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Introductory paper of the 8th International Symposium on Andean Geodynamics (ISAG) special number

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The International Symposium on Andean Geodynamics (ISAG) is an international conference that was held, on average, every 3-4 years in different European cities between 1990 (Grenoble) and 2008 (Nice). These symposia usually offer an opportunity for researchers from Latin American countries and Europe as well as other countries to review the state of knowledge in geosciences on the Andes. After a long period without an edition, the 8th ISAG was organized for the first time in a Latin American country, Ecuador, from 24th to 26th September 2019. The organizing committee led by Pablo Samaniego relied heavily on the Instituto Geofísico of the Escuela Politécnica Nacional (IG-EPN) and the Institut de Recherche pour le Développement (IRD), in particular through its office in Quito, and through the Laboratoire Mixte International in France and Ecuador: "Seismes et Volcans dans les Andes du Nord" (LMI-SVAN); and the French Embassy in Ecuador. Field trips in tectonics, seismotectonics and volcanology at emblematic sites in Ecuador were organized by researchers from the IRD (Isterre and LMV), the Institut de Radio Protection Nucléaire (IRSN), IG-EPN and the University of Geneva. Four invited speakers gave presentations: Peter Molnar (University of Boulder) on the mechanisms of the Andes uplift, Suzanne Kay (Cornell University) on its magmatism, Victor Ramos (University of Buenos Aires) on the scientific approaches developed through time for the Andean orogeny and Eric Calais (Ecole Normale Supérieure de Paris) on the difficulty of dialogue between seismic risk specialists and the authorities in Haiti. The symposium also provided an opportunity for more than 250 participants to meet, with more than 80 oral presentations and over 150 posters. As a result of this conference, the Editor of the Journal of South American Earth Sciences proposed to the organizing committee to publish a special issue on the contours of these presentations. Following the peer review process, 19 papers are published in this special issue. These manuscripts reflect the various disciplinary fields, geophysics and deep imaging, tectonics, volcanism, geomorphology and seismic hazard, from the local scale to the Andes as a whole. Not surprisingly, a higher density of works is found in Ecuador and the northern Andes (Figure 1). As this collection of articles reflects the outlines of a symposium and not a specific scientific question, our aim here is not to develop a synthesis of current knowledge on the Andes. We therefore present these articles in sequence, by discipline, although this categorization may appear subjective since some articles are multidisciplinary.

Geophysics

Geophysical imagery is fundamental to constrain the current geometry of the Andean structure at depth and is still the most needed technique in many places where different geodynamical models have been proposed.

Based on P-wave receiver functions, Bianchi et al. (2021, 2022) show that the Nazca slab near the 20 degrees south latitude in the Central Andes flattens below the sub-Andes close to the 660 km discontinuity. This flattening makes the mantle colder and thickens the mantle transition zone (MTZ - classically between a depth of 410 and 660 km). Because the flattened Nazca slab is located just below the MTZ and not inside the MTZ in most of the region, the thickening of the MTZ results mainly from a lowering of the “660 km” discontinuity rather than from a modification of the “410 km” discontinuity.

The Ecuadorian Andes record a complex geological history. The fragmentation of the Farallon plate at approximately 23 Ma gave birth to the Nazca and Coco plates. The subduction of the Nazca in Ecuador has specific features due to the geological history and structure of the overriding plate. Yet, there was no comprehensive tomography study of Ecuador down to the slab until Araujo et al. (2021)’s study. By inverting the data of the Ecuadorian Seismic Network RENSIG, they provide evidence for a continuous Wadati-Benioff zone in southern Ecuador that clearly defines the topography of the Farallon plate. They also provide evidence for a tear in the Nazca plate along an axis oriented N110^{o}E, that may have resulted from the buckling of the plate at the sharp bend of the trench line between Peru and Ecuador.

Regions of propagating compressive deformation can present a significant seismic hazard. Identifying geological seismogenic structures is key to analyze this hazard and this identification requires a precise location of earthquakes. The faults under the Precordillera located in the northern sector of the Pampean flat-slab (San Juan, Argentina), belong to thin or thick skin tectonics, with an unclear distribution. By combining the analysis of 74 crustal events with other geophysical and geological data, Rivas et al. (2021) have built a 3D structural model, and identity this seismic deformation to be mostly concentrated in the basement (thick skin) below the décollement of the Precordillera, with important implications for seismic hazards with respect to these previously unconstrained structures.

Schmitz et al. (2021) review and add new wide-angle seismic data to map the Moho under Venezuela. They evidence significant variations in this complex region where the Caribbean meets the northern Andes.

Koch et al. (2021) studied the deep structure below the volcanic arc of Ecuador using seismic properties. They created two 3D models for the crust and the upper mantle in that region. They observe an anti-correlation of elevation and crustal thickness between the Western and Eastern Cordilleras that can be explained by lateral density variations. Their models show several low velocity zones within the crust beneath arc volcanoes with less than 14% melt and which that may correspond to the long-term storage of mush zones in the mid-crust.

Tectonics

Sedimentary archives in the Andean forelands are powerful tools to reconstruct the chronology of paleoenvironments and tectonic evolution. Santonja et al. (2021) coupled this analysis with sedimentary petrography and U–Pb zircon geochronology data in the well-exposed Miocene Ñirihuau Basin, North Patagonian Andes. They identified different alluvial, lacustrine, deltaic and fluvial paleo-environments. Although a transition from extension to compression was previously proposed, its precise dating was debated. New geochronological information dates the compressive period from 13.4 Ma onwards.

The different geodynamic models of the Andes are constrained by the dating of the rapid exhumation periods. In the Northern-Eastern Cordillera of Colombia, Velandia et al. (2021) use low temperature thermochronology to confirm a first period of exhumation at around 50 Ma, probably along the Boyacá fault, and then the initiation of transpression at around 20 Ma along the Bucaramanga Fault system, which then appears to have migrated northwards with cooling peaks near 12 and 5 Ma. These data are consistent with reconstructions based on sedimentary facies.

The southern Colombian Andes host both Jurassic magmatism and metamorphism associated with subduction of the Farallon Plate; however, the mechanisms of this remain poorly understood. Restrepo et al. (2021) provide new U-Pb dating and geochemical data to conclude that magmatism and metamorphism took place around 160 Ma in a volcanic arc context. The metamorphic rocks probably correlate with those found further north, which may correspond to different levels of metamorphism exhumed from different structural levels.

The Paleogene variation in the subduction direction and dip in the northern Andes led to the formation of a period of magmatism in the Amaga Basin of Colombia in the Miocene, the genesis and age of which remained poorly constrained. Bernet et al. (2020) used fission tracks on apatite and zircon to confirm an age of 12-6 Ma for this magmatism. Geochemistry also reveals that this magma was derived from the dehydration and melting of the slab, coupled with a magmatic evolution in the lower crust; the ascent of these magmas was probably favored by a pull-apart period around 12-9 Ma.

A masterpiece of this Special Issue is the manuscript by Ramos (2021) which presents a complete review of 50 years of Plate Tectonic concepts applied to Andean geodynamics. This remarkable review adopts a historical perspective by tracing the development of ideas on the evolution of the Andes proposed by different experts in Andean geology. This synthesis once again illustrates the need for cross disciplines so as to be able to understand a geological object such as the Andes.

A 2000 km-long dextral strike-slip fault system separates the North Andean Sliver from South America, from Ecuador to Venezuela. Audemard M et al. (2021) studied the cumulative displacement along this major discontinuity. Based on a synthesis of the existing geological and geophysical data, they quantify a maximum of 35 km of displacement of the North Andean Sliver with respect to South America since the Pliocene. Thus, despite its length, this fault system has accumulated a rather modest total displacement.

Volcanology

Several regions in the Andes are particularly threatened by volcanic phenomena. Reconstructing the history of eruptions is fundamental for hazard assessments and provides necessary data for risk evaluations.

Sumaco is a young-looking back-arc stratovolcano located in the northern SubAndean zone of Ecuador, 105 km east of Quito. By combining a geomorphological study and by dating ashes in a sediment core drilled in a close lagoon, Salgado Loza et al. (2021) identified notable activity in the last 4400 years, with at least six separate eruptive phases during the last century. The Sumaco should thus be considered a potentially active volcano.

Pululahua, 15 km north of Quito, is a potentially active dome complex for which the eruptive history was poorly constrained. Andrade et al. (2021) date three eruptive stages of activity at 18-12 ka BP, 2.6-2.3 ka BP and 2.2 ka BP, characterized by large explosive eruptions responsible for the formation of the current caldera-like depression. The lava geochemistry does not show significant variations through time. Interestingly, Andrade et al. were able to quantify the volume of dense rock equivalent material produced by these eruptions and to assess their magnitudes.

Volcanoes build up but they also collapse, producing debris avalanches, sometimes several times through the volcano's lifespan. Based on a large geological study and several K-Ar ages, Mariño et al. (2021) reconstructed the eruptive chronology of the Tutupaca volcanic complex, located in Southern Peru. In addition, they studied the triggering mechanisms of a collapse event that affected Tutupacau. By using cosmogenic nuclide 10Be dating on feldspaths, they date the debris avalanche between 6.0 ± 0.7 and 7.8 ± 1.5 ka. Based on the similarity with a younger debris avalanche, the authors conclude that the dome growth process coupled with the effect of the hydrothermally-altered substratum was responsible for these recurrent collapses.

Geomorphology

Geomorphic markers may be used to evidence and quantify recent tectonic activity. This analysis is complicated by large-scale rockslides, widespread Plio-Pleistocene volcanism, and glacial and fluvial erosion that mixed together to hamper tectonic imprint in the topography. Jagoe et al. (2021) address this issue in the northern Neuquen Basin (Argentina) with structural evidence of neotectonics. Using different geomorphic indices, they compare their measurements to known fault locations. They conclude that post-glacial rockfalls strongly hamper the local tectonic imprint on the landscape.

The dating of Quaternary sediments is fundamental both in terms of documenting recent tectonic activity on faults and analyzing the imprint of climate on geomorphology. Dating methods require the development of analytical laboratories, of which there are few in the Andean countries. Guzmán et al. (2021) positively test ESR ages of dated alluvial terraces of the Santo Domingo River in western Venezuela obtained in a new laboratory located in that country. Furthermore, their results confirm the overestimation of ESR ages obtained on debris flow deposits for which "bleaching" (inheritance zeroing) is not effective.

Analogical and numerical models predict variations of vertical movements in the Andes associated with variations in the subduction processes. Nevertheless, documenting these variations is challenging. Regard et al. (2021) map marine terraces and pediments and compile their ages along the coast of southern Peru to propose that surface uplift has been discontinuous over the last 12 Ma. They evidence a cycle of 4 Ma that was predicted by published numerical models simulating episodic tectonic underplating.

Seismic hazard

Earthquakes damage infrastructures. When these infrastructures are pre-Columbian historical monuments, their conservation in the face of a seismic hazard is a particular challenge. Combey et al. (2021) have developed a database, RISC ("Seismic Risk, Incas and Society in Cusco"), which makes it possible to inventory the damage created by earthquakes on the pre-Columbian architecture in the Cusco area. This database is intended to become a reference tool to monitor this damage in the future and facilitate conservation actions.

A critical issue for seismic and tsunami hazard assessments in the Caribbean is to know whether large earthquakes can occur along the Caribbean plate subduction beneath the North Andean Sliver. Although no mega-earthquakes have occurred in the last 500 years along this convergent boundary, Lizarazo et al. (2021) compiled and analyzed GPS data from the nationwide GPS array in Colombia to obtain a 3-dimensional velocity field. Using these data, they identified a fully locked patch along the subduction interface south of the city of Cartagena with potential for a Mw 8 and a 600-year return period earthquake. Their model also appears to be consistent with the low strain rate determined from geological markers.

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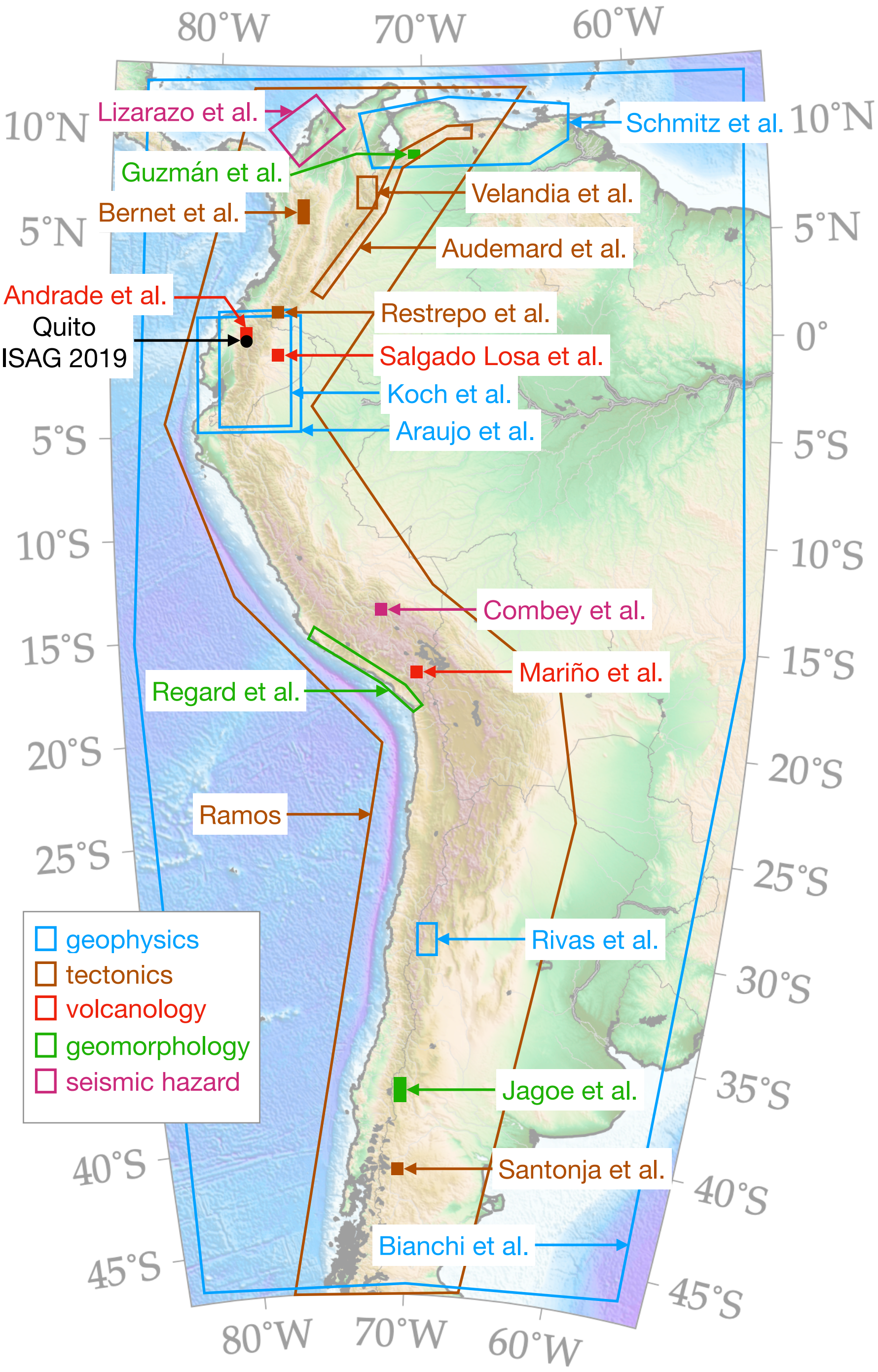

Figure 1: The geographical imprint of the papers published in the ISAG special issue of J. of South American Earth Sciences.

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