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Introductory paper of the 8th International Symposium on Andean Geodynamics (ISAG) Special Number

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¹ The International Symposium on Andean Geodynamics (ISAG) is an international con-
² ference that was held, on average, every 3-4 years in different European cities between 1990
³ (Grenoble) and 2008 (Nice). These symposia usually offer an opportunity for researchers
⁴ from Latin American countries and Europe as well as other countries to review the state
⁵ of knowledge in geosciences on the Andes. After a long period without an edition, the 8th
⁶ ISAG was organized for the first time in a Latin American country, Ecuador, from 24th
⁷ to 26th September 2019. The organizing committee led by Pablo Samaniego relied heavily
⁸ on the Instituto Geofísico of the Escuela Politécnica Nacional (IG-EPN) and the Institut
⁹ de Recherche pour le Développement (IRD), in particular through its office in Quito, and
¹⁰ through the Laboratoire Mixte International in France and Ecuador: “Seismes et Volcans
¹¹ dans les Andes du Nord” (LMI-SVAN); and the French Embassy in Ecuador. Field trips in
¹² tectonics, seismotectonics and volcanology at emblematic sites in Ecuador were organized

13 by researchers from the IRD (Isterre and LMV), the Institut de Radio Protection Nucléaire
14 (IRSN), IG-EPN and the University of Geneva. Four invited speakers gave presentations:
15 Peter Molnar (University of Boulder) on the mechanisms of the Andes uplift, Suzanne Kay
16 (Cornell University) on its magmatism, Victor Ramos (University of Buenos Aires) on the
17 scientific approaches developed through time for the Andean orogeny and Eric Calais (Ecole
18 Normale Supérieure de Paris) on the difficulty of dialogue between seismic risk specialists
19 and the authorities in Haiti. The symposium also provided an opportunity for more than
20 250 participants to meet, with more than 80 oral presentations and over 150 posters. As
21 a result of this conference, the Editor of the Journal of South American Earth Sciences
22 proposed to the organizing committee to publish a special issue on the contours of these
23 presentations. Following the peer review process, 19 papers are published in this special is-
24 sue. These manuscripts reflect the various disciplinary fields, geophysics and deep imaging,
25 tectonics, volcanism, geomorphology and seismic hazard, from the local scale to the Andes
26 as a whole. Not surprisingly, a higher density of works is found in Ecuador and the northern
27 Andes (Figure 1). As this collection of articles reflects the outlines of a symposium and not
28 a specific scientific question, our aim here is not to develop a synthesis of current knowledge
29 on the Andes. We therefore present these articles in sequence, by discipline, although this
30 categorization may appear subjective since some articles are multidisciplinary.

31 Geophysics

32 Geophysical imagery is fundamental to constrain the current geometry of the Andean struc-
33 ture at depth and is still the most needed technique in many places where different geody-
34 namical models have been proposed.

35

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

43

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

53

54 Regions of propagating compressive deformation can present a significant seismic haz-

55 ard. Identifying geological seismogenic structures is key to analyze this hazard and this
56 identification requires a precise location of earthquakes. The faults under the Precordillera
57 located in the northern sector of the Pampean flat-slab (San Juan, Argentina), belong to
58 thin or thick skin tectonics, with an unclear distribution. By combining the analysis of 74
59 crustal events with other geophysical and geological data, Rivas et al. (2021) have built a
60 3D structural model, and identify this seismic deformation to be mostly concentrated in the
61 basement (thick skin) below the décollement of the Precordillera, with important implica-
62 tions for seismic hazards with respect to these previously unconstrained structures.

63
64 Schmitz et al. (2021) review and add new wide-angle seismic data to map the Moho under
65 Venezuela. They evidence significant variations in this complex region where the Caribbean
66 meets the northern Andes.

67
68 Koch et al. (2021) studied the deep structure below the volcanic arc of Ecuador using
69 seismic properties. They created two 3D models for the crust and the upper mantle in
70 that region. They observe an anti-correlation of elevation and crustal thickness between the
71 Western and Eastern Cordilleras that can be explained by lateral density variations. Their
72 models show several low velocity zones within the crust beneath arc volcanoes with less than
73 14% melt and which that may correspond to the long-term storage of mush zones in the
74 mid-crust.

75 **Tectonics**

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

83
84 The different geodynamic models of the Andes are constrained by the dating of the rapid
85 exhumation periods. In the Northern-Eastern Cordillera of Colombia, Velandia et al. (2021)
86 use low temperature thermochronology to confirm a first period of exhumation at around 50
87 Ma, probably along the Boyacá fault, and then the initiation of transpression at around 20
88 Ma along the Bucaramanga Fault system, which then appears to have migrated northwards
89 with cooling peaks near 12 and 5 Ma. These data are consistent with reconstructions based
90 on sedimentary facies.

91
92 The southern Colombian Andes host both Jurassic magmatism and metamorphism as-
93 sociated with subduction of the Farallon Plate; however, the mechanisms of this remain
94 poorly understood. Restrepo et al. (2021) provide new U-Pb dating and geochemical data
95 to conclude that magmatism and metamorphism took place around 160 Ma in a volcanic arc
96 context. The metamorphic rocks probably correlate with those found further north, which

97 may correspond to different levels of metamorphism exhumed from different structural levels.

98

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

106

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

113

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

120 **Volcanology**

121 Several regions in the Andes are particularly threatened by volcanic phenomena. Recon-
122 structing the history of eruptions is fundamental for hazard assessments and provides nec-
123 essary data for risk evaluations.

124

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

130

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

138

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

148 **Geomorphology**

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

156
157 The dating of Quaternary sediments is fundamental both in terms of documenting recent
158 tectonic activity on faults and analyzing the imprint of climate on geomorphology. Dating
159 methods require the development of analytical laboratories, of which there are few in the
160 Andean countries. Guzmán et al. (2021) positively test ESR ages of dated alluvial terraces
161 of the Santo Domingo River in western Venezuela obtained in a new laboratory located in
162 that country. Furthermore, their results confirm the overestimation of ESR ages obtained
163 on debris flow deposits for which “bleaching” (inheritance zeroing) is not effective.

164
165 Analogical and numerical models predict variations of vertical movements in the Andes
166 associated with variations in the subduction processes. Nevertheless, documenting these
167 variations is challenging. Regard et al. (2021) map marine terraces and pediments and
168 compile their ages along the coast of southern Peru to propose that surface uplift has been
169 discontinuous over the last 12 Ma. They evidence a cycle of 4 Ma that was predicted by
170 published numerical models simulating episodic tectonic underplating.

171 **Seismic hazard**

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

178

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

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192 Triboilgas, Raspberry Shake, InColor, Retsch, Minga Service, Sultana del Condor Minera
193 S.A

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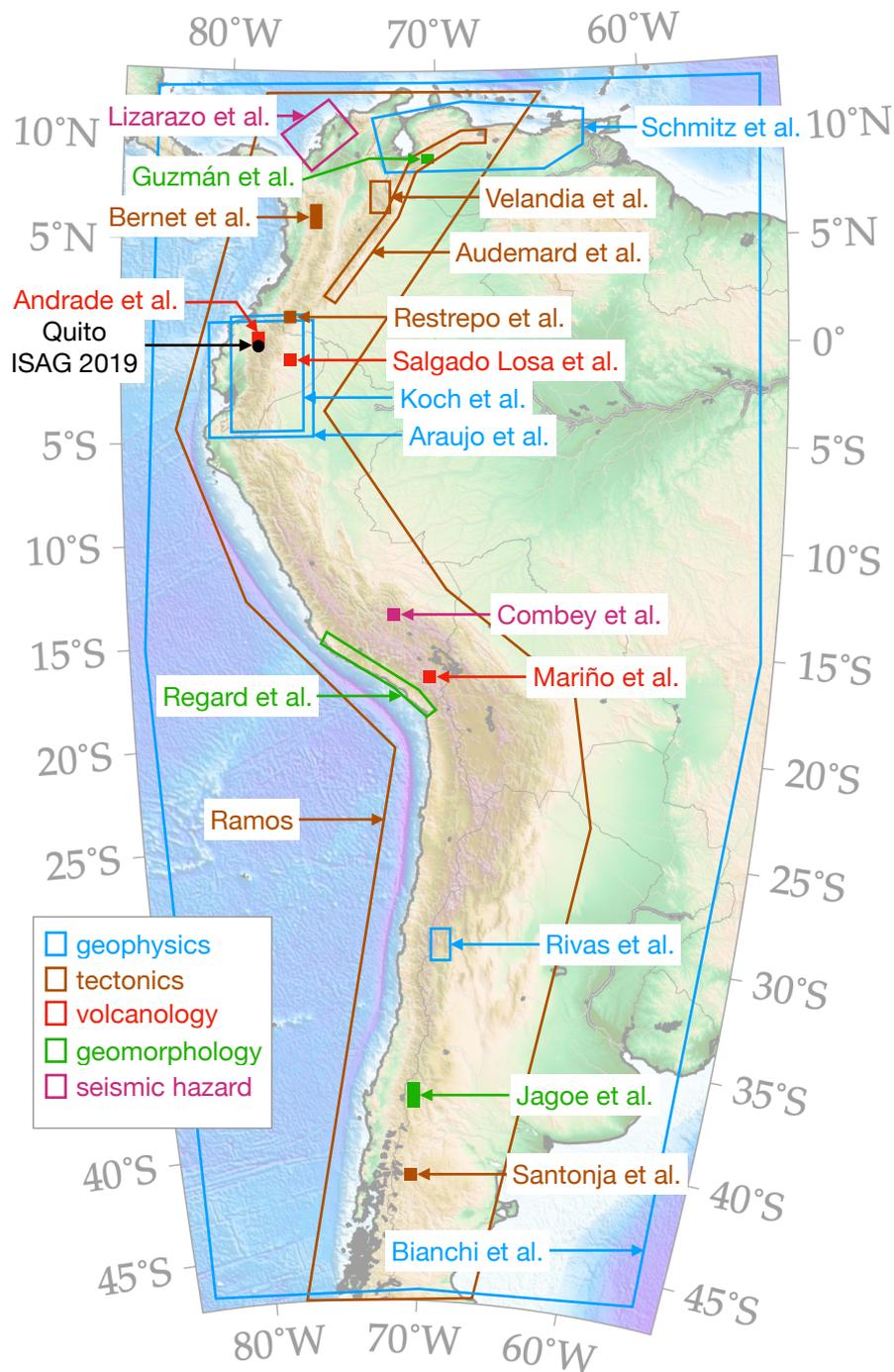


Figure 1: The geographical imprint of the papers published in the ISAG special issue of J. of South American Earth Sciences.

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