







Chapter 1



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Physiographic and Geological Setting of the Colombian Territory

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Abstract The territory of the Republic of Colombia is in the northwestern corner of South America, a region influenced by the Caribbean and Nazca oceanic plates, and the South American continental plate. In Colombia, six natural regions are distinguished: Andean, Caribbean, Pacific, Orinoquia, Amazonian, and Insular. The Andean region corresponds to the great mountain belt of the Andes, which in Colombia is divided into the Western, Central, and Eastern Cordilleras, separated by the inter-Andean valleys of the Cauca and Magdalena Rivers. The Caribbean region is to the north and include the coastal areas of the Caribbean Sea. It is a region of flat to undulating relief, with some high topography, among which the Sierra Nevada de Santa Marta stands out. The Pacific region, in the west of Colombia, has flat to undulating morphology and host the serranía de Baudó. To the east, the territory consists of the Orinoquia and Amazonian regions, with their flat and undulating surface, the first corresponds to plains and savannas, while the second corresponds to the Amazonian jungle, where are some isolated ranges as the serranía de Chiribiquete. The Caribbean Insular region groups the San Andrés, Providencia, and Santa Catalina Islands, besides of islets, atolls, and reef banks; whilst the Pacific Island region encompass the Gorgona and Gorgonilla Islands, and the Malpelo Islet. Caribe, Magdalena-Cauca, Orinoco, Amazonas, and Pacífico are the main hydrographic watersheds of the country. The geological setting of Colombia is diverse, with rocks of multiple types and ages, spanning the Paleoproterozoic to Holocene, as well as geological structures of diverse type and origin, reflecting a complex and diverse geological history. This geological framework has led to the identification of 23 marine and continental sedimentary basins.

Keywords: *Colombian geography, natural regions, hydrographic watersheds, sedimentary basins.*

Resumen El territorio de la República de Colombia está ubicado en la esquina noroccidental de Suramérica, región influenciada por las placas oceánicas del Caribe y de Nazca y la placa continental de Suramérica. Seis regiones naturales han sido identificadas: Andina, Caribe, Pacífica, Orinoquia, Amazonia e Insular. La zona andina es la prolongación de la gran cordillera de los Andes, que en Colombia se divide en las cordilleras Occidental, Central y Oriental separadas por los valles interandinos de los ríos Cauca

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y Magdalena. La región Caribe se localiza al norte y corresponde a las zonas costeras del mar Caribe. Es un área de relieve plano a ondulado con algunas elevaciones, entre las que se destaca la Sierra Nevada de Santa Marta. La región Pacífica, ubicada al occidente colombiano, es de morfología plana a ondulada. Allí se encuentra la serranía de Baudó. Las regiones Orinoquia y Amazonia, de superficie ondulada y plana, ocupan el oriente del territorio; la primera corresponde a llanuras y sabanas, mientras que la segunda es selvática, con algunas zonas montañosas aisladas como la serranía de Chiribiquete. La región Insular del Caribe está conformada por las islas de San Andrés, Providencia y Santa Catalina, con islotes, atolones y bancos de arrecifes; las islas de Gorgona y Gorgonilla y el islote de Malpelo hacen parte de la zona Insular del océano Pacífico. Hidrográficamente se identifican cinco cuencas: Caribe, Magdalena–Cauca, Orinoco, Amazonas y Pacífico. La constitución geológica del territorio de Colombia es muy variada, con rocas de diferentes tipos y edades entre el Paleoproterozoico y el Holoceno, así como estructuras geológicas de diverso tipo y origen, que reflejan una historia geológica compleja. Esta armazón geológica ha dado lugar a la identificación de 23 cuencas sedimentarias, algunas marinas y otras continentales.

Palabras claves: *geografía colombiana, regiones naturales, cuencas hidrográficas, cuencas sedimentarias.*

1. Introduction

Geographically, the 2 070 408 km² that make up the continental (55.15%) and marine (44.85%) territory of the Republic of Colombia are located in the northwestern corner of South America. Politically, this area is divided into 32 departments and a capital district, Bogotá (Figure 1). The second political–administrative division is by municipalities. In total, Colombia has 1101 that grouped make up the departments (see the 1101 municipalities of Colombia in Google Earth, Supplementary Information). These political–administrative divisions must be borne in mind when reading *The Geology of Colombia*, since in several chapters they are indicated and used as reference points. In addition, in the national territory, six large natural regions are distinguished: Andean, Caribbean, Pacific, Orinoquia, Amazonian, and Insular (Figure 2).

It is believed that the current Colombia geological setting results of the accretion of different continental and oceanic affinity geological terranes that allowed the growth of the national territory from the Proterozoic basement located to the east of the country (Gómez et al., 2015a, 2015b). Mountain uplift and the formation of the inter–Andean valleys, as a consequence of the Andean Orogeny, shaped the Colombian landscape. The main physiographic features, such as cordilleras and ranges, and some localities that due to their geological relevance deserve to be highlighted, including massifs and valleys, are present in Figure 3. Figure 4 shows the main rivers of Colombia and the five major hydrographic watersheds that group the Colombian drainage systems: Caribe, Magdalena–Cauca, Orinoco, Amazonas, and Pacífico.

The tectonic framework of Colombia is influenced by the interaction between the Caribbean and Nazca oceanic plates, and the South American continental plate, with ocean ridges,

oceanic trenches, subduction zones, accretionary prisms, deformation belts, transform faults, and several other structural elements, as defined by Gómez et al. (2015a, 2015b) based on the findings of numerous researchers (Figure 5).

The geological processes that contributed to the formation of the national territory yield different types of rocks (Figure 6) and controlled the formation of folds and faults (Figure 7), some of which mark the boundaries between geological terranes and sedimentary basins, where converged the processes that allowed the formation and accumulation of hydrocarbons. Based on geological criteria and multiple aspects that Pardo et al. (2007a) considered for oil and gas exploration, the Agencia Nacional de Hidrocarburos (ANH) delimited 23 marine and continental sedimentary basins (Figure 8).

2. Andean Region

The Andean region corresponds to the great mountain belt of the Andes, which in Colombia is divided into three branches: the Western, Central, and Eastern Cordilleras. The Western and Central Cordilleras are forked north of the border of Colombia and Ecuador, in the so–called Nudo de Los Pastos; they run N–S, relatively parallel to the coast of the Pacific Ocean, and are separated by the inter–Andean valley of the Cauca River, a tributary of the Magdalena River. The Eastern Cordillera is the longest, oriented NE, and is detached from the Central Cordillera in the Macizo Colombiano, and on the border with Venezuela forks into the serranía de Perijá, N–S oriented, marking the binational limit. The Central and Eastern Cordilleras are separated by the Magdalena River Valley, which discharges into the Caribbean Sea. Each of the three mountain ranges has a different geological composition and geotectonic environment.

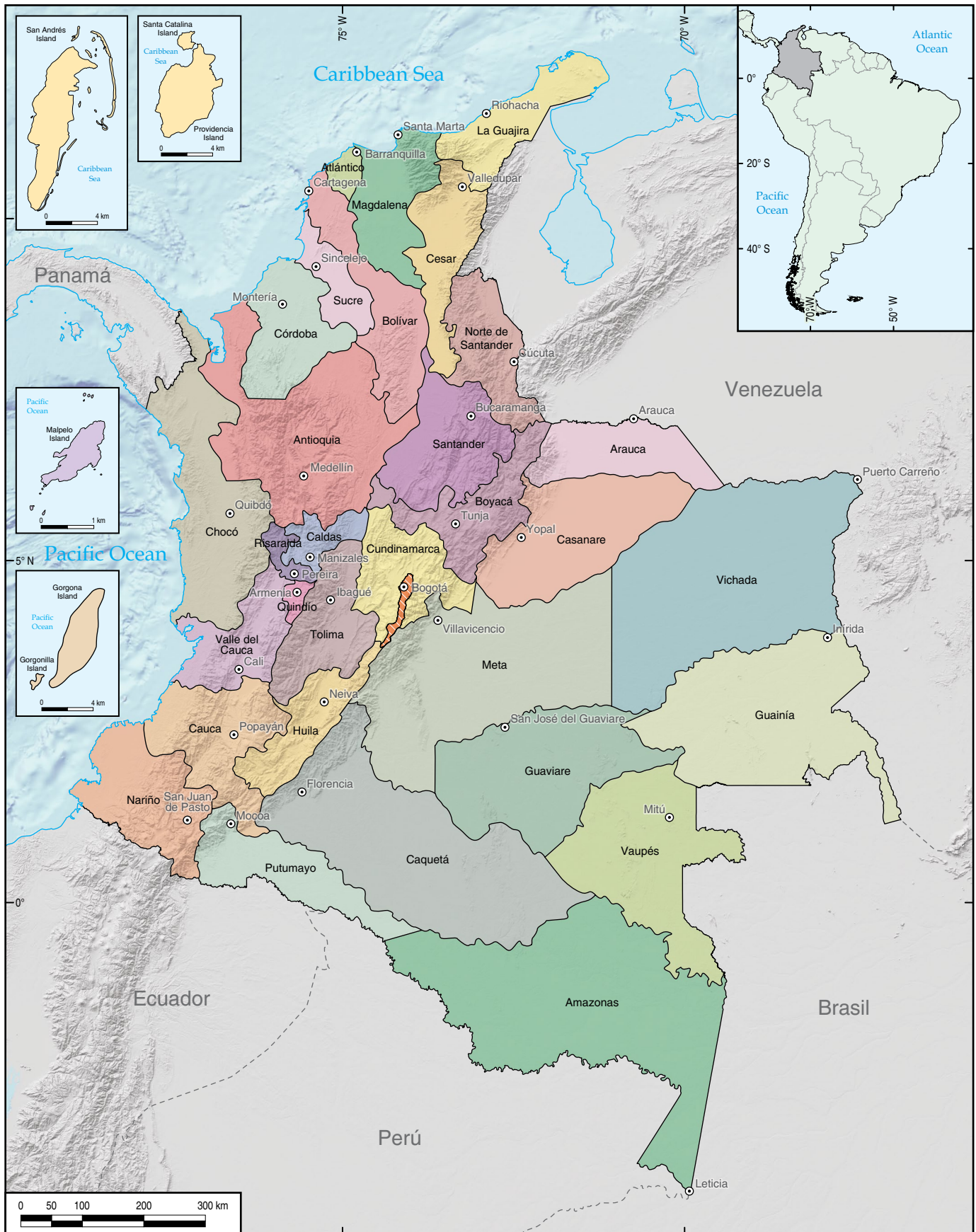


Figure 1. Political-administrative division of Colombia into departments. The figure also shows the capitals of the 32 departments. Modified from Instituto Geográfico Agustín Codazzi (1999).

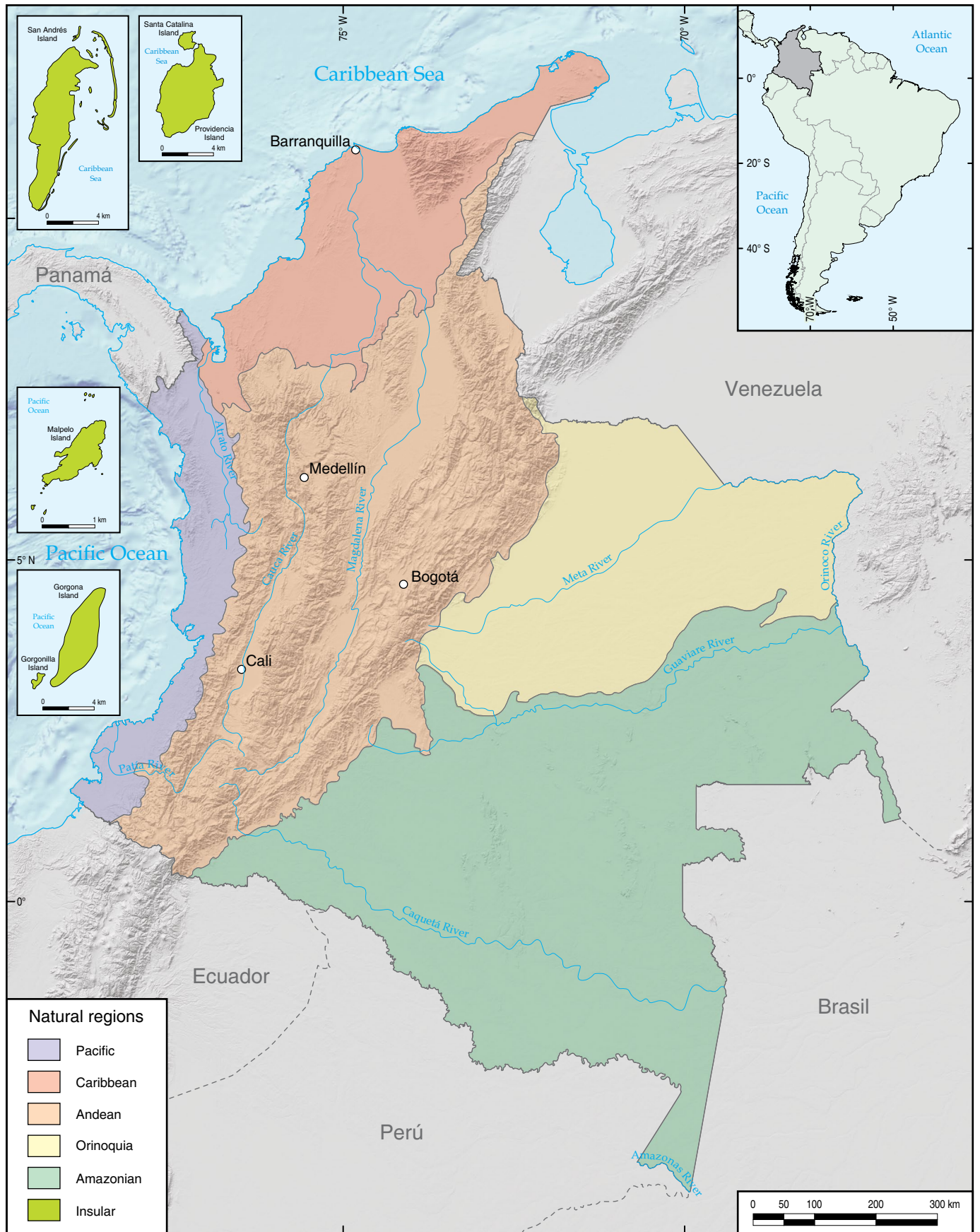


Figure 2. Natural regions and main cities of Colombia.

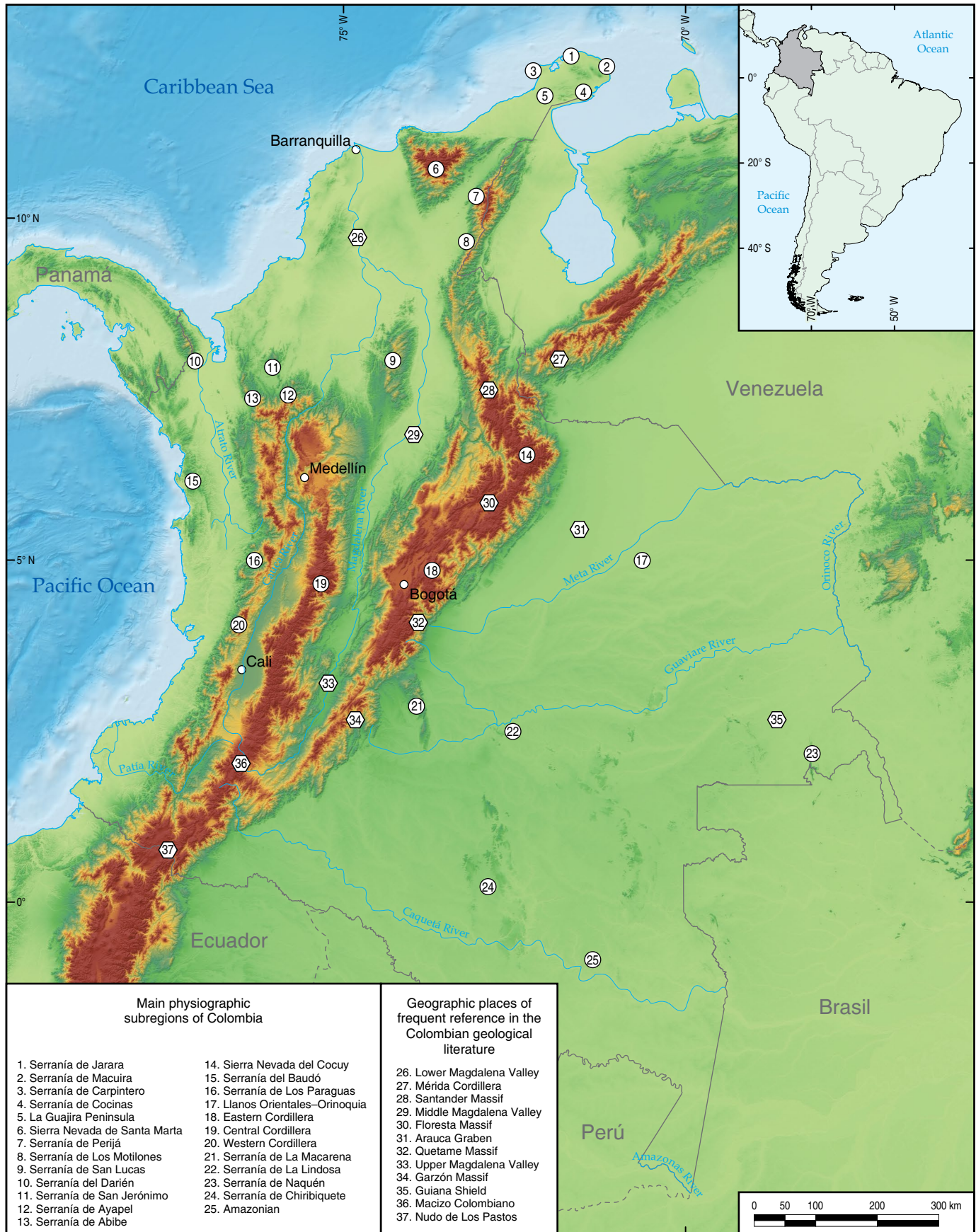


Figure 3. Main physiographic features of the Colombian territory and geographic places of frequent reference in the literature on Colombian geology.

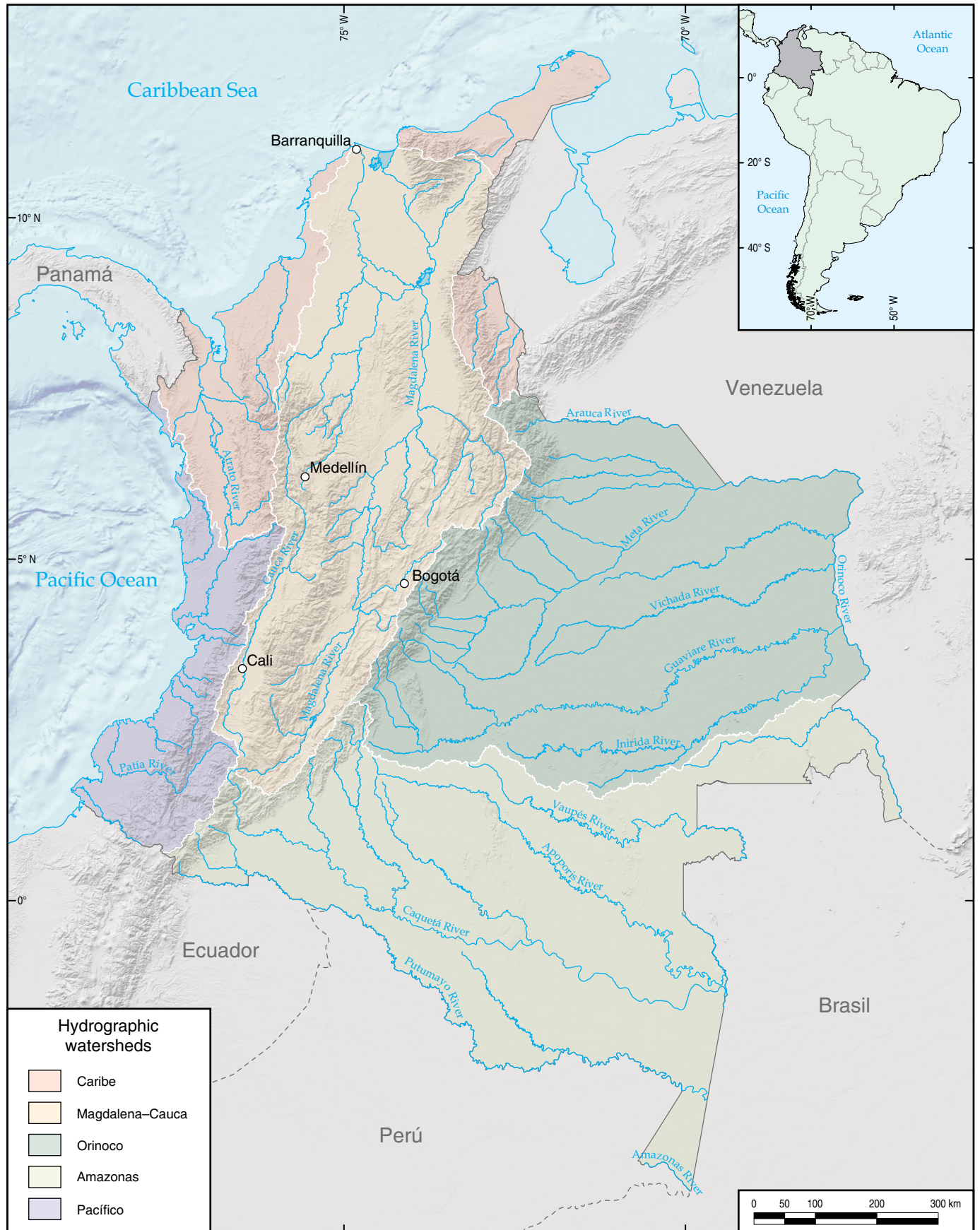


Figure 4. Main rivers of the country and hydrographic watersheds. Modified from Instituto de Hidrología, Meteorología y Estudios Ambientales (2013).

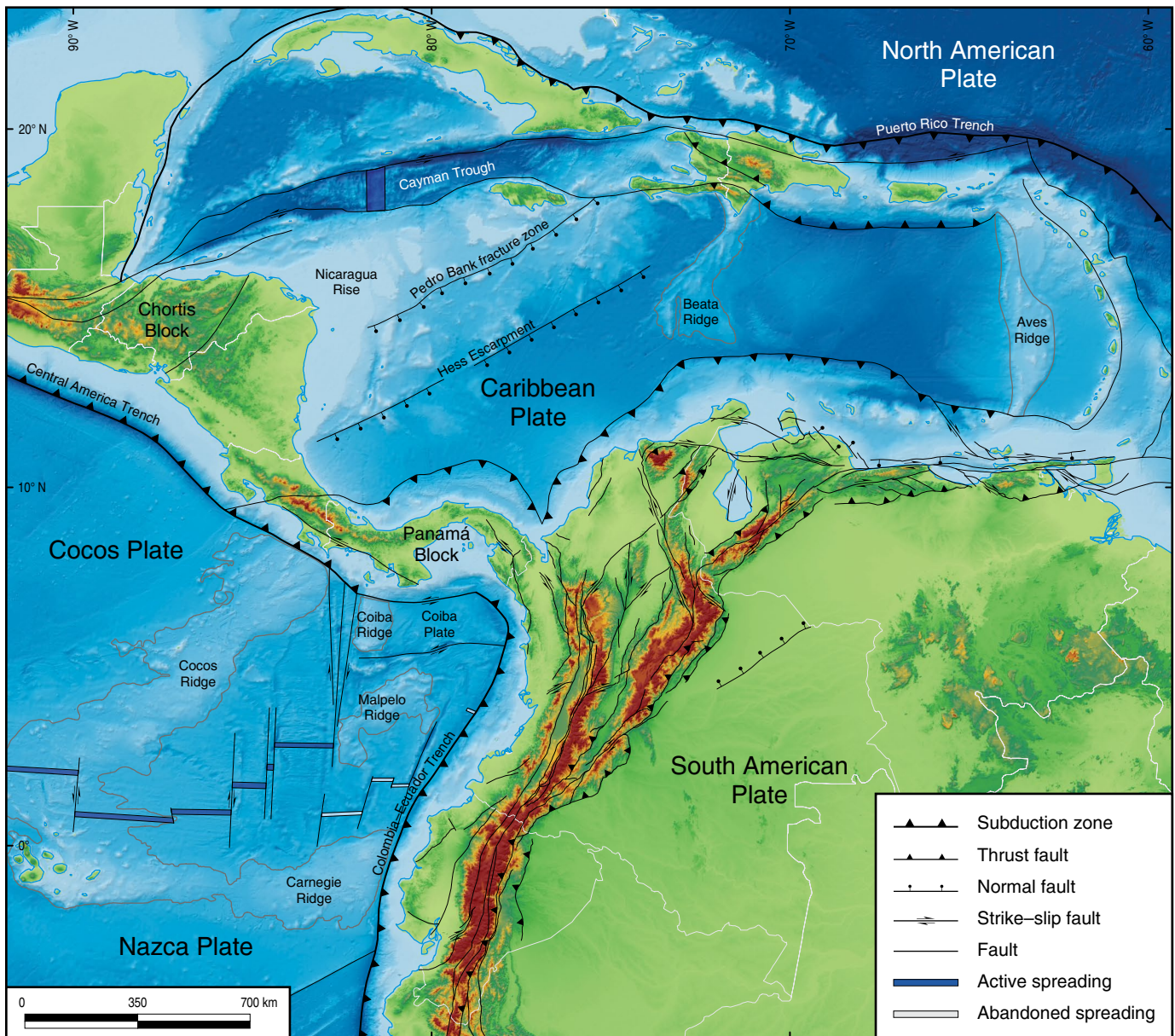


Figure 5. Tectonic scheme of northern South America and the Caribbean (Gómez et al., 2015a, 2015b).

The Western Cordillera is essentially constituted by Cretaceous sedimentary, gabbroic, and basaltic rocks of the Caribbean–Colombian oceanic plateau, accreted to the western margin of Colombia during the Late Cretaceous to Paleogene. In the southern sector, there are Paleogene plutonic and volcanoclastic rocks, while in the northern part, there are Miocene basalts and Pliocene volcanoclastic rocks, as well as small Neogene intrusions. At the southern end of the mountain range are deposits of Neogene and Quaternary volcanic eruptions, and some of the volcanoes in this area are active and are part of the Southern Volcanic Segment of Colombia (Monsalve–Bustamante, 2020).

The Central Cordillera has a low–grade polymetamorphic Triassic basement, with the last event recorded in the Jurassic. This basement is intruded by Permian, Mesozoic, and some Ce-

nozoic plutons generated by the subduction of the Nazca Plate under the South American Plate. In the eastern flank, the Mesozoic intrusions are linked to Jurassic volcanoclastic sequences. Also, Mesoproterozoic – Neoproterozoic high–grade metamorphic rocks incorporated during the different orogenies recorded in Colombia are exposed. In the western flank, are found volcanoclastic and low–grade metamorphic rocks of the Cretaceous. Locally, Cretaceous marine sedimentary sequences are presented both the western and eastern flanks of the cordillera. The Neogene – Quaternary volcanoes, some of which are active, of the central and northern segments of Colombia (Monsalve–Bustamante, 2020) are located towards the summit of this mountain range. The Miocene molasse deposits of the Magdalena River Valley and volcanoclastic fans overlies the eastern foothills of

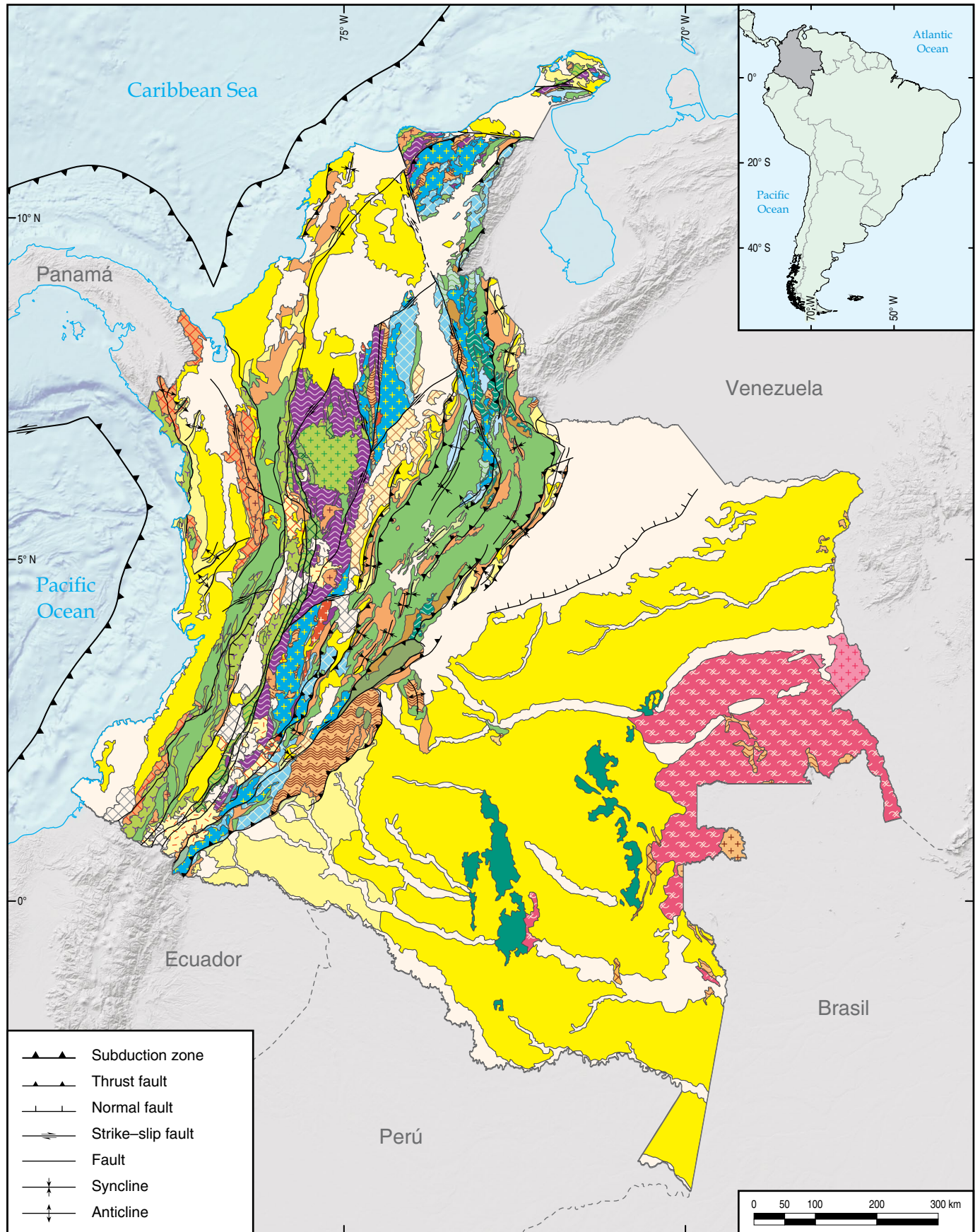


Figure 6. Geological map of Colombia. After Gómez et al. (2019).

Legend

	Quaternary basaltic rocks		Jurassic volcanic rocks
	Quaternary volcanic rocks		Jurassic plutonic rocks
	Quaternary volcaniclastic rocks		Triassic sedimentary rocks
	Quaternary sedimentary rocks		Triassic volcaniclastic rocks
	Pliocene – Pleistocene volcaniclastic rocks		Triassic plutonic ultramafic rocks
	Pliocene volcanic rocks		Triassic plutonic rocks
	Pliocene volcaniclastic rocks		Triassic low grade metamorphic rocks
	Miocene basaltic rocks		Paleozoic sedimentary rocks
	Neogene sedimentary rocks		Permian plutonic rocks
	Neogene plutonic rocks		Carboniferous plutonic rocks
	Paleogene – Neogene sedimentary rocks		Carboniferous sedimentary rocks
	Paleogene sedimentary rocks		Devonian sedimentary rocks
	Paleogene plutonic rocks		Silurian – Devonian low grade metamorphic rocks
	Paleogene volcaniclastic rocks		Ordovician plutonic rocks
	Cretaceous – Paleogene sedimentary rocks		Ordovician low grade metamorphic rocks
	Cretaceous sedimentary rocks		Ordovician sedimentary rocks
	Cretaceous volcanic rocks		Cambrian – Ordovician sedimentary rocks
	Cretaceous medium grade metamorphic rocks		Neoproterozoic plutonic rocks
	Cretaceous plutonic ultramafic rocks		Neoproterozoic volcaniclastic rocks
	Cretaceous basaltic rocks		Meso–Neoproterozoic high grade metamorphic rocks
	Cretaceous volcaniclastic rocks		Mesoproterozoic plutonic rocks
	Cretaceous low grade metamorphic rocks		Mesoproterozoic low grade metamorphic rocks
	Cretaceous plutonic rocks		Paleoproterozoic plutonic rocks
	Jurassic sedimentary rocks		Paleoproterozoic medium grade metamorphic rocks
	Jurassic volcaniclastic rocks		

this mountain range. The Cauca–Almaguer and Silvia–Pijao Faults, exposed in the western foothills, are the tectonic limits of the Colombian continental terranes.

The Eastern Cordillera has a basement of Mesoproterozoic – Neoproterozoic high–grade metamorphic rocks exposed in the Garzón and Santander Massifs and the serranía de La Macarena. In this mountain range are also found Ordovician low–grade metamorphic rocks, especially in the Santander Massif; Paleozoic (Cambrian – Ordovician and Devonian) sedimentary sequences, some of them fossiliferous; and a

thick succession of Cretaceous marine and Cenozoic continental sedimentary rocks that were deformed during the Andean Orogeny. In the Santander Massif and the western flank of the serranía de Perijá, the Jurassic record consist of sedimentary rocks, intrusions, and volcaniclastic sequences. Jurassic plutons are also present in the extreme south of the cordillera. South of the eastern flank, the Borde Amazónico Fault System and the Algeciras Fault mark the boundary with the Caguán–Putumayo Basin. To the north, the Borde Llanero Fault System serves as a boundary with the Llanos Orientales

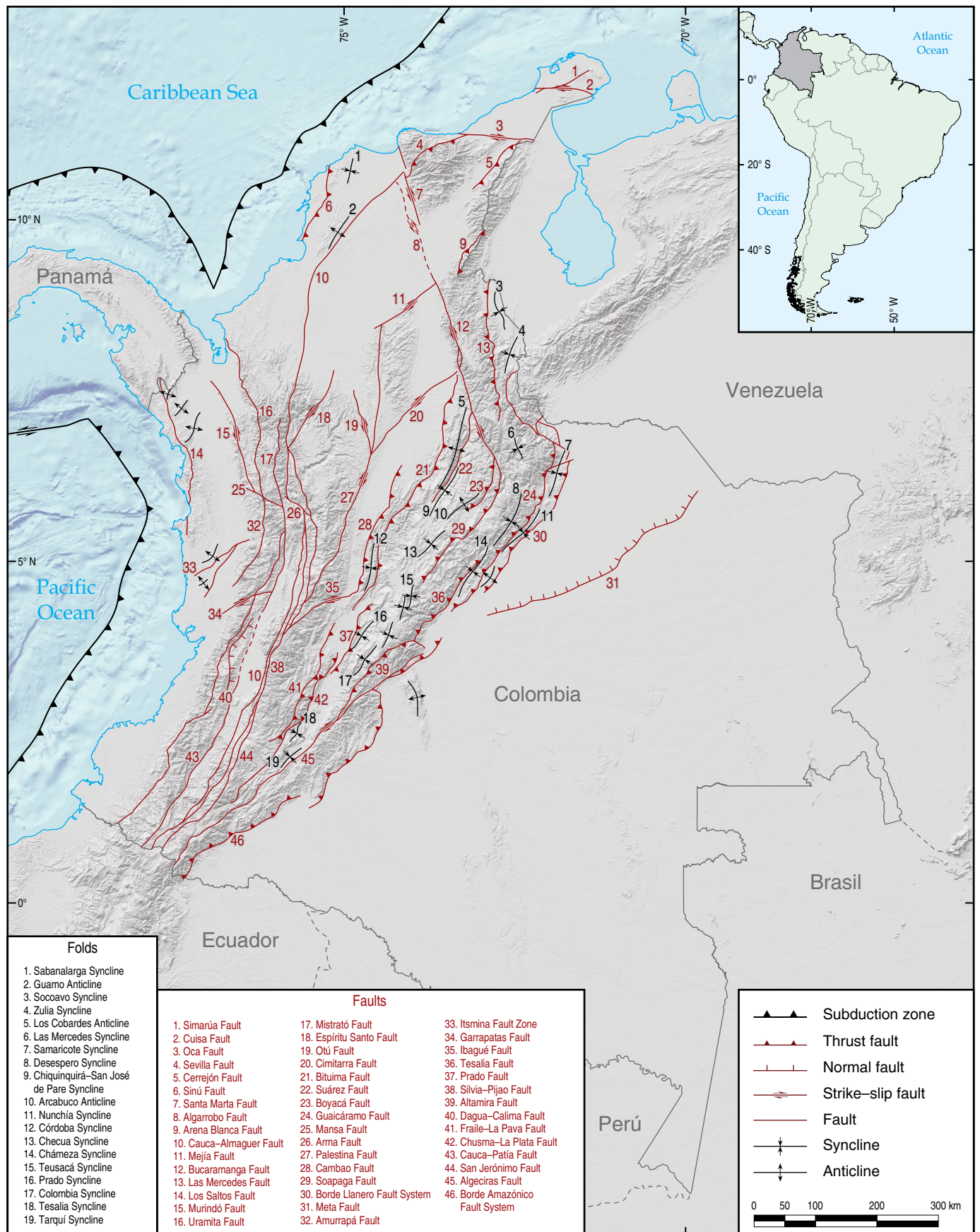


Figure 7. Main geological structures of Colombia. After Gómez et al. (2019).

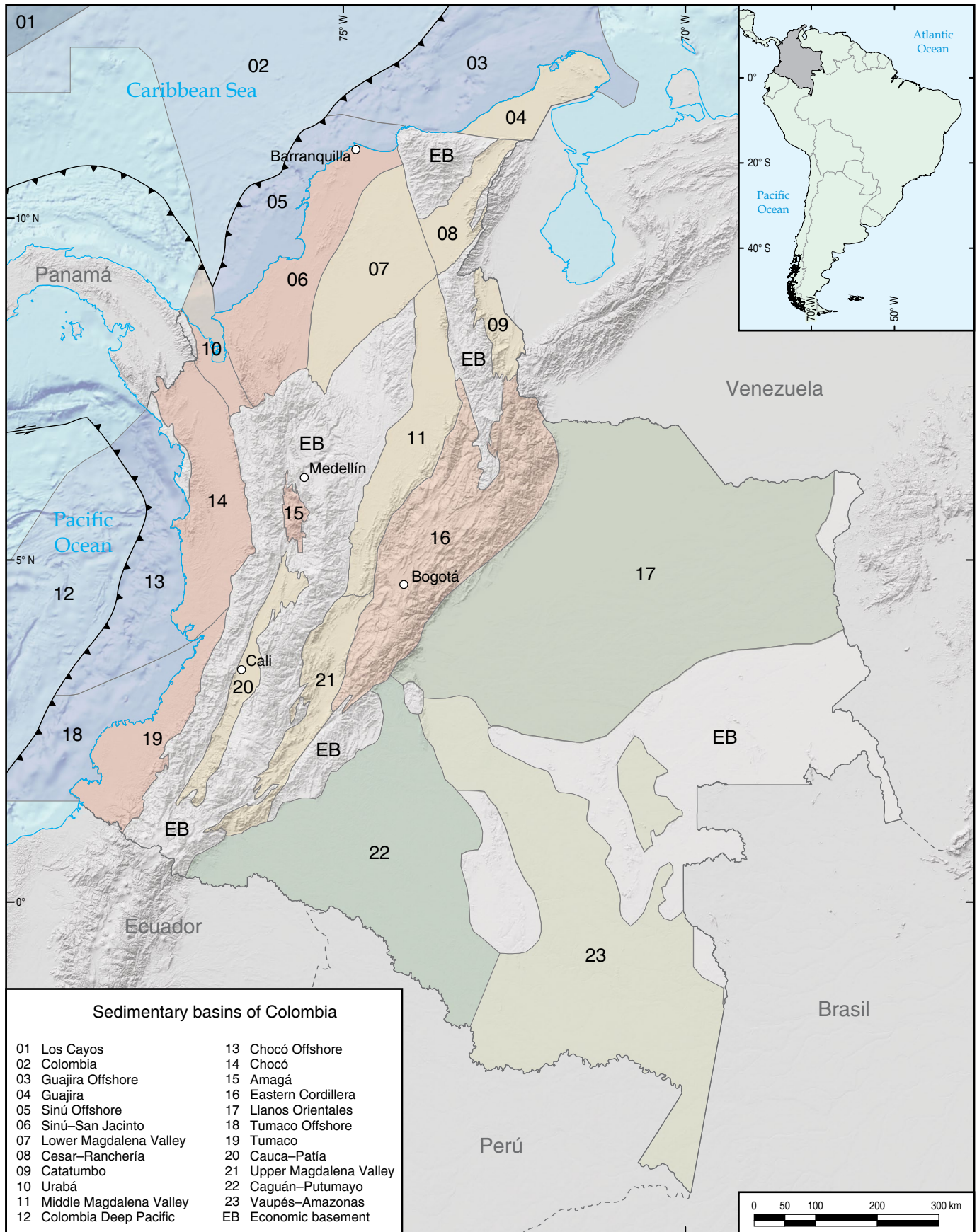


Figure 8. Sedimentary basins of Colombia. Modified from Pardo et al. (2007b).

Basin. These geological structures mark the limit of the Andean zone over eastern Colombia.

3. Caribbean Region

The Caribbean Region is between the Caribbean Sea and the northern foothills of the Andes. This region has 85% flat to undulating relief and some low-elevation hills, associated with lowland coasts, and include coastal plains, alluvial plains, salt flats and floodplains, mangrove plains, coastal lagoons, beaches and sandbanks, dune fields, platforms and reef bars, among other geomorphological features (Molina *et al.*, 1998). The other 15% of the littoral corresponds to cliffs, where stands out the Sierra Nevada de Santa Marta (SNSM), with the Cristóbal Colón and Simón Bolívar Peaks over 5700 masl, the serranías de Jarara, Macuira, Carpintero, and Cocinas in La Guajira Peninsula; and the serranías de Abibe, Ayapel, Darién, and San Jerónimo in the southwestern sector. Mud diapirism and the alluvial delta of the Magdalena River are important geological features of this region.

The serranías de Jarara, Macuira, Carpintero and Cocinas, located in the Alta Guajira, are composed by Triassic and Cretaceous low-grade metamorphic assemblages. In some areas, Jurassic intrusives are exposed, as well as Triassic and Cretaceous marine and Jurassic continental sedimentary rocks.

The SNSM is a triangular block bounded to the north by the Oca Fault and to the west by the Santa Marta Fault. The Sevilla Fault cross the range in SW-NE direction. To the east, along the boundary with the Cesar-Ranchería Basin, are mainly found Cretaceous marine and Cenozoic continental sedimentary rocks. This basin separates it from the serranía de Perijá, the north extension of the Eastern Cordillera. The oldest rocks exposed are Mesoproterozoic high-grade metamorphic rocks, while Jurassic plutons conform most of the SNSM. To the northwestern corner, Triassic and Cretaceous medium to low-grade metamorphic rocks are intruded by a Paleogene granitoid, and to the eastern flank are found mainly Triassic and Jurassic sedimentary and volcanoclastic rocks.

The serranías de Abibe, Ayapel, Darién, and San Jerónimo are formed by Paleogene sedimentary rocks surrounded by Neogene sedimentary formations and Quaternary alluvial deposits.

4. Pacific Region

The coastal plains of western Colombia and some mountain ranges, such as the serranía del Baudó, make up the Pacific region. This region is a narrow fringe that extends between the Pacific Ocean and the foothills of the Western Cordillera. Morphologically, the northern sector has high coasts with cliffs, beaches, and floodplains in the interior of large bays (González *et al.*, 1998). The central and southern parts are dominated

by low alluvial and flooded coasts interrupted by short cliffs (González *et al.*, 1998).

In the serranía del Baudó, Cretaceous basalts and Paleogene volcanoclastic sequences are found, derived from an island arc accreted to the continental margin. In the other areas of the Pacific region, there are Paleogene and Neogene sedimentary units, and alluvial and coastal deposits of the Quaternary.

5. Orinoquia and Amazonian Regions

The plains of the northern sector of eastern Colombia form Orinoquia, while the Amazonian constitutes the jungle region of southeastern Colombia, where the serranía de Chiribiquete stands out. These two regions are the largest in the country, the least inhabited and the least developed. Both regions are bounded to the west by the foothills of the Eastern Cordillera, while to the east, they extend until the borders of Brasil and Venezuela. Geographically, the boundary between the Orinoquia and the Amazonian regions is defined along the Guaviare River.

In Orinoquia and Amazonian, the basement is formed by Paleoproterozoic and Mesoproterozoic medium- and low-grade metamorphic rocks, respectively, with Paleoproterozoic and Mesoproterozoic granitic intrusions and Neoproterozoic volcanoclastic rocks. This igneous-metamorphic assemblage is part of the western sector of the Guiana Shield and is covered by Neoproterozoic (Ediacaran and Cryogenian), Cambrian - Ordovician, and Ordovician marine sedimentary rocks with fossiliferous levels, exposed in mountainous areas such as serranías de Chiribiquete and La Lindosa or reported in borehole cores (Dueñas-Jiménez & Montalvo-Jónsson, 2020; Dueñas-Jiménez *et al.*, 2020). Cretaceous marine and Cenozoic continental sedimentary rocks cover, in most of these regions, the oldest rocks. Ibañez-Mejía *et al.* (2011) indicate that in wells located in the southwestern part of the Putumayo Basin, they found Proterozoic metamorphic rocks under the sedimentary cover, confirming that the Proterozoic basement extends to the Eastern Cordillera.

6. Insular Region

The insular region in the Caribbean Sea comprises the archipelago of San Andrés and Providencia and several cays, while in the Pacific Ocean comprise the Gorgona, Gorgonilla, and Malpelo Islands.

The insular region of the Colombian Caribbean includes three main islands: San Andrés, Providencia, and Santa Catalina, and other smaller islands, atolls, and coral reefs (Ortiz-Royero, 2012). Geologically, this zone is located in the Lower Nicaragua Rise between the Pedro fracture zone and the Hess Escarpment (Rogers *et al.*, 2007).

According to Geister & Díaz (2007), the archipelago consists of a platform of carbonates and reefs that cover deep volcanic

cones. The authors state that according to the available information, the atolls, islands, and coral banks to the south of the archipelago were formed around volcanoes in the early Cenozoic, and that subsidence and settlement of carbonates over shallow areas and in the summits of the volcanoes during the Cenozoic and the Quaternary facilitated their formation. Additionally, these features are oriented NNE, possibly following geological structures with the same orientation (Geister & Díaz, 2007). The island of San Andrés comprises mainly limestone deposits of the Pleistocene, while Providencia and Santa Catalina are part of the same composite volcanic cone; they are essentially alkaline and calc-alkaline volcanic rocks of middle Miocene and Pliocene age, respectively (Álvarez-Gutiérrez et al., 2014). To the south of Providencia, some intercalations of Miocene reef limestone between volcanic series and Quaternary marine sedimentary deposits are located (Geister & Díaz, 2007).

The Colombian insular region in the Pacific Ocean is made up of the Gorgona and Gorgonilla Islands, the Malpelo Islet, and El Viudo and El Horno rocky promontories (Díaz et al., 2001). More than 80% of the surface of the two main islands is constituted by igneous rocks, including basal peridotites and gabbros covered by basaltic lavas with komatiite flows (Díaz et al., 2001; Echeverría, 1982; Gansser et al., 1979; Parada & Tchegliakova, 1990). The remaining 15% corresponds to upper Eocene to upper Miocene sedimentary rocks and Quaternary sedimentary deposits that conform beaches, small deltas of surface currents, and some terraces. Reef zones surround the southern part of the main island (Díaz et al., 2001). Malpelo is a cliff formed entirely by basic volcanic rocks and in Gorgonilla, Bermúdez et al. (2016, 2019) report the boundary of the Cretaceous – Paleogene with the presence of tektites from the Chicxulub impact.

7. Conclusions

The marine and continental territory of the Republic of Colombia is in the northwest of South America, where interact the Caribbean and Nazca oceanic plates and the South American continental plate. Between the Proterozoic and the Holocene multiple geological events originated the current physiography setting that comprises six natural regions, five major drainage basins, 23 sedimentary basins, and diverse lithologies.

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Explanation of Acronyms, Abbreviations, and Symbols:

SNSM

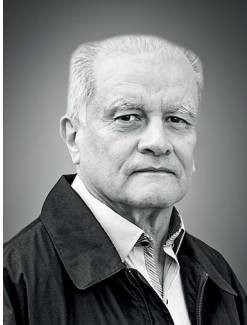
Sierra Nevada de Santa Marta

Authors' Biographical Notes



Jorge GÓMEZ TAPIAS is a geologist and has worked as a cartographer at the Servicio Geológico Colombiano for 20 years, during which time, he has authored approximately 70 geological maps. He is the coordinator of the Grupo Mapa Geológico Colombiano of the Dirección de Geociencias Básicas, which was recognized by Colciencias as a research group in 2017. GÓMEZ is the

first author of the Geological Map of Colombia at a scale of 1:1 M—editions 2007 and 2015— and of the 26 map sheets of the Geological Atlas of Colombia at a scale of 1:500 K and is the co-editor of the book *Compilando la geología de Colombia: Una visión a 2015*. Since February 2018, he has served as vice president for South America on the Commission for the Geological Map of the World. He was a co-coordinator and the first author of the Geological Map of South America at a scale of 1:5 M 2019. Since October 2020, he was elected as a member of the International Union of Geological Sciences (IUGS) Nominating Committee for the term 2020–2024. Currently, he is the editor-in-chief of *The Geology of Colombia*. GÓMEZ is in charge of coordinating all the activities related to the project and the editorial process.



Alberto NÚÑEZ-TELLO is a geologist who graduated from the Universidad Nacional de Colombia and is a specialist in environmental management and disaster prevention for the Universidad del Tolima. He has worked for 32 years at the Servicio Geológico Colombiano in different positions, including that of technical director. His main interest is in regional geological mapping and geological risk management.



Daniela MATEUS-ZABALA is a geologist who graduated from the Universidad Nacional de Colombia Sede Bogotá in 2016 and is a copyeditor of scientific and science outreach texts. She has participated in geological and geomorphological mapping projects, petrographic and geochemical characterization of rocks, and geochemical evaluation of soils. Since 2017, she has been part of

the Grupo Mapa Geológico de Colombia and is a deputy editor of *The Geology of Colombia*. In this editorial project, she supported the coordination of the editorial process stages and coordinated the advisory work for the project provided by the Observatorio Colombiano de

Ciencia y Tecnología and the Asociación Colombiana para el Avance de la Ciencia; she was also in charge of the writing and proofreading of texts written in Spanish and English and conducted the editorial review of the chapters.



Fernando Alirio ALCÁRCEL-GUTIÉRREZ is a geologist who graduated from the Universidad Nacional de Colombia and is a specialist in geomatics graduated from the Universidad Militar Nueva Granada. He has been part of the Grupo Mapa Geológico de Colombia since 2012. He has co-authored several publications from the group, including the *Catálogo de dataciones radiométricas de Colombia en ArcGIS y Google Earth*, and he is also the first

author of the informative Geological Map of Colombia 2019 at a scale of 1:2 M. ALCÁRCEL has extensive experience in the vectorization and digitization of graphic material for scientific publications, which is why he is the main graphic artist for *The Geology of Colombia* and is in charge of elaborating and improving the figures and maps.



Rubby Melissa LASSO-MUÑOZ is a geological engineer who graduated from the Universidad Nacional de Colombia Sede Medellín in 2016. LASSO has worked in the petroleum industry and conducted science outreach with communities. Since 2019, she has worked on the Grupo Mapa Geológico de Colombia in the Servicio Geológico Colombiano and has been in charge of coordinating

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Eliana MARÍN-RINCÓN is a geologist who graduated from the Universidad de Caldas in 2017. In the editorial process of *The Geology of Colombia*, she is in charge of preparing and adjusting the chapters' figures. MARÍN also supports the science outreach events through general logistics management and maintains the correspondence with and databases of participants.



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