in two pathways: 1) $\text{opx} + \text{cpx} + \text{melt}_1 \Rightarrow \text{ol} + \text{melt}_2$, and 2) $\text{opx} + \text{melt}_1 \Rightarrow \text{cpx} + \text{ol} + \text{melt}_2$. There, the last geochemical imprint corresponds to adakitic-like melts within an orthopyroxene-rich mantle column. According to the authors, these adakitic melts were probably related to the ongoing subduction system in the western South American margin.

The paper of *Haller et al.* titled “Cenozoic intraplate magmatism of central Patagonia, Argentina” provides an extensive review of the Cenozoic intraplate igneous activity of the center and south of the Chubut province (Fig. 1). In this article, the authors gathered

all available information (e.g., petrographic, geochronological, field observations) together with unpublished data, which allowed them to characterize almost all the Cenozoic igneous outcrops of this Patagonia region and establish their stratigraphic order. According to the authors, most of the studied rocks display alkaline affinities with OIB-like signatures, typical of magmas derived from garnetiferous peridotite sources, which would have originated by large-scale geological processes that include a slab window opening, lithospheric extensional periods and possibly due to the stagnation of an oceanic slab at the mantle transition depths.

The article of *Ramírez de Arellano et al.* titled “Neogene Patagonian magmatism between the rupture of the Farallon plate and the Chile ridge subduction” characterizes geochemically and groups the Neogene igneous rocks of southern Patagonia (Fig. 1). Five igneous suites were identified by the authors, which correlate with the subduction processes during and after to the approaching and subsequent subduction of a mid-ocean ridge. The Suite 1 (25-20 Ma) are typical calc-alkaline rocks of a magmatic arc, whereas the Suite 2 represent the transition between sub-alkaline to alkaline rocks during the subduction of hot oceanic lithosphere. The Suite 3 are rocks with high Sr/Y ratio, formed during the subduction of the trailing edge of the Nazca plate. Suites 2 and 3 occurred prior to the opening of the Chile ridge slab window. The Suite 4 comprises alkaline basalts produced by the decompression melting induced by the Chile ridge slab window opening and it is the only one which is not influenced by a subduction component. Finally, the Suite 5 are andesites with high Sr/Y ratio generated by the subduction of the leading edge of the Antarctic plate (Quaternary Austral Volcanic Zone), representing the reestablishment of the subduction-derived magmatism. Suites 3 and 5 would correspond to magmas with high Sr/Y produced by the passage of the

leading and trailing edges of oceanic plates prior and after the formation of the slab window. The authors suggest an origin related to melting of a heterogeneous mantle contaminated by a subduction erosion event to explain this geochemical feature.

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Dear Editor of Journal of South American Earth Sciences:

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