Chapter 3

Tectonostratigraphic Terranes in Colombia: An Update
First Part: Continental Terranes

https://doi.org/10.32685/pub.esp.35.2019.03
Published online 14 April 2020

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Abstract The quite abundant geological information that has been produced in recent years in Colombia, especially in geochronological and geological mapping, necessitates updating the mosaic of geological terranes that comprise the Colombian territory. Several modifications to these characteristics and boundaries are proposed for terranes such as Chibcha, Tahamí, and Calima. Some small terranes that have been defined recently, including Anacona, Ebéjico (Quebradagrande), and Pozo (Arquía), are placed within the context of the larger terranes. In addition, some new terranes, including Yalcón, Bocaná, Aburrá, Kogi, and Tairona, are defined and their characteristics are described. With these new geochronological data, we propose that the metamorphic Cajamarca Complex be replaced by two new lithodemical units: the Antioquia Complex, which covers mostly rocks that formed during Permian and Triassic metamorphism, and the Coello Complex, which comprises metamorphic rocks that formed during Jurassic metamorphism. Future lines of investigation are proposed to solve remaining problems, especially the boundaries of some of the newly defined terranes.
Keywords: *continental terranes, accretions, displaced terranes, Colombia, Andes.*

Resumen La abundante cantidad de información geológica que se ha generado en los últimos años en Colombia, en particular geocronológica y cartográfica, implica la necesidad de actualizar el mosaico de terrenos geológicos que constituyen el territorio colombiano. En este capítulo se proponen modificaciones relacionadas con las características y las fronteras de varios terrenos incluidos el Chibcha, el Tahamí y el Calima. Algunos pequeños terrenos que han sido propuestos recientemente, entre ellos el Anacona, el Ebéjico (Quebradagrande) y el Pozo (Arquía), se localizan dentro del contexto de los grandes terrenos. También, se definen y describen nuevos terrenos, incluidos el Yalcón, el Bocaná, el Aburrá, el Kogi y el Tairona. Con los datos geocronológicos recientes disponibles se propone que el Complejo Cajamarca sea remplazado por dos nuevas unidades litodémicas: el Complejo Antioquia que agrupe rocas formadas durante un evento metamórfico pérmico–triásico y el Complejo Coello que agrupe rocas formadas por metamorfismo jurásico. Además, se sugieren futuras líneas de investigación para resolver las incógnitas que quedan por solucionar, en particular en relación con las fronteras de algunos de los nuevos terrenos.
Palabras clave: *terrenos continentales, acreciones, terrenos desplazados, Colombia, Andes.*

Citation: Restrepo, J.J. & Toussaint, J.F. 2020. Tectonostratigraphic terranes in Colombia: An update. First part: Continental terranes. In: Gómez, J. & Mateus–Zabala, D. (editors), The Geology of Colombia, Volume 1 Proterozoic – Paleozoic. Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 35, p. 37–63. Bogotá. https://doi.org/10.32685/pub.esp.35.2019.03

1. Introduction

The concept of terranes, which emerged in the 1970s in western North America (Berg et al., 1978; Coney et al., 1980; and others), has been used in Colombia since 1983, particularly in two regional studies that suggested that the northwestern corner of South America consists of a mosaic of terranes, which would have been accreted into the Amazonian Craton during several geological periods. A recompilation that was conducted by the Servicio Geológico Colombiano (SGC) and coordinated by Etayo–Serna et al. (1983) proposed 34 terranes or geological provinces primarily based on the lithostratigraphy of each terrane or province. Restrepo & Toussaint (1988) focused on comparing and contrasting the lithostratigraphic and tectonic characteristics of each of the five proposed megaterranes. Toussaint & Restrepo (1989) named each terrane after a pre–Columbian ethnic group to avoid confusion with the names of formations, groups, or geological provinces and proposed a new map. In addition to the cratonic region, the Terranes Andaquí, Chibcha, and Tahamí, which have continental basements, and the Terranes Calima and Cuna, which have oceanic basements, were proposed from east to west. Subsequently, other authors (e.g., Restrepo–Pace et al., 1997; Cediel et al., 2003; Moreno–Sánchez & Pardo–Trujillo, 2003; and others) conducted regional studies by using the concept of terranes. New terranes were identified in the area between the Tahamí and Calima Terranes, that is, between the continental and oceanic domains, namely, the Panzenú, Anacona, Pozo (Arquía), Ebéjico (Quebradagrande), and Amagá–Sinifaná Terranes, among others, which divide megaterranes into smaller terranes (e.g., Ordóñez–Carmona & Pimentel, 2002; Restrepo et al., 2009; Martens et al., 2014). Some terrane names, which are indicated in parentheses previously, were also changed to indigenous names. The use of U–Pb zircon in situ dating with laser ablation multi–collector inductively coupled plasma mass spectrometry (LA–MC–ICP–MS) reassessed the ages of several metamorphic units that were previously determined based on K–Ar and Rb–Sr dating, which changed the characteristics of the terranes. Moreover, several research studies sought to locate the terranes of Colombia within the geodynamic framework of the relationships among the Amazonian Craton, Laurentia, Pangea, proto–Caribbean, Caribbean, and other terranes in the region (i.e., Kennan & Pindell, 2009).

Based on the above topics, an updated overview of the terranes of Colombia is performed (see Figure 1). The continental terranes are treated in this chapter, whereas the oceanic terranes are examined in another chapter in this multivolume book (Toussaint & Restrepo, 2020). Furthermore, new questions are raised for future research studies because one can no longer understand the geological relationships among neighboring areas that belong to different terranes and the geological evolution of Colombian territory while disregarding the theory of tectono–stratigraphic terranes, especially in an area bordering the Pacific Ocean. This task would be similar to trying to understand the relationships between living beings while disregarding the concept of biological evolution.

However, some recent articles presented autochthonistic models based on abundant geochemical and geochronological data (i.e., Cochrane et al., 2014a), but some critical field relationships were not discussed in depth. In addition, well–known important geological facts that imply the terrane concept to be explained were not mentioned. Although new instrumental measures are very important in geology, good field work is irreplaceable.

2. Amazonian Craton in Colombia

2.1. Introduction

In Colombia, the geological units that are considered to be autochthonous in relation to the Amazonian Craton are located between the foothills of the Garzón Massif and Eastern Cordillera and the borders with Venezuela, Brasil, and Perú.

The Amazonian Craton in Colombia mainly consists of a metamorphic basement called the Mitú Migmatitic Complex, which is Paleoproterozoic in age and is affected by syn– and post–tectonic plutonism, some of which is anorogenic, of intermediate to acidic composition and Mesoproterozoic in age. Local sedimentary rocks, which were sometimes affected by low–grade Neoproterozoic metamorphism, cover the high–grade metamorphic basement. These rocks include the Tunuí Group, La Pedrera Formation, and the Piraparaná Formation. Paleozoic, Cretaceous, and Cenozoic sedimentary rocks cover a great portion of the Precambrian basement.

2.2. Characteristics of the Autochthonous Region

In the eastern region of Colombia along the borders with Brasil and Venezuela, high–grade metamorphic rocks were described by Galvis et al. (1979), who named these rocks the Mitú Migmatitic Complex. This unit was renamed the Mitú Complex to include magmatic rocks (López et al., 2007), but this terminology has not been widely accepted (i.e., Rodríguez et al., 2011). Because of the diversity of rocks in the area, Ibañez–Mejia & Cordani (2020) recommend discontinuing the use of this name. The rocks are mostly migmatites, granitic gneisses, amphibolites, and granitoids. According to Cordani et al. (2016), two different belts are present in the area: the Atabapo belt, which was named after the Atabapo River along the border between Colombia and Venezuela, and the Vaupés belt. In the Atabapo belt, the rocks range in age from 1800 to 1740 Ma (U–Pb zircon ages for all the dates in this paragraph), while the rocks in the Vaupés belt range from 1580 to 1520 Ma. In the younger Vaupés belt, older rocks from 1780 to 1740 Ma are considered "basement inliers". A

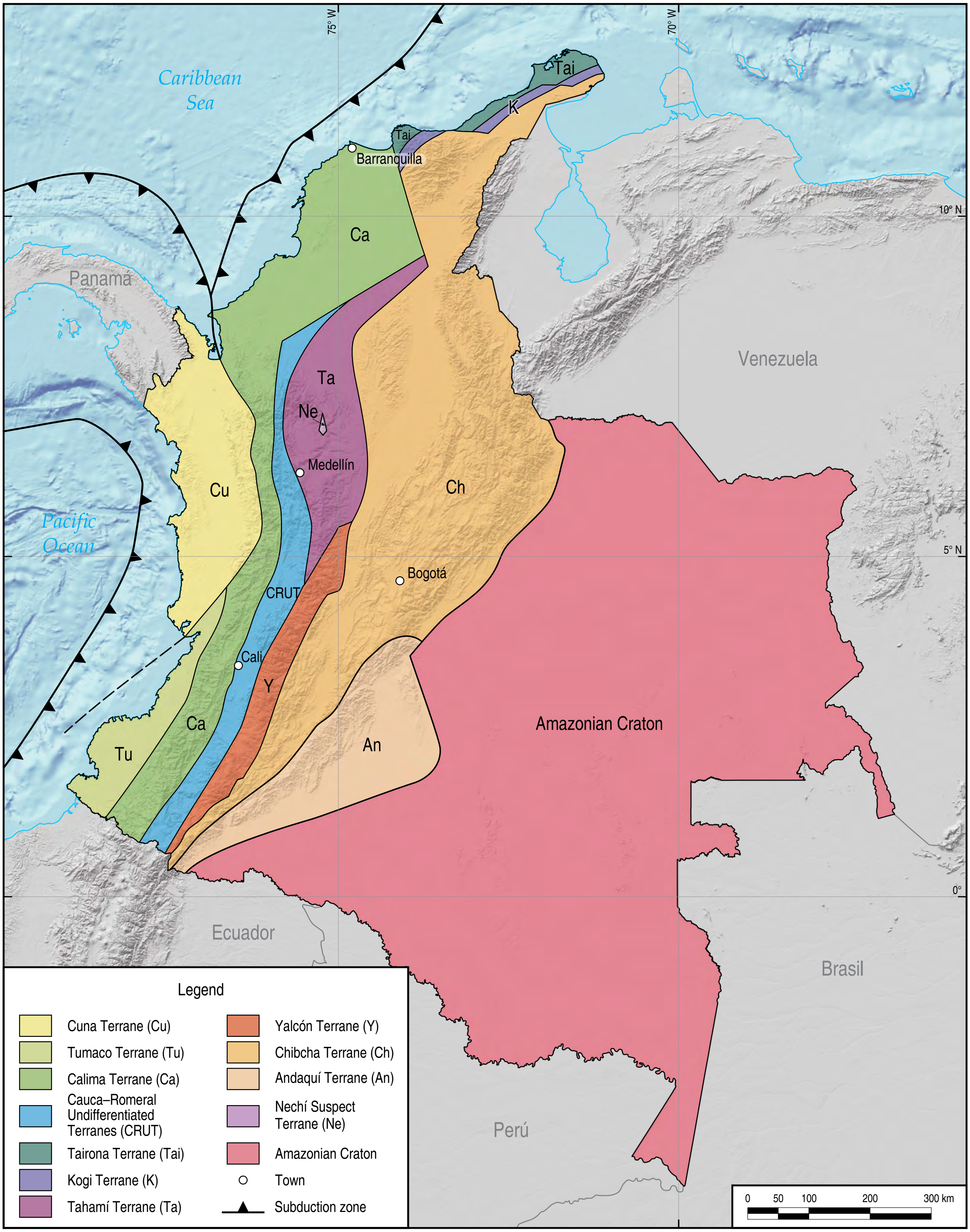


Figure 1. Schematic map of the proposed geologic terranes in Colombia: (An) Andaquí Terrane; (Ch) Chibcha Terrane; (Y) Yalcón Terrane; (Ta) Tahamí Terrane; (K) Kogi Terrane; (Ca) Calima Terrane; (Tu) Tumaco Terrane; (Tai) Tairona Terrane; (Cu) Cuna Terrane; (Ne) Nechí Suspect Terrane; (CRUT) Cauca–Romeral Undifferentiated Terranes: strips formed by smaller continental and oceanic terranes, such as the Pozo (Arquía), Ebéjico (Quebradagrande), and Amagá–Sinifaná Terranes, among others.

similar situation occurs within the Araracuara basement, which was dated between 1725 and 1756 Ma (Ibañez–Mejia et al., 2011; Cordani et al., 2016), but datings in the nearby Apaporis River yielded ages between 1593 and 1530 Ma, with the older ages interpreted by the latter authors as basement inliers. These units belong to the so–called Río Negro–Juruena Province of the Amazonian Craton (Cordani et al., 2000).

The Mitú Migmatitic Complex is intruded by several plutons and particularly by the Parguaza Batholith, whose western edge crops out in Colombia between Puerto Carreño and Inírida and spans over 30 000 km^2 in Venezuela. Generally, these rocks are monzogranites with Rapakivi–type orbicular texture such as the Mitú Monzogranite or the Matraca Granite, syenogranites such as the Parguaza Syenite, and potassium granites with riebeckite. The Parguaza Granite is an A–type granite that corresponds to intraplate anorogenic intrusions. In the Venezuelan portion of the granite, only a conventional U–Pb age of 1.54 Ga and Rb–Sr isochron ages of 1531 and 1545 Ma were obtained (Gaudette et al., 1978); in the western portion in Colombia, eight Ar–Ar datings in biotite and hornblende yielded ages from 1237 to 1383 Ma (Ochoa et al., 2012), while two ages of 1401 ± 2 and 1392 ± 5 Ma were obtained by U–Pb LA–ICP–MS in zircons (Bonilla–Pérez et al., 2013). Although these later authors argued that the Colombian portion of the granite was younger, another possibility is that the conventional method that was used for the Venezuelan sample did not date the intrusion's age. The small Matraca Granite, which is another anorogenic granite near Inírida, was dated at 1343 ± 8 Ma (Bonilla et al., 2016).

In Guainía, the Mitú Migmatitic Complex is unconformably covered by sedimentary or metasedimentary sequences. Gold–bearing metasedimentary rocks in Guainía and Vaupés yielded detritic zircon ages that indicated a maximum deposition age of 1776 Ma (Amaya et al., 2017), enabling these researchers to correlate these rocks with the Tunuí Group in serranía de Naquén, which consists of a basal metaconglomerate, metamudstone, quartzite, and phyllites that were metamorphosed in the greenschist facies (Renzoni, 1989; González, 1989). The general sedimentation environment was fluvial and deltaic with tidal flat deposits and meandering rivers. In the Amazon Region, the cover is represented by La Pedrera and Piraparaná Formations (Galvis et al., 1979). La Pedrera Formation consists of very low–grade metamorphic rocks, mainly metaconglomerates and metasandstones, while schistose quartzites are covered by the Piraparaná Formation, which consists of a volcanic material that includes rhyolitic and rhyodacitic lavas, pyroclasts, agglomerates, doleritic dikes and sills, and gabbros such as the Tijereto Gabbro (Galvis et al., 1979). Arkose sandstones and ferruginous sedimentites are associated with this volcanic sequence. Priem et al. (1982, 1989) obtained an Rb–Sr age of 1200 Ma and several K–Ar ages from 920 Ma to 732 Ma for the volcanic rocks in the Piraparaná Formation, which may suggest a late Neoproterozoic event.

The origin of the granitic rocks in the Mitú Complex has been subjected to different interpretations. The Parguaza and Matraca Granites are generally agreed to be anorogenic granites (Gaudette et al., 1978; Bonilla et al., 2016). Based on chemical analyses of the granitic orthogneisses in the Mitú area, Rodríguez et al. (2011) showed that these rocks plotted entirely within the field of A–type granites, while Cordani et al. (2016) considered that these rocks formed during orogenic cycles. Defining the true nature of these granites is important to understand the evolution of the craton.

In the Guayana Shield, a very low– to low–grade metamorphism event, which is reflected in some K–Ar datings for the Mitú Complex at that age, is called the Nickerie event (1400–1200 Ma). This regional intraplate thermal event affected the entire crust (Cordani et al., 2016). The event was followed by the development of major faults, which are mainly oriented in the NW direction and are associated with intense mylonitization. Notwithstanding, as noted by Kroonenberg (1982a), the characteristics of the Nickerie event in the Guayana Shield in general and the Orinoquia and Amazonia regions in particular seem very different from those in the Precambrian region of the Garzón Massif in the Andaquí Terrane. Intraplate magmatism occurred locally in the region of San José de Guaviare with the intrusion of peralkaline nepheline syenites. Priem et al. (1982) reported Rb–Sr and K–Ar ages from 445 to 495 Ma, and Rodríguez et al. (2011) determined U–Pb zircon and Ar–Ar biotite ages from 577 to 494 Ma. The oldest age was interpreted as the intrusion age during the Pan–African Orogeny that affected Gondwana, while the Ordovician age was interpreted as the cooling event.

Because of the anorogenic origin of many of the granites in this area, including the Parguaza Granite, the extensive formation of anorogenic granitoid rocks from 1400 Ma to around 600 Ma was an important continental–crust builder in the area of the NW Amazonian Craton as contrasted with subduction–related magmatic rocks.

The younger units, particularly those with lower Paleozoic, Mesozoic, and Cenozoic sedimentites, are components of the Amazonian Craton–Andaquí Supraterrane and will be discussed below, as well as the position of the boundary between the Amazonian Craton and the terranes to the west.

3. Andaquí Suspect Terrane

3.1. Introduction

Located between the eastern edge of the Eastern Cordillera and the Llanos Orientales, the Andaquí Terrane crops out between latitudes 1° N and 3° 30' N. This terrane is elongated in the N–NE direction and essentially consists of the Garzón Massif and the serranía de La Macarena, which are basement blocks that were uplifted at the end of the Cenozoic.

A review of the Colombian terranes by Etayo–Serna et al. (1983) considered the existence of both the serranía de La Macarena Terrane and Garzón Terrane. Toussaint & Restrepo (1989) defined the Andaquí Terrane as including both terranes, whereas Gómez et al. (2015a) posited that these rocks belonged to the Chibcha Terrane.

The Andaquí Terrane is characterized by a continental basement that experienced high–grade metamorphism in the Stenian – Tonian period during the Grenvillian Orogeny.

3.2. Andaquí Terrane's Characteristics

The Garzón Group (Álvarez, 1981; Kroonenberg, 1982b), which mainly consists of a banded sequence of granulites and the Guapotón and Mancagua augen gneisses, is the basement of the Andaquí Terrane that crops out in the Garzón Massif and serranía de La Macarena. This group consists of banded granulites, felsic charnockitic granulites, granitic orthogneisses, amphibolites, paragneisses, quartzites and marbles. Based on several U–Pb, Pb–Pb, Ar–Ar, and Sm–Nd datings, Cordani et al. (2005) specified a Grenvillian age for the Guapotón–Moncagua Gneisses, El Vergel Granulites, and Las Margaritas Gneisses, which comprise the basement of the Garzón Massif. The datings by Ibañez–Mejia et al. (2011, 2015), who used the U–Pb zircon LA–MC–ICP–MS method, indicated that the genesis of the igneous protoliths occurred between 1.47 and 1.15 Ga. Some oil wells in the Putumayo Basin reached the basement. Thus, a migmatitic gneiss was dated at 986 Ma in the Payara–1 well, a migmatitic paragneiss in the Solita–1 well was dated at 1046 Ma, an amphibolite in the Mandur–2 well was dated at 1019 Ma, and a leuco–monzonite in the Caimán–3 well was dated at 952 Ma (Ibañez–Mejia et al., 2011). These results confirmed the Grenvillian age for the metamorphism of the Andaquí Terrane during the Putumayo Orogeny (Ibañez–Mejia et al., 2015). However, for these authors, the Putumayense Orogeny occurred because of the collision of NW Amazonia (present coordinates) with Baltica, while the Grenville Orogeny occurred because of the collision of western Amazonia with Laurentia, both occurring during the assembly of Rodinia.

The high–grade metamorphic rocks in the serranía de La Macarena are covered by marine sedimentites from the Güejar Group (Trumpy, 1943; Bridger, 1982), which were dated as Cambrian – Ordovician by numerous fossils, including trilobites, brachiopods, and graptolites (Harrington & Kay, 1951).

3.3. Andaquí Terrane's Boundaries with the Autochthonous Region and Accretion Age

A westward–dipping reverse–fault system, such as the Caguán and El Paujil Faults, overthrusts the Garzón Massif and serranía de La Macarena on the Llanos Orientales Basin (Figure 2). Notwithstanding, this complex network, which consists of faults that experienced important Cenozoic and particularly Miocene – Pliocene movements, is not the original suture, which is located below the thick sedimentary sequence of the basin's borders; therefore, the original area of the Andaquí Terrane would be considerably larger than the exposed section, which is shown in Figure 1. This suture would be located between the Mandur–2 well, which was amphibolite U–Pb zircon dated at 1019 Ma (Ibañez–Mejia et al., 2011), that is, Grenvillian in age, and belongs to the Andaquí Terrane, and a syenogranitic gneiss that was dated at 1756 Ma by U–Pb zircons (Cordani et al., 2016) and belongs to the Amazonian Craton near Araracuara at the confluence of the Yarí and Caquetá Rivers. NE of serranía de La Macarena, the boundary is also covered by Cenozoic sedimentites. The accretion would have occurred by the late Neoproterozoic. Additionally, many faults that currently delimit various Colombian terranes experienced important Cenozoic and particularly Miocene – Pliocene movements, implying that the characteristics of the original sutures are barely known. Based on the above, most of the current cartographic limits between terranes should not be considered to have been the original sutures or boundaries.

The Putumayo Orogeny (Grenvillian) in the Andaquí Terrane, which experienced high–grade metamorphism and intense tectonism, has the characteristics of a continental–collision orogeny. This orogeny occurred during the assemblage of the Rodinia supercontinent by the collision of Laurentia with western Amazonia and southern Baltica with NW Amazonia (Cawood & Pisarevsky, 2017; Ibañez–Mejia et al., 2011). One of the characteristics of this type of mountain chain is the overthrusting of the deepest metamorphic units of the roots, which then became allochthonous (Figure 3). Thus, the Garzón Group may have assimilated the roots of the mountain chain that were thrusted east over the Amazonian Craton or autochthonous block. In this hypothesis, the accretion of the Andaquí Terrane would have occurred at the end of the Putumayan Orogeny. Ibañez–Mejia et al. (2015) considered that a large portion of the Putumayo Orogeny formed during "the accretion of fringing arc terranes against the [Amazonia] continental margin". However, this concept cannot be discarded at the end of the Neoproterozoic during the assemblage of the Pannotia supercontinent. In any case, the accretion occurred before the sedimentation of the lower Paleozoic rocks because lower Paleozoic sedimentites such as those of the Güejar Group, Negritos Formation, and Araracuara Formation are found on both sides of the boundary (Restrepo & Toussaint, 1988).

The lack of paleomagnetic and microtectonic data from the area and the thick sedimentary cover of the boundary prevents us from defining the original position of the terrane, although the collisional nature of the chain does not suggest that this area formed as a completely autochthonous block.

However, the hypothesis that the Andaquí and Chibcha Terranes are allochthonous with respect to the Amazonian Craton does not imply that they were generated at considerable distances from Amazonia. Even though both the Andaquí and Chibcha Ter-

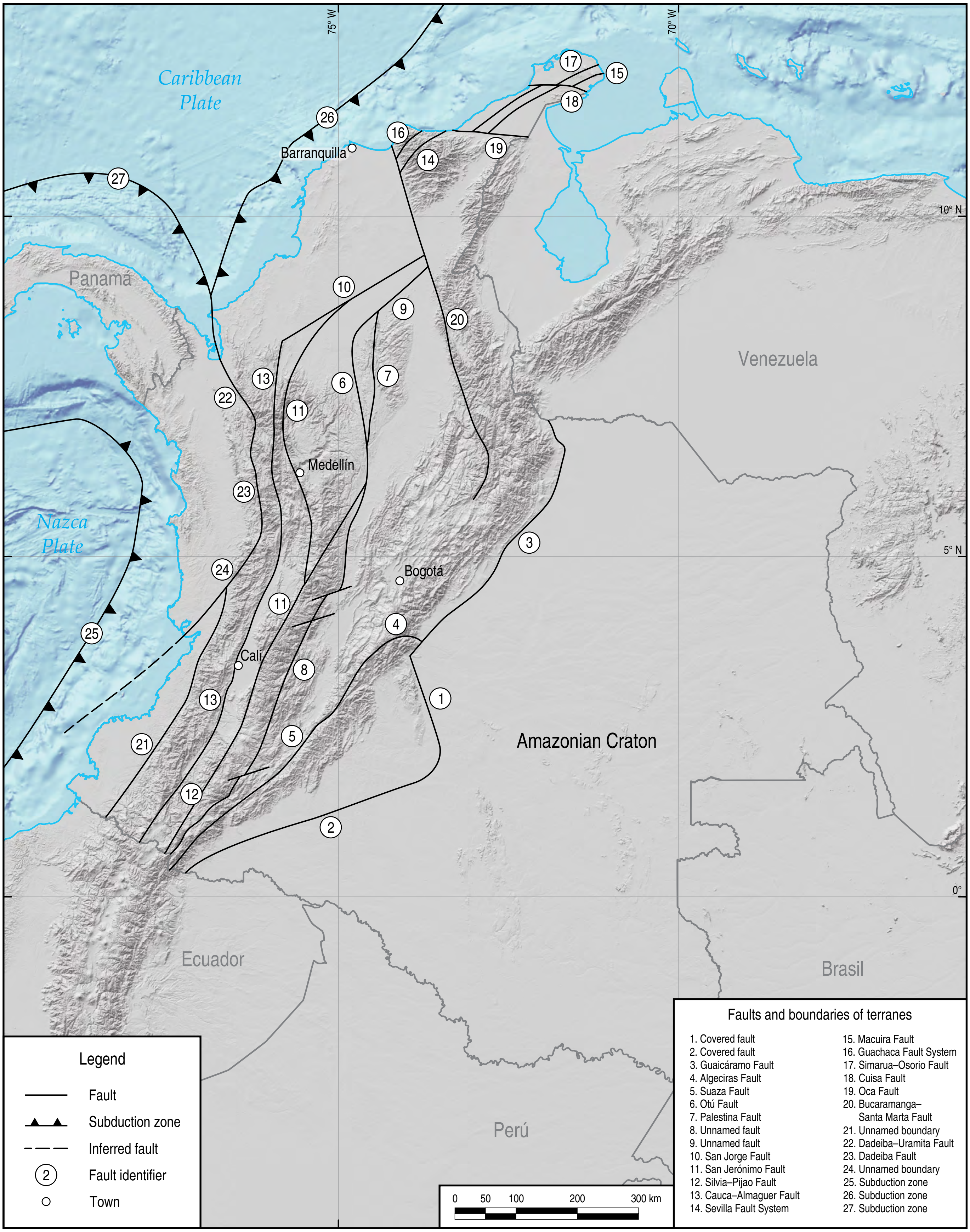


Figure 2. Map that shows the main faults in Colombia.

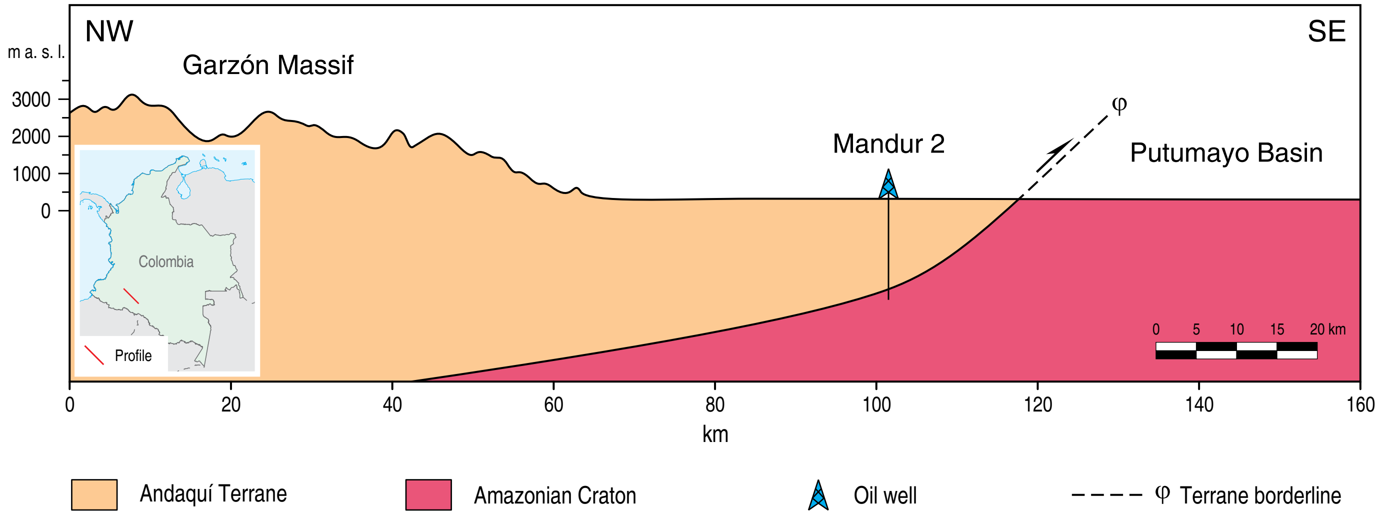


Figure 3. Overthrusting of the present Andaquí Terrane on the Amazonian Craton during the Putumayo Orogeny.

ranes have basements that formed during the Putumayan Orogeny as part of a larger Grenvillian event, this fact does not by itself imply that these rocks are components of the same terrane.

The Andaquí Terrane's western boundary with the Chibcha Terrane is quite complex, mostly because of important post–accretion movements. The current western boundary is represented, from north to south in the vicinity of the town of San Luis de Cubarral, by an east–west reverse fault that overthrusts the Andaquí Terrane on the Chibcha Terrane. Farther south, the limit is represented by the Altamira reverse fault, a short portion of the Algeciras dextral fault, and the Suaza reverse fault, which overthrusts the Andaquí Terrane on the Chibcha Terrane.

The late Paleozoic age of the Chibcha Terrane's accretion into the assemblage that comprises the Amazonian Craton and Andaquí Terrane will be discussed below.

3.4. Amazonian Craton–Andaquí Terrane Supraterrane

In the Macarena and Garzón Massifs, the unmetamorphosed Güejar Group, which was dated by abundant Cambrian – Ordovician fossils, is well known. The basal unit of the Güejar Group is represented by the Calizas de Ariari, which was detected during hydrocarbon explorations in the Amazonian Craton. The Güejar Group (Trumpy, 1943) is correlated with several sedimentary units that cover the craton, such as the Huitoto and Macaya (Bogotá, 1982), Araracuara (Herrera & Velásquez, 1978), and Negritos Formations, which were dated as Ordovician (Ulloa et al., 1982). The upper Paleozoic is largely absent from the Amazonian Craton region and Andaquí Terrane, although some thin layers that were found during hydrocarbon explorations in the Llanos Orientales may be upper Paleozoic (Agencia Nacional de Hidrocarburos, 2012). This characteristic of the Autochthonous Region–Andaquí Terrane strongly differentiates this assemblage from the processes that occurred to the west in the Chibcha Terrane, where the Cambrian and Ordovician are metamorphosed and the upper Paleozoic forms a thick sequence that will be discussed below.

4. Chibcha Terrane

4.1. Introduction

The Chibcha Terrane is located in the Eastern Cordillera, Santander Massif, serranía de Perijá, Magdalena River Valley, and eastern flank of the Central Cordillera. In this study, the SE regions of Sierra Nevada de Santa Marta (SNSM) and La Guajira Peninsula are also included in the Chibcha Terrane.

The review of Colombia terranes by Etayo–Serna et al. (1983) considered that this region consists of seven terranes and/or geological provinces. Restrepo & Toussaint (1988) defined the characteristics of an Eastern Andean Terrane, and Toussaint & Restrepo (1989) named this terrane the Chibcha Terrane. According to Gómez et al. (2015a), the Andaquí Terrane would be included in the Chibcha Terrane.

The Chibcha Terrane mainly consists of a Grenville metamorphic basement, primarily Stenian – Tonian, and a low– to medium–grade Famatinian (Caledonian) metamorphic event. Magmatism of intermediate to acidic composition prior to the Devonian mainly affected the Santander Massif, followed by an important late Paleozoic marine sedimentation that occurred throughout the Chibcha Terrane. Its accretion into the Amazonian Craton and Andaquí Terrane may have been late Paleozoic in age.

4.2. Characteristics of the Chibcha Terrane

The basement of the Chibcha Terrane is characterized by high–grade metamorphic rocks that formed during the Grenville tectogenesis. These rocks are primarily granitic gneisses, migmatites, amphibolites, paragneisses, marbles, and schists.

In the Santander Massif, the basement is identified as Bucaramanga Gneiss, in SNSM as Los Mangos Granulite, and in the eastern flank of the Central Cordillera as the San Lucas, El Vapor, and Guamocó Gneisses. The southernmost region of the terrane includes small outcrops such as the Davis Gneiss, Icarco Complex, and El Pital and Zancudo Migmatites.

The presence of a Precambrian basement in the Chibcha Terrane is corroborated by multiple radiometric data that indicate Grenville and late Neoproterozoic events. The Bucaramanga Gneiss, which mainly consists of quartz–feldspathic gneisses, granulites, orthogneisses, amphibolites, quartzites, and marbles, has been dated by K–Ar, Rb–Sr, and Ar–Ar between 945 Ma and 574 Ma (Goldsmith et al., 1971; Ward et al., 1973; Restrepo–Pace et al., 1997). Cordani et al. (2005) obtained a SHRIMP U–Pb zircon age of 864 Ma, which is interpreted as a metamorphic event.

Grenvillian ages were found for the section of the Chibcha Terrane in the eastern flank of the Central Cordillera; in particular in El Vapor Gneiss, El Hígado Amphibolite, El Pital Migmatite, and Zancudos Migmatite; and in the serranía de San Lucas. In fact, metamorphism ages between 1180 and 930 Ma were obtained by U–Pb LA–ICP–MS in zircons from a granulite in the San Lucas Gneiss, while the igneous age was defined as 1527 Ma (Cuadros et al., 2014); the Guamocó Gneiss was dated at 1048 Ma by U–Pb LA–ICP–MS (Leal–Mejía, 2011); both rocks are components of the serranía de San Lucas.

El Vapor Gneiss at latitude 6° 30’ N was dated at 894 ± 36 Ma by Rb–Sr WR isochrons (Ordóñez–Carmona et al., 1999); in this case, the age may correspond to a period of mylonitization. El Hígado Amphibolite to the west of the Garzón Massif was dated by Ar–Ar at 911 Ma (Restrepo–Pace et al., 1997). El Pital and Zancudo Migmatites (latitude 2° N) were dated between 1005 Ma and 972 Ma by U–Pb LA–MC–ICP–MS by Ibañez–Mejia et al. (2011).

The problems that are posed by Mesozoic dating in the Migmatitic Complex of La Cocha–Río Téllez, the metamorphic Complex of Aleluya, and the Tierradentro Gneisses and Amphibolites will be analyzed below.

Perhaps the most distinguishing feature of the Chibcha Terrane is the widespread metamorphism that affected Cambrian – Ordovician and Silurian sedimentary rocks. These metamorphic rocks are covered in several locations by unmetamorphosed Devonian sedimentary rocks, which indicate a Famatinian Orogeny. Neither the sedimentary rocks that cover the Andaquí Terrane nor the craton were affected by this metamorphism.

The early Paleozoic region of the Chibcha Terrane is represented by several assemblages, which include metasedimentary sequences that were affected by very low– to medium–grade metamorphism. The age of the protoliths is recognized, in some cases, by the presence of a few relatively well–preserved Ordovician fossils, and the age of the tectometamorphic event has been detected by both geochronological methods and the stratigraphic position of the overlying Devonian sedimentary formations. This Famatinian tectogenesis is well marked in the Quetame Massif by low–grade metamorphic rocks from the Quetame Group, which are covered by the Devonian Gutiérrez Sandstones (De La Espriella & Cortés, 1989); the Floresta Massif with the Busbanzá Phyllites and Schists, which was intruded by the Chuscales Pluton at 471 ± 22 Ma (Manosalva et al., 2017); the Santander Massif with Silgará Schists and Chicamocha Schists, whose metamorphism was defined as Famatinian (or Quetame–Caparonensis) by detrital zircons (Mantilla–Figueroa et al., 2016); the Perijá Andes with the Perijá Formation (Forero, 1970); the eastern flank of the Central Cordillera with La Cristalina Formation, which contains Ordovician graptolites and a low–grade metamorphic event up to a biotite isograd that unconformably cover high–grade metamorphic rocks from El Vapor Gneiss; and the southern portion of the Chibcha Terrane by the Amoyá and El Hígado Formations (Núñez et al., 1984; Mojica et al., 1988). Some of these pre–Devonian low–grade metamorphic rocks were deposited over high–grade Precambrian metamorphic rocks and have Ordovician fossils. The lithology of these units mainly consists of chloritic and muscovitic schists, phyllites, slates with some quartzite levels, and metaconglomerates with scarce marble. Ordovician fossils are found in La Cristalina, El Hígado, and Río Nevado Formations. The position of the Pompeya Metamorphites, Mazamorras Schists, Vitonco Metasedimentites, and Chingual Formation in southern Colombia suggests that these rocks could be correlated with formations that were affected by low–grade metamorphism during the early Paleozoic, although some of these rocks would have been affected by Jurassic metamorphism, which will be discussed below. Low– to medium–grade metamorphic units of Famatinian age are unconformably covered by well–dated sedimentary sequences of Devonian age, which is the case for sedimentary sequences such as the Devonian sedimentites of the Rovira, El Imán Formation, and Jagua and Granadillo Mudstones and Limestones, as dated by fossils.

In the Santander Massif, a key magmatic event occurred at the end of the Famatinian tectogenesis and before the deposition of Devonian sedimentites. These rocks are hornblendic metadiorites, syntectonic gneissic granites, granodiorites, and gabbros that were dated between 471 and 413 Ma (Boinet et al., 1985). In the Floresta Massif, the Chuscales granitic stock was Rb–Sr dated at 471 ± 22 Ma (Ulloa & Rodríguez, 1982). In the Quetame Massif, several small plutons intruded the metamorphic rocks of the Quetame Group and are unconformably covered by Devonian sedimentites (Renzoni, 1968).

After the erosional period that followed the Famatinian tectogenesis and emplacement of pre–Devonian plutons, which is marked by the absence or scarcity of Silurian sedimentites throughout the Colombian territory, the sea transgressed on a relatively well–leveled erosion surface. The main outcrops of Devonian sedimentites in Colombia are located in the serranía de Perijá, the Santander Massif through Las Mercedes Formation, La Floresta Massif through the Tíbet and La Floresta Formations, the Quetame Massif through the Gutiérrez Sandstones and Portachuelo Lutites, and Rovira near Ibagué along the eastern flank of the Central Cordillera. The ages of these formations were proven by the presence of numerous fossils.

In Colombia, non–metamorphosed, thick sequences of sedimentites of Carboniferous and Permian age are only found in the Chibcha Terrane, in which important epicontinental marine sequences were deposited; in the Llanos Basin, only thin upper Paleozoic sequences have been found (Agencia Nacional de Hidrocarburos, 2012). The Carboniferous is mainly represented by compact quartz sandstones that are frequently red, associated with gray–to–red limestones that are sometimes oolitic, and dark lutites with numerous fossils, particularly brachiopods, bryozoans, and crinoids, which show that the base of the Mississippian is generally absent and indicate the beginning of the transgression at the end of this period or the beginning of the Pennsylvanian. The Permian primarily consists of massive gray limestones, dark lutites, and few sandstones. These rocks were only clearly detected in the Santander Massif and serranía de Perijá and show fossiliferous levels with fusulinids and algae. During the Carboniferous and Permian, sedimentation was characterized by both clastic and calcareous deposits, indicating a shallow–marine platform environment. In several regions, these sedimentites are layered in angular unconformities over Devonian sedimentary sequences or Cambrian – Ordovician and Precambrian metamorphic complexes, although concordance between Devonian and Carboniferous layers is observed in other areas.

4.3. Chibcha Terrane's Accretion into the Andaquí Terrane–Amazonian Craton Assemblage

At the end of the Paleozoic, the Chibcha Terrane accreted into the assemblage that had consisted of the Andaquí Terrane and Amazonian Craton since the end of the Precambrian or earlier. Large differences between the geologic processes that occurred on both sides of the boundary are noted during the Paleozoic.

The differences are well marked during the early Paleozoic, when the important Famatinian tectogenesis occurred in the Chibcha Terrane, including the Quetame Massif now being adjacent to the craton, whereas calm marine sedimentation occurred on the other side of the boundary. Differences are also noted in the development of pre–Devonian, intermediate to acidic magmatism in the Chibcha Terrane, whereas no magmatism was detected in the Amazonian Craton. The differences continued during the late Paleozoic with important marine sequences in the Chibcha Terrane, whereas these rocks are very thin or absent from the Amazonian Craton (Agencia Nacional de Hidrocarburos, 2012). Thus, Devonian sequences with thicknesses that exceed 2400 m occur in the Quetame Massif, and Carboniferous sequences with thicknesses that exceed 2000 m occur in the Labateca and Río Batá areas; however, no evidence of this thick deposition is found east of the boundary.

Regarding the type of movement of the boundary, only a dextral movement can be assumed at that time because of the dextral movement of North America in relation to the Amazonian Craton during the Paleozoic and the faunal similarity of the later Devonian, Carboniferous, and Permian rocks in Colombia with those of the SW region of North America (see, in particular, Forero, 1984; Dalziel, 1997). Thus, the Chibcha Terrane most likely was derived from the vicinity of this region, and accretion probably occurred during the complex movements between Gondwana and Laurentia, which ultimately facilitated the formation of Pangea. In contrast, early Mesozoic units, such as the Saldaña Formation (Upper Triassic) and Motema Formation (Jurassic), are located on both sides of the eastern boundary of the Chibcha Terrane. Thus, an assemblage called "Colombian East" formed at the end of the Paleozoic or beginning of the Mesozoic, which brought together the autochthonous Amazonian Craton, the Andaquí Terrane, and the Chibcha Terrane.

4.4. Chibcha Terrane's Boundaries

A section of the Chibcha Terrane's boundary with the Amazonian Craton is found to the north of Villavicencio. This boundary is currently represented by the Guaicáramo Fault System, which has reverse characteristics at the latitude of Nevado del Cocuy and dextral movement farther south. This network of faults experienced an important Cenozoic movement and is therefore not the original boundary. The Chibcha Terrane's boundary with the assemblage that consisted of the autochthonous regions and the Andaquí Terrane during the Neoproterozoic has been previously treated.

The data that have been collected thus far indicate that the Chibcha and Tahamí Terranes have quite different histories. The extensive Jurassic plutonism that occurred in the Chibcha Terrane had no effect on the Tahamí Terrane, whereas the Permian – Triassic metamorphism and intense Late Cretaceous magmatism of the Tahamí Terrane had no effect on the western boundary of the Colombian East, as confirmed by the presence of non–metamorphosed, Paleozoic sedimentary rocks in the Chibcha Terrane. The compressional tectonic events that affected the Tahamí Terrane during the Cretaceous also clearly contrast with the environment of calm distension that occurred during that time in the Chibcha Terrane. The boundary between these terranes is represented by the Otú Fault, which was intersected during the Paleocene by the Palestina Fault. The large differences on both sides of the Otú Fault had already been detected by Feininger (1970). The northern boundary in the Plato depression is covered by a thick sequence of Cenozoic sedimentites. In this study, the basement of this area is assumed to be oceanic, as proposed by Mora–Bohórquez et al. (2017) based on seismic profiles.

4.5. Post–accretion Events in the Colombian East Supraterrane

After the formation of the Colombian East, the supraterrane that comprised the Amazonian Craton, the Andaquí Terrane, and the Chibcha Terrane was characterized by an important Triassic and Jurassic magmatism event that affected the western region of the Colombian East and a very thick sequence of Cretaceous marine sedimentites that deposited in a calm subsidence environment without interruptions by any compressional tectonic movement. This situation shows a strong contrast between the processes that occurred during the Mesozoic in the Colombian East with those in the westernmost regions of the country, particularly in the Tahamí Terrane and terranes with oceanic basements, which experienced important metamorphic and magmatic events and intense tectonism.

Since the Late Triassic, an environment of regional distension permitted the formation of grabens that were limited by normal faults, and important clastic sedimentary sequences, most of which were continental, were deposited, including the Girón Group, the Quinta Formation in serranía de Perijá, and the Luisa Formation. Some small marine incursions were detected, including the Payandé Formation, the Morrocoyal Formation in serranía de San Lucas, and the Batá Formation north of the Quetame Massif. Volcanism of quite varied composition, such as the Saldaña Formation, occurred during the Early Jurassic; this formation consists of banks of limestones, siltstones, and conglomerates that were intercalated with rhyolitic, dacitic, andesitic, and basaltic lavas. The fauna indicates a Late Triassic to Early Jurassic age (Mojica, 1980; Mojica & Macía, 1981).

An important Jurassic magmatism event affected the western boundary of the Chibcha Terrane and its eastern boundary in the Santander Massif. It includes several important batholiths in the SNSM that will be discussed below, the Rionegro Batholith, which was dated between 196 and 172 Ma in the Santander Massif; the Norosí and Guamocó Batholiths in Serranía de San Lucas; the Norosí and Guamocó Batholiths in serranía de San Lucas, which were dated between 187 and 174 Ma (Leal–Mejía, 2011); and the Segovia and Ibagué Batholiths along the eastern flank of the Central Cordillera, which were dated at approximately 189 and 166 Ma by U–Pb dating, respectively (Leal–Mejía, 2011; Bustamante et al., 2010, 2017). In the southern portion of the terrane, several intrusives were dated at 187–170 Ma (Jaramillo et al., 1980; Arango et al., 2015; Zapata et al., 2015). The Mocoa Monzogranite was dated between 181 and 170 Ma, and the Algeciras and Altamira monzogranites and Teruel Latite were dated between 172 and 169 Ma. Some of metamorphic rocks associated to these igneous bodies were attributed to La Cocha–Río Téllez Migmatitic Complex (Zapata et al., 2017).

A recent study by Rodríguez et al. (2017) showed that the so–called Ibagué Batholith actually consists of two bodies: one that was subjected to metamorphism and another that is exclusively igneous. A similar situation likely occurs in the southernmost region. The metamorphic rocks in the Tierradentro Gneisses and Amphibolites and La Cocha–Río Téllez Migmatitic Complex also likely belong to various units, albeit undifferentiated (see the discussion of the Yalcón Terrane below).

The massive volume of magma that intruded during the Jurassic stands out, being the most important magmatic event of the Colombian Andes.

During the Cretaceous, the Colombian East was affected by tectonic distension phenomena and strong subsidence, which enabled epicontinental marine sedimentation in a calm environment, reaching a thickness of 10 000 m in the Cundinamarca Basin. No unconformities have been detected in this sedimentary sequence; the magmatism is reduced to some small gabbro stocks, whereas metamorphism is totally absent. Thus, the characteristics of the Colombian East during the Mesozoic were very different from those of the terranes to the west.

4.6. Chibcha Terrane of the SNSM and La Guajira Peninsula (LGP)

The SNSM was divided into three different terranes in the overview by Etayo–Serna et al. (1983). From SE to NW, these terranes are the Sierra Nevada, Sevilla, and Santa Marta Terranes. In the LGP, the Baja Guajira, Cosinas, and Ruma Terranes have been proposed. Restrepo & Toussaint (1988) considered that the Sierra Nevada Terrane and sections of the Baja Guajira and Cosinas Terranes could be correlated with the Chibcha Terrane and that the Sevilla Terrane is quite similar to the Tahamí Terrane. According to Gómez et al. (2015a), the Sierra Nevada Terrane could be correlated with the Chibcha Terrane, whereas the Cosinas Terrane and the SE region of the Baja Guajira Terrane could be correlated with the Tahamí Terrane. According to these authors, the Santa Marta and Ruma terranes are included in the Caribbean Megaterrane.

As shown, the terminology that is used for the SNSM and LGP terranes is confusing. Indeed, a terrane such as Baja Guajira, as defined by Etayo–Serna et al. (1983), likely encompasses three different Terranes; similarly, the correlations with the Tahamí and Calima terranes that were proposed by Restrepo & Toussaint (1989) are not fully proven. Based on the above, the Sierra Nevada Terrane and SE section of the Baja Guajira Terrane are included in the Chibcha Terrane. The term "Kogi Terrane" ("Kogui" in Spanish) is proposed to name the assemblage that comprises the Sevilla Terrane and the metamorphic rocks in the midsection of the Baja Guajira and Cosinas Terranes. We also propose grouping the Santa Marta and Ruma Terranes into a single terrane, which could be called "Tairona" (Figure 1).

New geochronological studies and the increased mapping accuracy of some of these regions will help us improve the knowledge base regarding the SNSM and LGP Terranes, although much remains to be investigated.

The Chibcha Terrane in the SNSM is characterized by a Precambrian continental basement, typified by Los Mangos Granulites, which was U–Pb zircon dated at 971 Ma, the age of metamorphism (Ordóñez–Carmona et al., 2002); the Dibulla Gneiss, which was dated between 1184 Ma by isochron Rb–Sr dating (Cardona, 2003) and 1145 Ma by U–Pb zircon dating (Cordani et al., 2005); and several anorthosites, such as those of Niyala, Río Frío, Orihueca, and the Río Sevilla. Los Mangos Granulites and Dibulla Gneiss are assemblages of migmatites, granulites, amphibolites, orthogneisses, quartzites, and marbles. In the LGP, the SE region of the Baja Guajira Terrane is similar to the Chibcha Terrane in the SNSM, with the Jojoncito Gneiss U–Pb dated at 916 ± 19 Ma (Cordani et al., 2005).

The Chundua Formation, which consists of Carboniferous dark lutites, limestones, and sandstones, crops out in the Chibcha Terrane in the SNSM and is the only occurrence of Paleozoic sedimentites at this location. Indeed, the SNSM apparently lacks the typical Cambrian – Ordovician units that were affected by low–grade metamorphism and Devonian sedimentites that are characteristic of the Chibcha Terrane in the Eastern Cordillera and Santander Massif, although these units crop out in the serranía de Perijá to the SE of the SNSM.

Similar to other regions, the Chibcha Terrane in the SNSM was affected by an important Permian – Triassic magmatism event, with the volcanic–sedimentary Corual and Guatapurí Formations (Tschanz et al., 1974) and vast Jurassic batholiths such as the Central, Patillal, and Pueblo Bello Batholiths dated between 189 Ma and 171 Ma (Tschanz et al., 1974). In the southernmost section of the LGP, Jurassic sedimentites from the Cuisa and Cheterló Formations (Geyer, 1973) were intruded by the Ipapure Granodiorite (Renz, 1960).

5. Yalcón Terrane

5.1. Introduction

In this study, the existence of a new terrane called "Yalcón", which is characterized by Jurassic metamorphism, is proposed. Previously, the Yalcón Terrane had not been differentiated from the Chibcha Terrane or the Tahamí Terrane. As shown below, the possibility of a new Jurassic terrane was proposed by Rodríguez et al. (2017) for the Anzoátegui region.

5.2. Discussion of the Southeastern Margin of the Central Cordillera

The metamorphic ages that were recently assessed by Ar–Ar (Blanco–Quintero et al., 2013) and U–Pb LA–MC–ICP–MS dating of the Tierradentro Gneisses and Amphibolites (Rodríguez et al., 2017) in La Cocha–Río Téllez Migmatitic Complex and Aleluya Metamorphic Complex (Hernández–González & Urueña–Suárez, 2017; Zapata et al., 2017) suggest the presence of a Jurassic metamorphic event on the western flank of the southern section of the Central Cordillera, a region that has been considered to belong to either the Chibcha Terrane or Tahamí Terrane.

Apparently, the ages that were assessed by these authors indicate that the protoliths of these metamorphic complexes have Early Triassic and Jurassic ages and that the metamorphism occurred during the Jurassic from 160 Ma to 144 Ma. This event was contemporary with the intense magmatism that affected this region, beginning with the volcanism of the Saldaña Formation and culminating with the intrusion of large batholiths, such as the Ibagué and Mocoa Batholiths and the Páez Quartz Monzodiorite, among other bodies. This observation is difficult to reconcile with the fact that Devonian sedimentites (such as those from Rovira) and Carboniferous sedimentites (including those from the Granadillo Mudstones and Limestones in the same region) have not been affected by metamorphism. The same occurs with the Triassic and Early Jurassic sedimentites in the Luisa and Payandé Formations.

In the Ibagué region, the Tierradentro Gneisses and Amphibolites, which mainly consist of quartz–feldspathic gneisses, amphibolites, hornblendic gneisses, granodioritic gneisses, and metatonalites, had been dated as Precambrian based on K–Ar dating by Barrero & Vesga (1976), with an age of 1360 ± 270 Ma, although another dating of this unit yielded an age of 171 ± 13 Ma. However, recent U–Pb–zircon datings by Bustamante et al. (2017) in this area indicated magmatic ages of 271 Ma for an orthogneiss and 234 Ma for an amphibolite. Conversely, Rodríguez et al. (2017) used the same method and found a younger age of 157.3 ± 2.6 Ma, which is considered to be an age of magmatic crystallization in amphibolites, whereas metamorphic zircon overgrowths indicated ages of 154.5 ± 3.6 Ma and 143.7 ± 1.5 Ma. These ages are close to the Ar–Ar ages by Blanco–Quintero et al. (2013) in amphiboles (146.5 ± 1.1 Ma and 157.8 ± 0.6 Ma) and phengite (146.5 ± 1.1 Ma) in the type section of the Cajamarca Complex. These data convincingly prove the existence of Jurassic metamorphism in the western portion of the Ibagué Batholith, as proposed by Blanco–Quintero et al. (2013) and Rodríguez et al. (2017). The Ibagué Batholith is intrusive in several locations in the Tierradentro Gneisses and Amphibolites and was U–Pb dated at approximately 145–138 Ma (Bustamante et al., 2017; Rodríguez et al., 2017). These data apparently contradict the very close presence of non–metamorphosed sedimentites from Rovira, which were paleontologically dated as Devonian, and the Luisa, Payandé, and Saldaña Formations, which were dated by both fossils and geochronology to the Late Triassic – Jurassic. Indeed, the Jurassic metamorphism had no effect on the Paleozoic and early Mesozoic sedimentites in the Chibcha Terrane, and the proximity of these metamorphic and sedimentary units cannot be explained by a simple lateral change in facies. The explanation for such paradoxes is one of the main characteristics of the notion of allochthonous terranes.

Rodríguez et al. (2017) postulated that the so–called Ibagué Batholith is not a single unit but actually comprises two different bodies. The first body consists of syntectonic or late tectonic intrusions called the Anzoátegui Metatonalite, which is associated with Tierradentro schists, quartzites, gneisses, and amphibolites and would have experienced metamorphism between 158.2 Ma and 150 Ma. The second body consists of granodiorites and quartz diorites called the Ibagué Tonalite, which intruded between 145 Ma and 138 Ma and did not experience metamorphism. These authors noted that the Chibcha Terrane was unaffected by Jurassic metamorphism and proposed the likely existence of a new terrane between the Chibcha Terrane and Tahamí Terrane.

Farther south, near Sibundoy, the so–called Granadillo Mudstones and Limestones, which consist of conglomerates, mudstones, limestones, and sandstones with Carboniferous fossils (Moreno–Sánchez et al., 2007), are in contact with metamorphic rocks that are attributed to the La Cocha–Río Téllez Migmatitic Complex, whose protoliths were dated by U–Pb zircon LA–ICP–MS between 235 Ma and 194 Ma, while the metamorphism was dated at 163.6 ± 4.7 Ma (Zapata et al., 2017). These results are similar to those in the Ibagué region and show an apparent geological incompatibility when disregarding the presence of two different terranes.

In the Palermo region, the Aleluya Metamorphic Complex, which is located 22 km to the west of Neiva, primarily consists of migmatites, quartzites, metasandstones, and marbles; U–Pb LA–ICP–MS dating indicated protolith ages between 235 Ma and 194 Ma, and the metamorphism of a granofels was dated at 169.1 ± 2.7 Ma (Zapata et al., 2017). The Saldaña Formation is in fault contact with the western edge of the Aleluya Metamorphic Complex and was U–Pb–dated between 188.9 and 172.9 Ma (Zapata et al., 2017). The Saldaña Formation is preceded in the same region by sedimentary deposits in the Luisa and Payandé Formations from the Early Triassic and Jurassic, so the hypothesis of a strong Middle Jurassic metamorphism is difficult to interpret when disregarding the presence of different terranes in this region. The precise position of the boundary between the terranes should be further studied.

García–Chinchilla & Vlach (2017) detected migrations of Mesozoic magmatic belts in the Garzón region. The oldest belt would have developed between 200 Ma and 183 Ma along the eastern flank of the Central Cordillera. Migration to the east would have subsequently occurred with intrusions between 176 Ma and 170 Ma, which would have affected the eastern portion of the Eastern Cordillera. This event would have been followed by a new event between 165 Ma and 130 Ma on the eastern flank of the Central Cordillera. These data support the hypothesis by Rodríguez et al. (2017) of the presence of two magmatic events along the eastern flank of the Central Cordillera. Based on the above, the first two events likely occurred in two different terranes, and the later event followed accretion.

On the eastern flank of the Central Cordillera, south of Mariquita, some units clearly belong to the Chibcha Terrane. On the one hand, units with low–grade metamorphism such as El Hígado and Río Nevado Formations have Ordovician protoliths that were dated by the presence of graptolites, Devonian sedimentites in La Jagua and Rovira, and Carboniferous sedimentites from the Granadillo Mudstones and Limestones. On the other hand, some medium to high–grade metamorphic rocks also belong to Chibcha. For example, La Plata granitic orthogneiss (on the eastern flank of the Central Cordillera at around 2° 30' N), which consists of anatectic granites, quartzofeldspathic gneisses, amphibolites, and granulites, was intruded by La Plata Tonalite, which was dated at 274.8 Ma by using the U–Pb LA–MC–ICP–MS method (Leal–Mejía, 2011), indicating that the high–grade metamorphism predated the Triassic. Near El Pital, Ibañez–Mejia et al. (2011) dated El Pital Migmatite at 1000 Ma and Las Minas augen gneiss at 990 ± 7 Ma by U–Pb LA–ICP–MS. These datings permit these units to be located within the Chibcha Terrane, as described here.

The hypothesis by Rodríguez et al. (2017) for the Anzoátegui region could be generalized to the entire eastern flank of the southern section of the Central Cordillera. Accordingly, the Tierradentro metamorphic rocks, syntectonic intrusion of the Anzoátegui Metatonalite, La Cocha–Río Téllez Metamorphic Complex, and Aleluya metamorphic rocks belong to a terrane that would have experienced Jurassic metamorphism in a compressive environment at a distance from the representative units of the Chibcha Terrane, which were not affected by this event. Some or all of the metamorphic units in the Cajamarca Complex in the southern region of the Central Cordillera are probably components of this terrane. We propose naming this set the "Yalcón Terrane", which is the name of an indigenous ethnic group led by Cacica Gaitana, who opposed the Spanish conquistadors in the Timaná region, Huila. According to this hypothesis, Jurassic metamorphism occurred in the Yalcón Terrane, whereas the western edge of the Chibcha Terrane was too far from the metamorphic zone to be affected.

A change in the tectonic regime that was related to possible changes from a head–on W–E convergence to a more oblique N–S convergence between the oceanic and continental materials to the east is one likely cause of the features between the terranes. The two terranes would have joined slightly before the Jurassic magmatism, such as the Ibagué Tonalite, which would have affected both the eastern edge of the Chibcha Terrane and the western edge of the Yalcón Terrane. Accretion may have occurred earlier in the southernmost section.

The boundary between both terranes was partially lost because of these subsequent intrusions. Later, the original boundary would have been sectioned into various segments by a N–NE fault system that included the Ibagué, Cucuana, La Plata–Chusma, Aucayao, and San Francisco–Yunguillo Faults, among others (Figure 4). Other more recent faults also affected this region. The formations shown in Figure 4, Anabá, El Imán, Luisa, and Payandé, are paleontologically well–dated sedimentary sequences that belong to the Chibcha Terrane. All of them are older than the Jurassic metamorphic event (160–140 Ma) that affected the Yalcón Terrane. The presence of older unmetamorphosed sedimentary sequences and younger metamorphic sequences in close proximity shows one of the essential characteristics of the terrane concept: this contiguity cannot be explained without the presence in this region of two different terranes, Chibcha and Yalcón; the metamorphism took place in the Yalcón Terrane before the terranes were close by, not affecting the sedimentary rocks of the Chibcha Terrane. In the southernmost section, the width of Los Andes narrows with the confluence of the three cordilleras. Apparently, the southern sections of the Chibcha and Andaquí Terranes end in this region and are not present in Ecuador. This observation would imply that the Yalcón Terrane, which is apparently correlated with the Salado Terrane in Ecuador (Litherland et al., 1994), would be in direct contact with the Amazonian Craton. Subsequent studies should more precisely determine the location of the terranes in this region.

Regardless of the proposed explanations for the Jurassic metamorphism on the eastern edge of the central Andes, the southern section of the Central Cordillera shows fundamental differences between the Yalcón Terrane and Tahamí Terrane. Thus, Permian – Triassic metamorphism is characteristic of the Tahamí Terrane, whereas Jurassic metamorphism is characteristic of the Yalcón Terrane. Subsequent studies, particularly geochronological studies, should focus on locating the boundaries between these terranes.

5.3. Yalcón Terrane’s Characteristics and Boundaries

Based on the above discussion, we propose the presence of the Yalcón Terrane in the southern section of the Central Cordillera, with the following characteristics. The lithology of the Yalcón Terrane primarily consists of Jurassic metamorphic rocks that include a portion of the Cajamarca Complex, which has graphitic, chloritic, and muscovitic schists and some amphibolites, quartzites, and marbles. The rocks from this sequence were dated as Jurassic in age (Blanco–Quintero et al., 2013), as mentioned above, and include metamorphic rocks that are associated with the Tierradentro Gneisses and Amphibolites, La Cocha–Río Téllez Migmatitic Complex, metamorphic rocks from the Aleluya Metamorphic Complex, the Anzoátegui Metatonalite, and the metamorphic components of the Ibagué and Mocoa Batholiths, which have not yet been separated from their igneous sections.

As previously discussed, the boundary between the Chibcha Terrane and Yalcón Terrane is partially blurred by post–accretion Jurassic intrusions. However, this boundary may be located near the Avirama and Inzá Faults, which have early Paleozoic or Mesozoic sedimentary rocks that belong to the Chibcha Terrane on their eastern side and Jurassic metamorphic units from the Yalcón Terrane on their western side. The presence of several tectonic imbrications complicates the definition of the boundary. The original boundary was then displaced by an NNE fault system and, particularly in the southernmost region, Cenozoic faults. Accretion into the Chibcha Terrane occurred at the end of the Jurassic, probably through a network of N–NE dextral faults, which matches geotectonic models that have been proposed for that time (e.g., Pindell et al., 2012).

The western boundary of the Yalcón Terrane is represented by the Silvia–Pijao Fault, which separates this area from the Quebradagrande Terrane or some small flakes of the Tahamí Terrane.

The northern boundary with the Tahamí Terrane is difficult to locate, mostly because of the lack of reliable geochronological data for the metamorphic rocks in the Cajamarca Complex at latitudes near the Armenia–Ibagué road or farther north. Nevertheless, the data clearly indicate that the term “Cajamarca Complex” should no longer be used because this unit consists of metamorphic rocks that belong to two terranes. The Permian – Triassic metamorphic rocks in the Tahamí Terrane should be regrouped into a new lithodemic unit that we propose to denominate the “Antioquia Complex”, and the metamorphic rocks in the Yalcón Terrane should be regrouped into another new unit that we propose to name the “Coello Complex”, based on the name of the river that crosses the city of Cajamarca. In the Antioquia Complex, most of the rocks from the Ayurá–Montebello Group as defined by Botero (1963) would be included, but the amphibolites and the zone that comprises a portion of the Anacona Terrane would be excluded. Additionally metamorphic rocks are present in the NW section of the Central Cordillera, which were named the “Valdivia Group” by Hall et al. (1972), and the eastern side of the Central Cordillera, which were described by Feininger et al. (1972) as “Metamorphic rocks of the Central Cordillera” (west of the Otú Fault). These rocks include quartz–muscovite schists, quartz–feldspar paragneisses, granitic orthogneisses, quartzites, amphibolites, and marbles. However, some of the rocks in the southern portion of the area that were studied by these authors could belong to the Jurassic Yalcón Terrane and thus would be components of the Coello Complex.

In the Coello Complex, the majority of rocks are greenschists and quartz–muscovite schists with graphite, such as the rocks along the Armenia–Ibagué road from the Pericos Fault to La Línea pass (latitude 4° 30’ N).

As originally defined along the Armenia–Ibagué highway (Maya & González, 1995), the Cajamarca Complex mostly consists of greenschist–facies metamorphic rocks, typically greenschists and graphite–quartz–muscovite schists that are

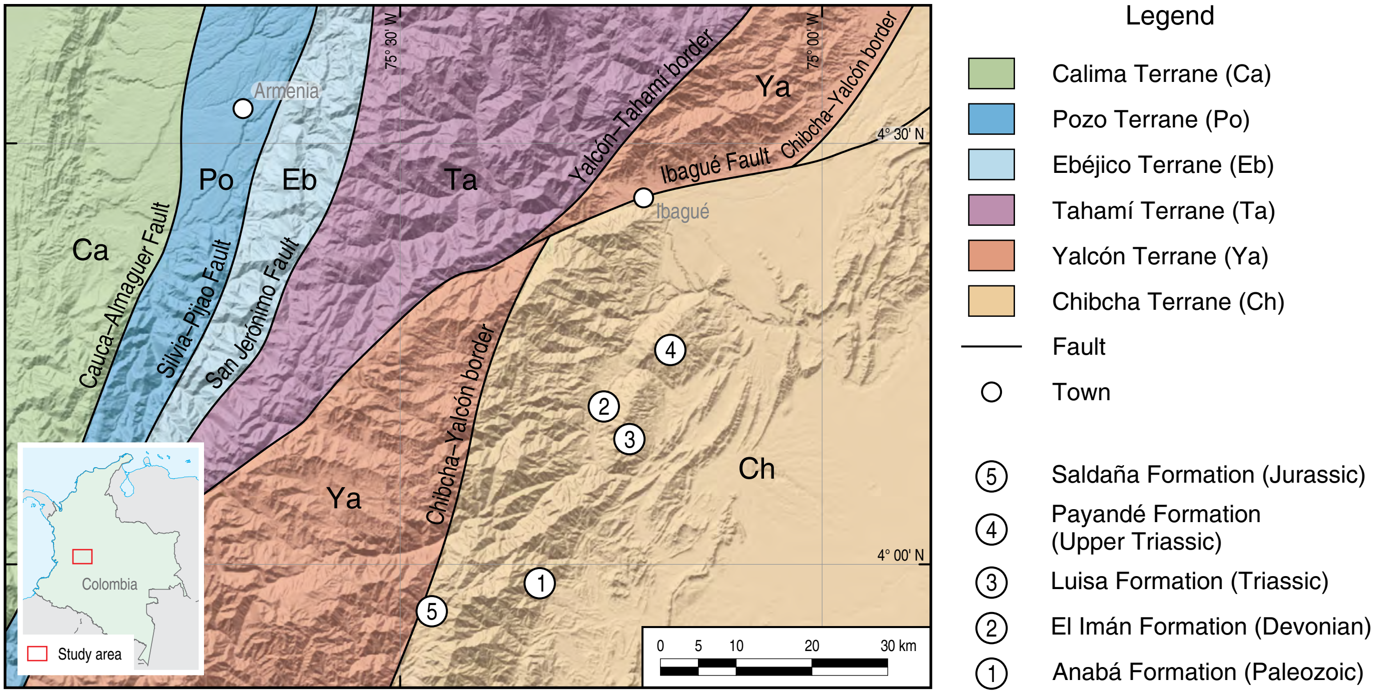


Figure 4. Schematic map of terranes and faults in the Ibagué area.

locally known as "blackschists". Rocks that were Ar–Ar dated by Blanco–Quintero et al. (2013) to the Jurassic were obtained from this sequence. More samples must be dated along this roadcut to see if the entire sequence is Jurassic or if two different units with similar aspects are present. Close to the top along the western limit, La Línea Gneissic Granite, which was dated at 236.2 ± 6.3 Ma (Cochrane, 2013), shows that this gneiss is a component of the Permian – Triassic units, so the Tahamí Terrane extends south to at least latitude 4° 28' N.

We tentatively propose that the Tahamí Terrane be restricted to the areas where Permian – Triassic metamorphic rocks are present, whereas the areas where Jurassic metamorphic rocks crop out would belong to the Yalcón Terrane. The exact boundaries of these terranes are currently uncertain.

Future studies should aim to identify the metamorphic units that were affected by Permian – Triassic metamorphism and those that were affected by Jurassic metamorphism to best define the boundary between the Tahamí and Yalcón Terranes.

6. Tahamí Terrane

6.1. Introduction

The Tahamí Terrane forms a large portion of the northern Central Cordillera, although small blocks may be present along the western flank of the southern Central Cordillera. In the first sketch of Colombian terranes that was prepared by Servicio Geológico Colombiano (Etayo-Serna et al., 1983), this area was assigned to two terranes, namely, the Puquí and Cajamarca, whereas Restrepo & Toussaint (1988) initially named this area the "Central Andean Terrane", which would comprise a polymetamorphic complex with ages ranging from the Precambrian(?) to Permian – Triassic. This terrane was later called "Tahamí" based on one of the most important indigenous cultures in the area at the arrival of the Spanish conquerors (Toussaint & Restrepo, 1989). According to Gómez et al. (2015a), the depicted Tahamí Terrane is quite similar to that proposed by Toussaint & Restrepo (1989).

6.2. Characteristics

This terrane generally consists of metamorphic rocks that were intruded by plutons with ages from the Triassic to Paleogene and minor Mesozoic sedimentary sequences. The metamorphic rocks consist of greenschists and graphite–muscovite–quartz schists (locally called "blackschists"), quartzites, and marbles. However, higher–grade rocks, mostly migmatites and amphibolites, are also present; locally, granulites are found in high–grade areas (Restrepo & Toussaint, 1985; Rodríguez et al., 2005). Syntectonic orthogneisses that were dated close to 240 Ma, such as the Samaná, Abejorral, Naranjal, and Palmitas Gneisses, intruded the metasedimentary sequence (Villagómez, 2010; Cochrane, 2013; Restrepo et al., 2011; Vinasco et al., 2006; Ibañez–Mejia et al., 2008). Although several formational names have been assigned to these metamorphic units, such as the Ayurá–Montebello Group (Botero, 1963), Cajamarca Group (Nelson, 1962), and Valdivia Group (Hall et al., 1972), the name that is presently used for these metamorphic rocks is the "Cajamarca Complex" (Maya & González, 1995). However, as previously described, the nature and extension of this complex must be reassessed.

Initial K–Ar and Rb–Sr datings for the Cajamarca metamorphic rocks yielded Permian – Triassic ages with large errors (i.e., Restrepo et al., 1991). Recent U–Pb dating in zircons yielded mostly Triassic ages for syntectonic granitic intrusions, migmatites, and amphibolites (Ibañez–Mejia et al., 2008; Restrepo et al., 2011; Cochrane et al., 2014b; Martens et al., 2014). These ages are close to 240 Ma and are interpreted as the time of the peak temperature of the metamorphism; some datings yielded younger ages close to 227 Ma, which may indicate a second metamorphic peak (Restrepo et al., 2011). In pre–tectonic intrusions, the magmatic ages in the zircons ranged from 277 to 267 Ma, whereas the metamorphic rims yielded ages from 236 to 227 Ma (Restrepo et al., 2011). With these results, the orogeny that affected the Tahamí Terrane extended at least from 277 to 227 Ma, thus confirming early assessments that this event was a Permian – Triassic orogeny (i.e., Hall et al., 1972).

A different chronological explanation was provided for these events by Vinasco et al. (2006), for whom the older ages (300–270 Ma) would be the age of metamorphism and the younger ages (ca. 250 Ma) would be magmatic ages; however, their article contained no images of the zircons to support the idea.

The great majority of these datings were undertaken on metaigneous rocks. In this sense, the dating of the metasedimentary Las Palmas Migmatite (Restrepo et al., 2011; Martens et al., 2014) is interesting in that the youngest detrital zircons indicate a maximum Carboniferous sedimentation age of 335 Ma (Restrepo et al., 2011). With this age, the proposals that the sedimentation or metamorphism was Precambrian (i.e., Nivia et al., 2006) or lower Paleozoic in age (Cediel et al., 2003) should be reevaluated. In addition, the presence of crinoids in marbles near the Palestina Fault (Patarroyo et al., 2017) precludes a Precambrian age for the protoliths (Silva–Tamayo et al., 2004).

Although a peak of approximately 240 Ma is presently widely accepted for the age of metamorphism, no datings of the metamorphism by this method have been conducted on medium–grade metasedimentary rocks. The initial metamorphism of some of these units occurred at a medium–pressure baric type followed by a low–pressure metamorphic environment (Montes & Restrepo, 2005), so two metamorphic peaks may have occurred within a short time. With a Carboniferous maximum sedimentation age, the first peak would have occurred during the Permian or Early Triassic.

The oldest post–tectonic stocks that intruded the metamorphic rocks are small granodioritic bodies such as El Buey and Montebello Stocks, which have Late Triassic ages (González, 1980; Vinasco et al., 2006). This terrane has a magmatic gap between the Jurassic and Early Cretaceous. The main intrusives are Late Cretaceous tonalites and granodiorites, including the Antioqueño Batholith (Feininger & Botero, 1982), which has an area of approximately 7000 km^2 and U–Pb ages from 93.5 to 58 Ma (Ordóñez–Carmona et al., 2008; Ibañez–Mejia et al., 2007; Restrepo–Moreno et al., 2007; Villagómez, 2010; Leal–Mejía, 2011). Some small stocks in the Medellín Valley are probably the first intrusions of this magmatism and include the Altavista Stock and San Diego Gabbro (96 Ma and 94 Ma, respectively, according to U–Pb dating; Correa et al., 2006).

Four magmatic pulses from the Late Cretaceous – Paleocene were defined by Leal–Mejía (2011): 96–92 Ma, 89–82 Ma, 81–72 Ma, and 63–58 Ma. As discussed below, the last pulse seems to have been generated by a different subduction zone, so its appurtenance to the Antioqueño Batholith proper can be questioned. Some of the small Cretaceous stocks are located on the westernmost side of the Tahamí and are cut by the Cauca–Almaguer Fault, as with the Honda Stock (76.4 Ma; Giraldo–Ramírez, 2017). On the eastern side, La Culebra Stock, which was dated at 87.5 Ma (Leal–Mejía, 2011), is truncated by the Otú Fault, indicating that the Otú Fault was still active after the beginning of the Late Cretaceous magmatism. The area where these intrusives crop out extends approximately 100 km in a W–E direction, indicating a low–angle subduction zone. As discussed below, the Tahamí Terrane was completely amalgamated into the composite craton plus the Chibcha and Yalcón Terranes during the Late Cretaceous. On the western side of the Tahamí, the Quebradagrande, Arquía, and Calima Terranes were accreted at approximately that time, and the younger magmatism was therefore generated by a more westward subduction zone, presumably with the Caribbean Plateau subducting under the Tahamí Terrane and the recently accreted terranes (Bayona et al., 2012). Paleocene – Eocene intrusives such as the Sonsón Batholith (61–56 Ma; Ordóñez–Carmona, 2001; Leal–Mejía, 2011; Cochrane, 2013), Manizales Stock (59.8 Ma; Bayona et al., 2012), El Hatillo Stock (54.6 Ma; Bayona et al., 2012), and Santa Barbara Batholith (60–58 Ma; Ordóñez–Carmona et al., 2011; Cochrane, 2013) are distributed along the entire width of the Central Cordillera, also indicating a shallow subduction zone (Bayona et al., 2012). A special mention is deserved for Paleocene intrusives within the Antioqueño Batholith (63–58 Ma; Leal–Mejía, 2011). These small intrusions are responsible for important gold mineralizations within the Antioqueño Batholith, such as Gramalote near San Roque, Antioquia (Leal–Mejía, 2011).

At the end of the Paleocene – Eocene plutonism, the area remained free of magmatism until the present volcanic chain initiated at approximately 4.3 Ma (Thouret et al., 1990) along the axis of the Central Cordillera, including the Tahamí Terrane. Small intrusions along the eastern flank of the range such as the Río Dulce Porphyries near Nariño, Antioquia, which were dated at 2.3 Ma (Leal–Mejía, 2011), may be the roots of the northern extension of this volcanism.

Locally, marine sedimentary rocks are present in the Tahamí Terrane. The oldest rocks are Late Jurassic (Tithonian) sedimentites known as the Valle Alto (González et al., 1977) and Aquitania sedimentary formations (Giraldo et al., 2015), whereas the youngest are Cretaceous in age and include La Soledad,

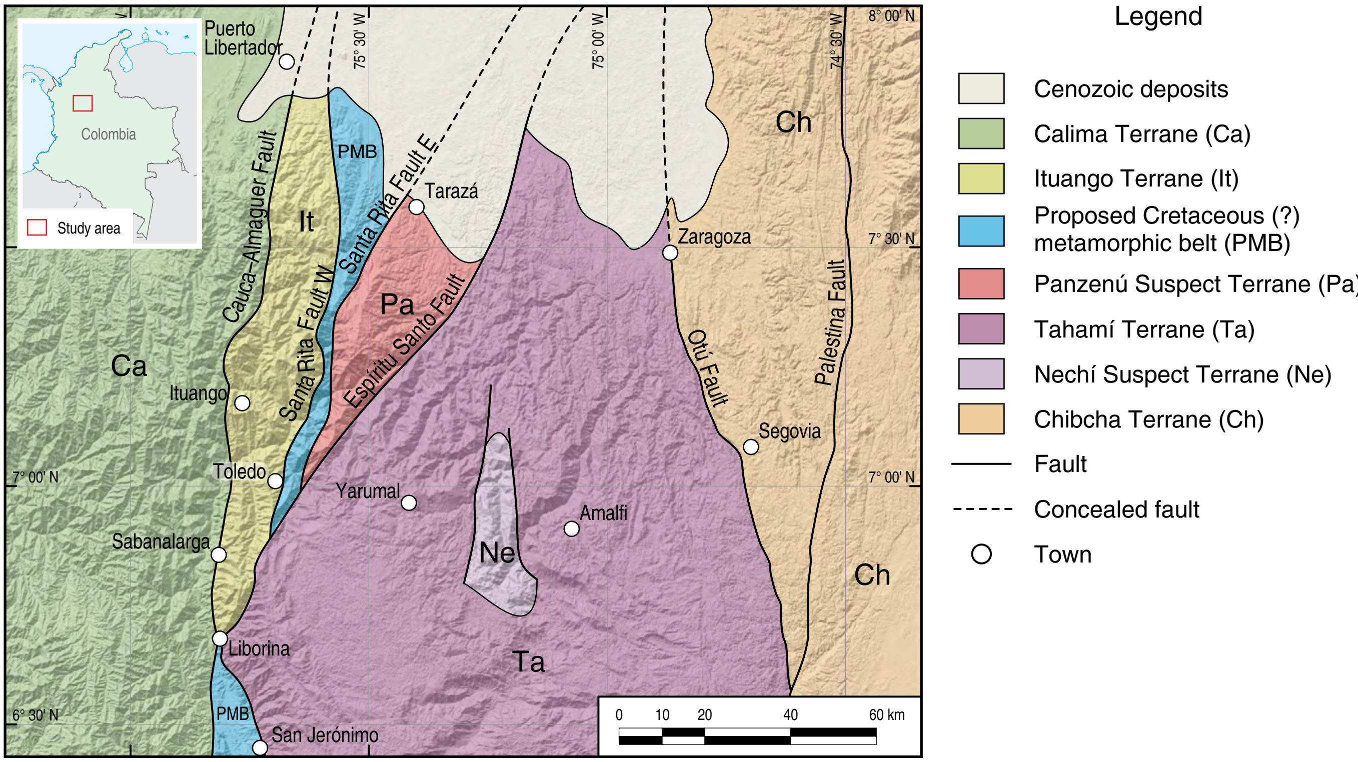


Figure 5. Schematic map of the hypothetical terranes in the northern portion of the Central Cordillera, freely adapted from Gómez et al. (2015a).

San Luis, and Abejorral Formations, which have Hauterivian to Albian ages (Bürgl & Radelli, 1962; Feininger et al., 1972); this sedimentation ceased during the Albian. Although some of the units are intensely folded, mineralogical metamorphism is not present. This compressive tectonic event occurred before the intrusion of the Antioqueño Batholith. A clearly different tectonic environment was found in the Chibcha Terrane, where thick sedimentation occurred in a distensive setting throughout the Late Cretaceous.

6.3. Extension and Boundaries

As originally defined, the Tahamí Terrane was separated in its northern section from the Chibcha Terrane to the east by the Otú Fault and at the latitude of Ibagué by the Pericos Fault, which was believed to be the southern extension of the Otú Fault (Restrepo & Toussaint, 1988). These are strike–slip faults with unknown displacements. A right–lateral displacement was assigned to the Otú Fault (Feininger, 1970). This fault was displaced around 28 km by the Palestina Fault, which is a right–lateral fault (see Feininger, 1970) and locally becomes the terrane's boundary. Many important geological differences are found on both sides of the boundary faults of the terrane, as shown in Table 1.

An area with no clarity regarding the extension and limits of the Tahamí is the exposed metamorphic rocks of the Ituango area in the NW portion of the terrane (Figure 5). On the one hand, low–grade metamorphic rocks such as metagreywackes, metasandstones, and slates with some ultramafic rocks are found at the Taque Creek, near Valle de Toledo, which could be younger than the Triassic, suggesting that the limit of the terrane is to the east of this locality. On the other hand, medium–grade metamorphic rocks are present to the west, such as the Pescadero Gneiss (Muñoz, 1980), which was dated by an Rb–Sr isochron at 253 ± 10 Ma (Restrepo et al., 1991), and "blackschists", which are similar to the Ancón Schists that consist of quartz, muscovite, and andalusite; the latter are located near Medellín and were dated by an Rb–Sr isochron at 226 ± 4 Ma (Restrepo et al., 1991). In addition, the presence of high–grade metamorphic rocks from the Panzenú Suspect

Table 1. Comparison of the main differences between the Chibcha, Yalcón, and Tahamí Terranes.

Geological units	Tahamí Terrane	Yalcón Terrane	Chibcha Terrane
Upper Cretaceous batholiths	Present	Absent	Absent
Jurassic mafic volcanic rocks	Absent	Absent	Present
Jurassic batholiths	Absent	Present	Present
Jurassic metamorphism	Absent	Present	Absent
Triassic syntectonic intrusives	Present	Absent	Absent
Upper Paleozoic metasedimentary rocks	Present	Absent	Absent
Lower Paleozoic metasedimentary rocks	Absent	Absent	Present
Precambrian metamorphic rocks	Absent	Absent	Present

Terrane to the east of this zone complicates the definition of the terranes in this area. The presence of small ultramafic lenses between these two blocks may indicate a complex limit. One possibility is that the Ituango area is a displaced Tahamí block that was moved north by transcurrent faults (Santa Rita faults?) and placed in contact with a sliver of metamorphic rocks of unknown age (Cretaceous?) that separate it from the Panzenú Terrane; several serpentinite bodies along the Santa Rita fault were indicated by Álvarez et al. (1970). In fact, west of Tarazá, small blocks of Quebradagrande–like rocks are shown in the geologic map of Colombia (Gómez et al., 2015a) to the west of the Panzenú Suspect Terrane and to the east of the metamorphic rocks of Ituango. In any case, this area must be studied in more detail to define the ages and contacts of the various metamorphic rocks and the evolution of this complex area.

Another difficulty in defining the Tahamí Terrane comes from the recent datings in the Central Cordillera, which showed the presence of Jurassic metamorphic rocks (Blanco–Quintero et al., 2013; Bustamante et al., 2017; Rodríguez et al., 2017; Zapata et al., 2017). These data challenge the assignment of a large portion of the central and southern Central Cordillera to the Tahamí Terrane. As discussed above, these new data led to the definition of a new terrane, namely, the Yalcón Terrane.

The area of the Central Cordillera south of approximately 4° 30' N has been less studied than the northern area, where most of the datings correspond to Cenozoic magmatic rocks. No Permian – Triassic datings of metamorphic rocks of what has been called the Cajamarca Complex have yet been found at this location, although metaigneous rocks of that age have been reported in the Arquía Complex to the west (Rodríguez & Arango, 2013). Although several geological facts are used to define the Tahamí Terrane, as discussed below, the presence of Permian – Triassic metamorphic rocks is an important indicator of this terrane.

The possibility that both Permian – Triassic and Jurassic metamorphic rocks with different origins are present in the Tahamí Terrane and Cajamarca Complex necessitates redefining both the terrane and the complex.

6.4. Geological History

Several models have been proposed to explain the Triassic orogeny that generated the basement of the Tahamí Terrane. A collisional model formed from the closure of Pangea was proposed by Vinasco et al. (2006). In this model, the Tahamí would have been located between Venezuela and the present Florida peninsula as a component of the Appalachians. In this context, explaining the migration of the Tahamí to its present position is difficult because this scenario implies movement contrary to that of the Caribbean Plate and the rest of terranes.

A very different model, where rifting after closure would have uplifted mantle material to heat the sedimentary sequence and produce extensional metamorphism, was proposed by Cochrane et al. (2014b). In this model, explaining the formation of the Aburrá ophiolites is difficult because a marginal basin would be required at approximately 228 Ma (Restrepo et al., 2007), when the area was supposedly completely surrounded by continental crust (Cochrane et al., 2014b). A third model positions the Tahamí along the western margin of Pangea, with an eastward–dipping subduction zone of Pacific crust (Cardona et al., 2010; Restrepo et al., 2011). This model does not exclude an extensional regime at some time.

According to the detrital zircon geochronology of Las Palmas migmatitic paragneisses, the Tahamí Terrane is related to the Loja and Amotape Terranes in Ecuador and perhaps to the Eastern Cordillera in Perú and the Chiapas Massif within the Maya Block in southern México and Guatemala (Martens et al., 2014). These terranes were probably contiguous during the closure of Pangea and were then dispersed to their present positions.

According to most models (i.e., Kennan & Pindell, 2009 and references therein), the terranes in western Colombia have moved northward from their original position in Ecuador or Perú. Thus, researchers have called the Tahamí and Chibcha "parautochthonous" terranes; however, a better designation would be "displaced" terranes because displacements occurred along transcurrent faults.

The age of the final docking of the Tahamí Terrane is believed to have been the Late Cretaceous (Toussaint & Restrepo, 1989). For example, in the northern portion of the Central Cordillera, both sides of the Otú Fault have been affected by Late Cretaceous magmatism. In the Segovia–Remedios mining district in the Chibcha Terrane, dikes that were related to Au mineralization have been dated between 89 and 85 Ma (Leal–Mejía, 2011). In the Tahamí Terrane, the Culebra Stock was dated at 87.5 Ma (Leal–Mejía, 2011). However, the truncation of the Culebra Stock indicates that the Otú Fault experienced important movements after the emplacement of this stock.

6.5. Panzenú Suspect Terrane

This suspect terrane was proposed by Ordóñez–Carmona & Pimentel (2002) for the Puquí Complex at the northern end of the Tahamí Terrane (Figure 5). This terrane consists of high–grade metamorphic rocks, including migmatites, gneisses, amphibolites, and granulites. The block is limited by the Espíritu Santo Fault to the south, the Murrucucú Fault to the north, and undetermined faults to the east and west.

The main reason for proposing this terrane seems to be the Rb–Sr isochron age for the gneiss of 306 ± 11 Ma compared to the Triassic ages found in the Tahamí Terrane. However, this terrane is herein listed as a suspect terrane until U–Pb datings for the metamorphism are available.

6.6. Possible Correlation between the Kogi Terrane in the SNSM and LGP and the Tahamí Terrane

The Kogi Terrane in the SNSM and LGP corresponds to the Sevilla Terrane and a portion of the Baja Guajira Terrane as defined by Etayo–Serna et al. (1983) and was included in the Tahamí Terrane in Toussaint & Restrepo (1989). This new terrane is proposed here because the correlation with the Tahamí Terrane is insufficiently proven.

The Kogi Terrane, which is separated from the Chibcha Terrane in the SNSM by a complex fault system that is associated in some areas with intense mylonitization, is characterized by assemblages of quartz–feldspathic gneisses, amphibolites, migmatites, schists, and marbles. These rocks are mainly the Muchachitos Gneiss, which was U–Pb dated between 276 and 288 Ma (Cardona et al., 2010); the Buritaca Gneiss, which was Ar–Ar dated at 147 ± 6 Ma (Cardona et al., 2006); the Sevilla Complex, for which a schist was Ar–Ar dated at 185.8 ± 1 Ma (Cardona et al., 2006); and the San Pedro metamorphites, which were intruded by granodiorites such as the Paleocene Buritaca and Latal plutons. In the LGP, these rocks include the Macuira Gneiss, which was dated at 265 Ma and was intruded by the Ar–Ar–dated 165.8 Ma Siapana Granodiorite (Cardona, 2003), and the Jaturuhu Schists and Uray Gneiss, which were U–Pb dated at 245.6 ± 3.9 Ma (Weber et al., 2010). These datings present a fairly large age range from the early Permian to the Late Jurassic, although these ages indicate some similarity to the Tahamí Terrane, which was also affected by Permian – Triassic metamorphism.

In the SNSM, the boundary between the Kogi and Chibcha Terranes is marked by complex tectonic imbrications that correspond to the Sevilla Fault System. These faults are a set of NW–dipping reverse faults, although dextral movements have also occurred. The great Jurassic batholiths did not affect the Kogi Terrane, in contrast to Eocene magmatism, such as that in the Buritaca Batholith, which was U–Pb dated at 50.8 Ma (Duque, 2010) and crosses the boundary. In the LGP, the boundary between the Kogi and Chibcha Terranes is marked by a set of tectonic imbrications with Cretaceous flakes of sedimentary rocks, such as those in the Poschachi Formation, thus suggesting subsequent movements in the boundary between these terranes.

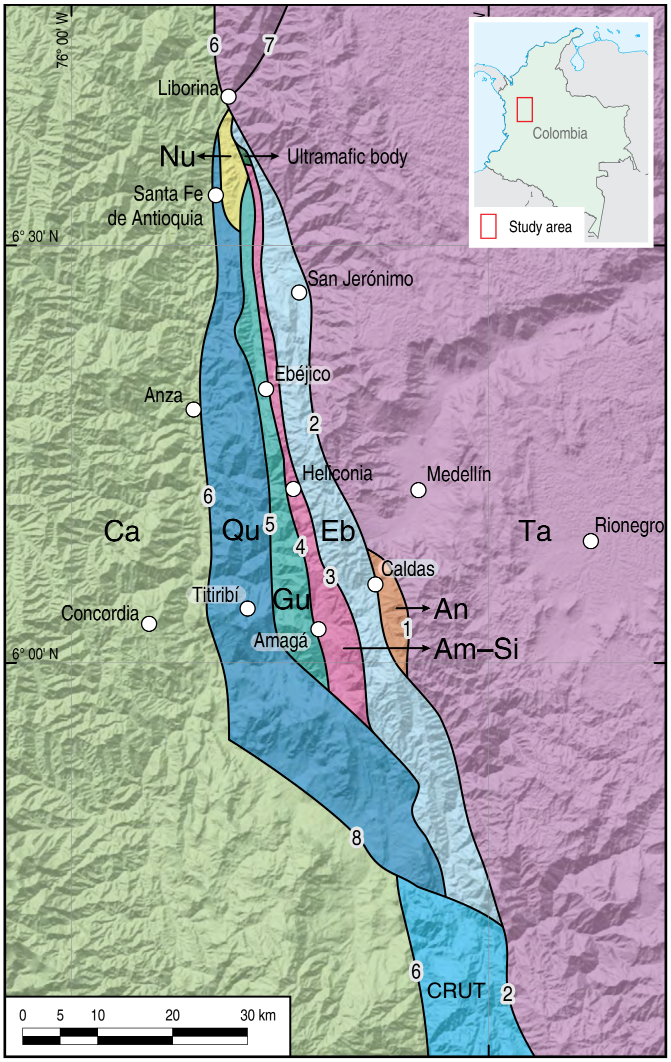
In the SNSM, the Tairona Terrane is connected to the Kogi Terrane by a network of unnamed reverse faults, several of which run oblique to the original boundary. The Buritaca Pluton apparently crosses the boundary between these terranes, thus suggesting a union in the early Paleocene – Eocene range. In the LGP, the Tairona Terrane is limited to the SE side by the Simarua–Osorio Fault, which shows strong mylonitization and overthrusts onto the Kogi Terrane. Eocene reef limestones that are associated with marls, mudstone, and sandstone from the Uitpa Formation cover the boundary, which indicates that the union between the Tairona and Kogi Terranes occurred during the Late Cretaceous – Paleocene .

6.7. Continental Terranes in the Cauca–Romeral Fault Zone

The Cauca–Romeral Fault Zone is located at the boundaries between the continental and oceanic basements. Within this zone, several small terranes of both continental and oceanic nature are found. Their locations approximately correspond to the Cauca–Romeral Terrane that was mapped by Etayo–Serna et al. (1983). But this area with high–tectonic complexity, is not a terrane but an aggregate of small terranes of different ages. The continental and oceanic domains have been subjected to constant transpression and distension since the Cretaceous, and their boundaries have broken, forming a mosaic of small terranes that are separated from their places of origin. Continental terranes such as the Anacona and Amagá–Sinifaná Terranes and possible Tahamí Terrane flakes and oceanic terranes, including the Ebéjico (Quebradagrande) and Pozo (Arquía) Terranes, among others, are located in this fault zone (Figure 6). This study aims to change the names of several of these terranes to avoid confusion with the names of pre–existing formations, groups, and complexes. The continental terranes of the Cauca–Romeral Fault Zone are the Anacona, Amagá–Sinifaná, and Guaca Terranes.

The small Anacona Terrane is located approximately 25 km south of Medellín between the Tahamí and Ebéjico (Quebradagrande) Terranes (Figure 7). This terrane consists of garnetiferous amphibolites, quartzites, kyanite–staurolite–garnet–biotite schists, and chlorite–muscovite schists that were intruded by an S–type granite, which converted later into a gneiss. The magmatic stage of the gneiss yielded Ordovician ages from U–Pb zircon dating (Martens et al., 2014), whereas an Ar–Ar age of ca. 360 Ma was obtained in hornblende from the Caldas Amphibolite (Restrepo et al., 2008) and age of 344 Ma was obtained in muscovite from La Miel Gneiss (Vinasco et al., 2006). These later ages are considered to mark the time of cooling after the metamorphism that affected the granite; these Ar spectra show that the terrane was not affected by the Tahami's Triassic metamorphism. Thus, the autochthonistic hypothesis that La Miel Gneiss is the basement of the Cajamarca Complex (Villagómez et al., 2011) is not plausible. The eastern boundary with the Tahamí Terrane is marked by the Santa Isabel Fault, and the western boundary with the Ebéjico (Quebradagrande) Terrane is marked by the San Jerónimo Fault. Further discussion of this terrane is provided by Restrepo et al. (2020).

The Amagá–Sinifaná Terrane is limited by faults in the Romeral Fault Zone. The Silvia–Pijao Fault to the east separates this terrane from the Quebradagrande Terrane, and the Amagá Fault to the west separates this terrane from the Guaca Terrane. This terrane consists of very low–grade metamorphic rocks that are known as the Sinifaná Metasedimentites (González, 1980)



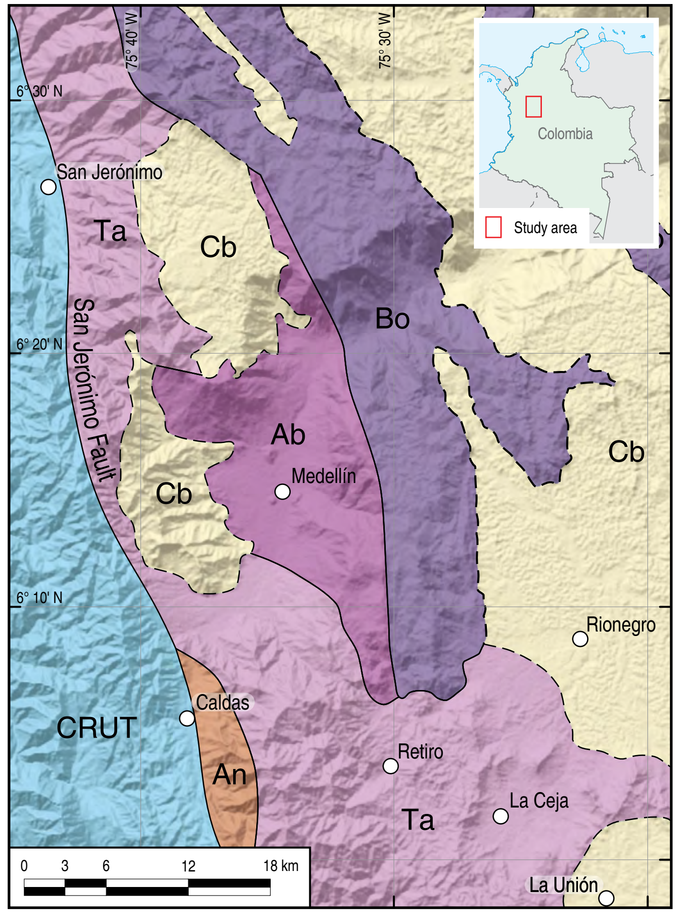
Legend

- Calima Terrane (Ca)
- Ultramafic body
- Nutabe Terrane (Nu)
- Quirimará Terrane (Qu)
- Guaca Terrane (Gu)
- Amagá–Sinifaná Terrane (Am–Si)
- Ebéjico Terrane (Eb)
- Anacona Terrane (An)
- Cauca–Romeral Undifferentiated Terranes (CRUT)
- Tahamí Terrane (Ta)
- Town
- Fault

Faults

1. Santa Isabel Fault
2. San Jerónimo Fault
3. Silvia–Pijao Fault
4. Amagá Fault
5. Quirimará Fault
6. Cauca–Almaguer Fault
7. Espíritu Santo Fault
8. Arma Fault

Figure 6. Schematic map of the small terranes in the Cauca–Romeral Fault Zone.



Legend

- Cretaceous batholiths and stocks (Cb)
- Cauca–Romeral Undifferentiated Terranes (CRUT)
- Anacona Terrane (An)
- Tahamí Terrane (Ta)
- Aburrá Terrane (Ab)
- Bocaná Terrane (Bo)
- Town
- Terrane boundaries
- Intrusive contacts

Figure 7. Schematic map of the terranes in the Medellín area.

and the Amagá granite stock, which intrudes the metasedimentites with the formation of a contact aureole. Detrital zircons from the metasedimentites were dated by Martens et al. (2012) and showed a strong affinity with zircons from the Cajamarca Complex; an Early Triassic maximum age of sedimentation was obtained. The Amagá granitic stock was dated by U–Pb in zircons with an age of 228 Ma (Vinasco et al., 2006), showing that the very low–grade metamorphism occurred between 290 and 228 Ma. Martens et al. (2012) proposed that this area is a sliver of the Cajamarca Complex that was moved northwestward by the Romeral Fault System. Amagá and Sinifaná are autochthonous indigenous names.

A somewhat similar situation is found west of Manizales, where the Chinchiná Gneiss (Mosquera, 1978; Puerta–Moreno, 1990) or Manizales Migmatite (Idárraga–García & Martínez–Uribe, 2005), which was dated at 224.7 ± 1.9 Ma (Cochrane, 2013), is in contact with the Pozo Terrane along the Silvia–Pijao Fault to the west and the Ebéjico (Quebradagrande) Terrane to the east along a nameless fault (Figure 8). In this case, within the Cauca–Rome-

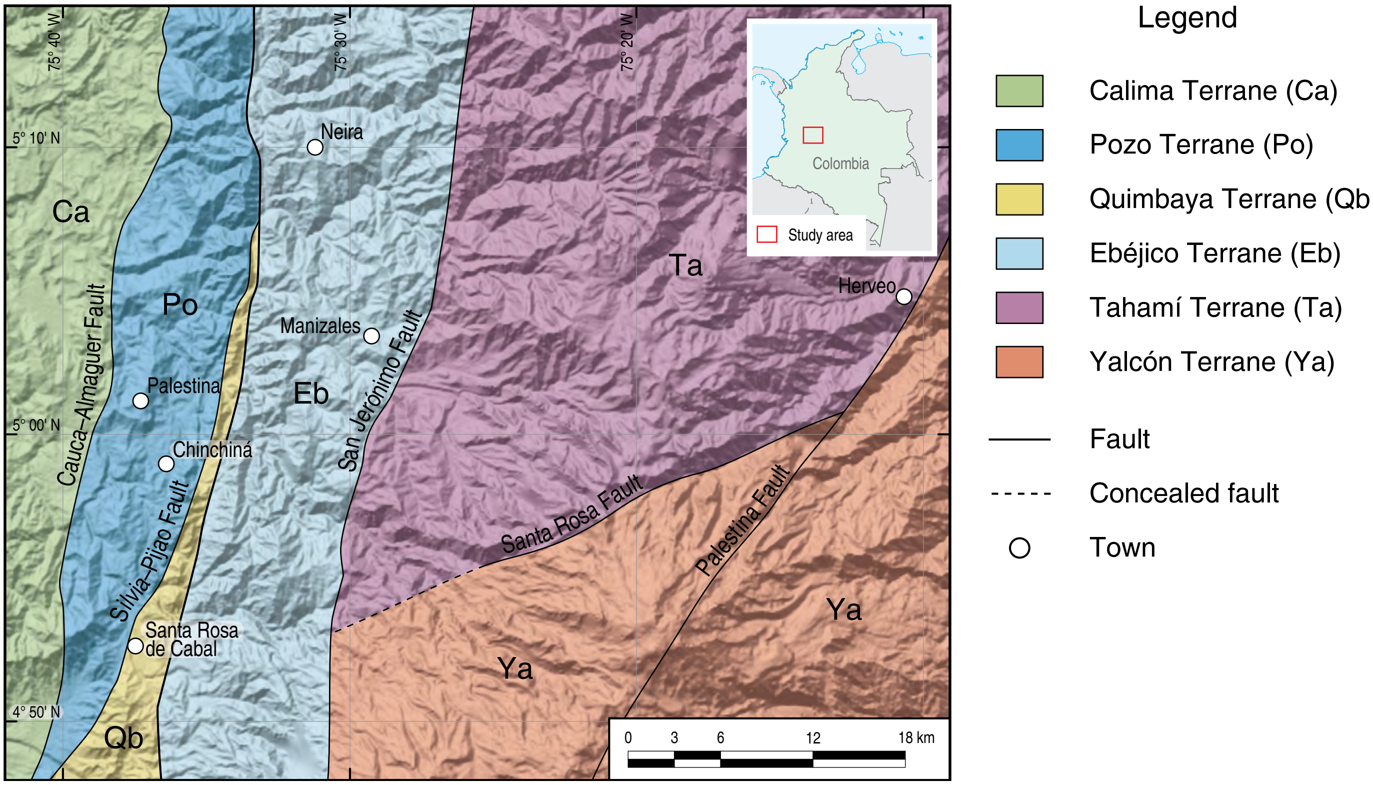


Figure 8. Schematic map of the Quimbaya Terrane in the Manizales area.

ral Fault Zone a high–grade block correlatable to the Cajamarca Complex was tectonically inserted. This block fulfills the definition of a terrane, and we propose calling this terrane the "Quimbaya Terrane" after one of the most known pre–Columbian tribes of this area.

The Guaca Terrane consists of the Pueblito Diorite within the Romeral Fault Zone and is separated from the Amagá–Sinifaná Terrane by the Amagá Fault to the east and the Quirimará oceanic Terrane (Sabaletas Schists) by the Quirimará Fault to the west. Ultramafic bodies are found along the Amagá Fault (González–Ospina, 2016). The diorite was dated by U–Pb zircons to the Triassic (233–236 Ma; Rodríguez–Jiménez, 2010). The Amagá Granite has a similar age but is geochemically an S–type granite (Vinasco et al., 2006) and is not comparable to the diorite. Guaca, an indigenous word, was the original name for the municipality of Heliconia, where most of the diorite is located.

7. Conclusions Regarding the Continental Terranes

The area within the Cauca–Romeral Fault Zone in Colombia consists of a mosaic of continental terranes, including the Andaquí, Chibcha, Yalcón, Tahamí, Kogi, and Anacona Terranes and the Panzenú Suspect Terrane. These terranes were accreted at different moments from the late Neoproterozoic to the Late Cretaceous (Figure 9). Most of the accretions involved displaced terranes: South American blocks were transported northward along transcurrent faults and are called para–autochthonous, but in a different manner to this term's usage for the Alpine overthrusts.

Some of the most characteristic features of the main terranes (Table 1) are as follows:

1. Andaquí Suspect Terrane: high–grade Putumayense basement that is covered by unmetamorphosed lower Paleozoic sedimentary rocks.
2. Chibcha Terrane: regional metamorphism of Cambrian, Ordovician and Silurian (?) sedimentary rocks, many of which were deposited over Putumayo or Grenville metamorphic basements. These metamorphic rocks were covered by Devonian and younger marine sedimentary rocks. Triassic, Jurassic, and Early Cretaceous granitoid rocks intruded some of these areas and formed extensive volcanic deposits during the Jurassic.
3. Tahamí Terrane: low– to high–grade metamorphosed metasedimentary and pre– to post–tectonic granitoid intrusions that formed during a Triassic metamorphism event. The metasedimentary rocks have a Carboniferous maximum age. The main magmatic event occurred during the Late Cretaceous.
4. Yalcón Terrane: low– to medium–grade Jurassic metamorphic rocks that were intruded by Jurassic plutons.

The newly defined Yalcón Terranes is located between the Tahamí and Ebéjico terranes to the west and the Chibcha Terrane to the east. This terrane comprises low– to medium–grade metamorphic rocks that formed during a Jurassic metamorphic

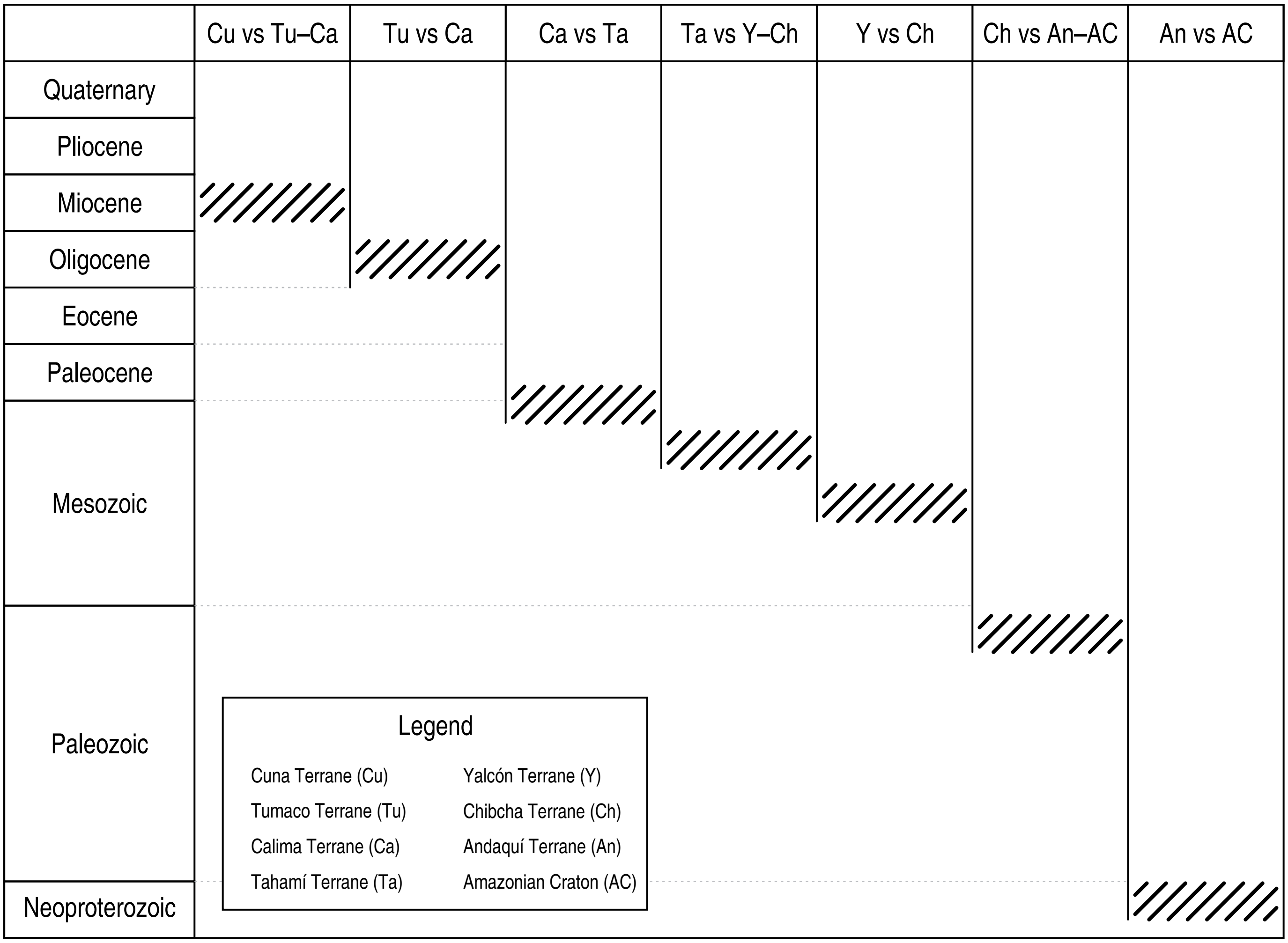


Figure 9. Timing of accretions of the Colombian terranes.

event. The Kogi Terrane in the SNSM and LGP has certain similarities to the Tahamí Terrane but is currently considered a different terrane.

The terrane concept applied to Colombian geology permits the explanation of many paradoxes that are difficult to explain from an autochthonous perspective.

Acknowledgments

Special thanks are given to Gómez et al. (2015b) for preparing the catalog of radiometric datings of Colombia. Without this catalog, the preparation of this document would have been much more time consuming. Also to Fernando ALCÁRCEL for drawing the final versions of the figures.

References

Agencia Nacional de Hidrocarburos. 2012. Cuenca de los Llanos Orientales: Integración geológica de la digitalización y análisis de núcleos. Digital Rock Physics Lab–ANH, 209 p. Bogotá.

Álvarez, J. 1981. Determinación de edad Rb/Sr en rocas del Macizo de Garzón, Cordillera Oriental de Colombia. Geología Norandina, (4): 31–38.

Álvarez, J., Rico, H., Vásquez, H. & Hall, R. 1970. Mapa geológico del cuadrángulo H–8 Yarumal y parte del H–7 Ituango, Colombia. Scale 1:100 000. Ingeominas. Bogotá.

Amaya, Z., Cramer, T., Bonilla, A., Franco, J., Campos, H., Cano, H., Castañeda, A., Roberto, O., Zuluaga, C., Zuluaga, C, Molano, J.C., Guerrero, J., Piraquive, A. & Cuellar, J. 2017. Los estratos auríferos meso–proterozóicos en los departamentos de Guainía y Vaupés, Colombia. XVI Congreso Colombiano de Geología. Memoirs, p. 995–1001. Santa Marta.

Arango, M.I., Rodríguez, G., Bermúdez, J.G. & Zapata, G. 2015. Catálogo de unidades litoestratigráficas de Colombia: Cuarzomonzonita de Anchique. Servicio Geológico Colombiano, 26 p. Bogotá.

Barrero, D. & Vesga, C. 1976. Mapa geológico del cuadrángulo K–9 Armero y mitad sur del J–9 La Dorada. Scale 1:100 000. Ingeominas. Bogotá.

Bayona, G., Cardona, A., Jaramillo, C., Mora, A., Montes, C., Valencia, V., Ayala, C., Montenegro, O. & Ibañez–Mejia, M. 2012.

Early Paleogene magmatism in the northern Andes: Insights on the effects of oceanic plateau–continent convergence. Earth and Planetary Science Letters, 331–332: 97–111. https://doi.org/10.1016/j.epsl.2012.03.015

Berg, H.C., Jones, D.L. & Coney, P.J. 1978. Map showing pre–Cenozoic tectonostratigraphic terranes of southeastern Alaska and adjacent areas. Scale 1:1 000 000. United States Geological Survey, Open–File Report 78–1085, 2 sheets. https://doi.org/10.3133/ofr781085

Blanco–Quintero, I.F., García–Casco, A., Ruiz, E.C., Toro, L.M., Moreno, M., Morata, D. & Vinasco, C.J. 2013. New petrological and geochronological data from the Cajamarca Complex (Central Cordillera, Colombia) in the Cajamarca–Ibagué region: Late Jurassic thermal resetting of Triassic metamorphic ages or Jurassic orogenic metamorphism? XIV Congreso Colombiano de Geología. Abstracts, p. 247. Bogotá.

Bogotá, J. 1982. Estratigrafía del Paleozoico inferior en el área Amazónica de Colombia. Geología Norandina, (6): 29–38.

Boinet, T., Bourgois, J., Bellon, H. & Toussaint, J.F. 1985. Age et répartition du magmatisme prémésozoïque des Andes de Colombie. Comptes Rendus des Séances de L'Académie des Sciences, 300(Serie II–10): 445–450. Paris.

Bonilla–Pérez, A., Frantz, J.C., Charão–Marques, J.C., Cramer, T., Franco–Victoria, J.A., Mulocher, E. & Amaya–Perea, Z. 2013. Petrografía, geoquímica y geocronología del Granito de Parguaza en Colombia. Boletín de Geología, 35(2): 83–104.

Bonilla, A., Frantz, J.C., Charão–Marques, J.C., Cramer, T., Franco, J.A. & Amaya, Z. 2016. Magmatismo Rapakivi en la cuenca media del río Inírida, departamento de Guainía, Colombia. Boletín de Geología, 38(1): 17–32. http://dx.doi.org/10.18273/revbol.v38n1-2016001

Botero, G. 1963. Contribución al conocimiento de la geología de la zona central de Antioquia. Universidad Nacional de Colombia, Anales de la Facultad de Minas, 57, 101 p. Medellín.

Bridger, C.S. 1982. El Paleozoico inferior de Colombia: Una revaluación en base en nuevos datos de campo. Bachelor thesis, Universidad Nacional de Colombia, 280 p. Bogotá.

Bürgl, H. & Radelli, L. 1962. Nuevas localidades fosilíferas en la Cordillera Central de Colombia (S. A.). Geología Colombiana, 3: 133–138.

Bustamante, C., Cardona, A., Bayona, G., Mora, A., Valencia, V., Gehrels, G. & Vervoort, J. 2010. U–Pb LA–ICP–MS geochronology and and regional correlation of Middle Jurassic intrusive rocks from the Garzón Massif, Upper Magdalena Valley and Central Cordillera, southern Colombia. Boletín de Geología, 32(2): 93–109.

Bustamante, C., Archanjo, C.J., Cardona, A., Bustamante, A. & Valencia, V.A. 2017. U–Pb ages and Hf isotopes in zircons from parautochthonous Mesozoic terranes in the western margin of Pangea: Implications for the terrane configurations in the northern Andes. The Journal of Geology, 125(5): 487–500. https://doi.org/10.1086/693014

Cardona, A. 2003. Correlações entre fragmentos do embasamento pré–Mesozóico da terminação setentrional dos Andes Colombianos, com base em dados isotópicos e geocronológicos. Master thesis, Universidade de São Paulo, 149 p. São Paulo. https://doi.org/10.11606/D.44.2003.tde-07042015-090410

Cardona, A., Cordani, U.G. & MacDonald, W.D. 2006. Tectonic correlations of pre–Mesozoic crust from the northern termination of the Colombian Andes, Caribbean region. Journal of South American Earth Sciences, 21(4): 337–354. https://doi.org/10.1016/j.jsames.2006.07.009

Cardona, A., Valencia, V., Garzón, A., Montes, C., Ojeda, G., Ruiz, J. & Weber, M. 2010. Permian to Triassic I to S–type magmatic switch in the northeast Sierra Nevada de Santa Marta and adjacent regions, Colombian Caribbean: Tectonic setting and implications within Pangea paleogeography. Journal of South American Earth Sciences, 29(4): 772–783. https://doi.org/10.1016/j.jsames.2009.12.005

Cawood, P.A. & Pisarevsky, S.A. 2017. Laurentia–Baltica–Amazonia relations during Rodinia assembly. Precambrian Research, 292: 386–397. https://doi.org/10.1016/j.precamres.2017.01.031

Cediel, F., Shaw, R.P. & Cáceres, C. 2003. Tectonic assembly of the northern Andean block. In: Bartolini, C., Buffler, R.T. & Blickwede, J. (editors), The circum–Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics. American Association of Petroleum Geologists Memoir, 79, p. 815–848. Tulsa, USA.

Cochrane, R.S. 2013. U–Pb thermochronology, geochronology and geochemistry of NW South America: Rift to drift transition, active margin dynamics and implications for the volume balance of continents. Doctorade thesis, University of Geneva, 118 p. Geneva, Switzerland. https://doi.org/10.13097/archive-ouverte/unige:30029

Cochrane, R., Spikings, R., Gerdes, A., Winkler, W., Ulianov, A., Mora, A. & Chiaradia, M. 2014a. Distinguishing between in–situ and accretionary growth of continents along active margins. Lithos, 202–203: 382–394. https://doi.org/10.1016/j.lithos.2014.05.031

Cochrane, R., Spikings, R., Gerdes, A., Ulianov, A., Mora, A., Villagómez, D., Putlitz, B. & Chiaradia, M. 2014b. Permo–Triassic anatexis, continental rifting and the disassembly of western Pangaea. Lithos, 190–191: 383–402. https://doi.org/10.1016/j.lithos.2013.12.020

Coney, P.J., Jones, D.L. & Monger, J.W.H. 1980. Cordilleran suspect terranes. Nature, 288(5789): 329–333. https://doi.org/10.1038/288329a0

Cordani, U.G., Sato, K, Teixeira, W, Tassinari, C.G.G. & Basei, M.A.S. 2000. Crustal evolution of the South American platform. In: Cordani, U.G., Milani, E.J., Thomaz–Filho, A. & Campos, D.A. (editors), Tectonic evolution of South America. 31st International Geological Congress. Proceedings, p. 19–40. Río de Janeiro, Brazil.

Cordani, U.G., Cardona, A., Jiménez, D.M., Liu, D. & Nutman, A.P. 2005. Geochronology of Proterozoic basement inliers in the Colombian Andes: Tectonic history of remnants of a fragmented Grenville belt. In: Vaughan, A.P.M., Leat, P.T. & Pankhurst, R.J. (editors), Terrane processes at the margins of Gondwana. Geological Society of London, Special Publication 246, p. 329–346. London. https://doi.org/10.1144/GSL.SP.2005.246.01.13

Cordani, U.G., Sato, K., Sproessner, W. & Fernandes, F.S. 2016. U–Pb zircon ages of rocks from the Amazonas territory of Colombia and their bearing on the tectonic history of the NW sector of the Amazonian Craton. Brazilian Journal of Geology, 46(1): 5–35. https://doi.org/10.1590/2317-4889201620150012

Correa, A.M., Pimentel, M., Restrepo, J.J., Nilson, A., Ordóñez, O., Martens, U., Laux, J.E. & Junges, S. 2006. U–Pb zircon ages and Nd–Sr isotopes of the Altavista Stock and the San Diego Gabbro: New insights on Cretaceous arc magmatism in the Colombian Andes. V South American Symposium on Isotope Geology. Abstracts in CD ROM, p. 1–3. Punta del Este, Uruguay.

Cuadros, F.A., Botelho, N.F., Ordóñez–Carmona, O. & Matteini, M. 2014. Mesoproterozoic crust in the San Lucas Range (Colombia): An insight into the crustal evolution of the northern Andes. Precambrian Research, 245: 186–206. https://doi.org/10.1016/j.precamres.2014.02.010

Dalziel, I.W.D. 1997. Overview: Neoproterozoic – Paleozoic geography and tectonics; review, hypothesis, environmental speculation. Geological Society of America Bulletin, 109(1): 16–42. https://doi.org/10.1130/0016-7606(1997)109<0016:ONPGAT>2.3.CO;2

De La Espriella, R. & Cortés, R. 1989. Contribución a la estratigrafía del Grupo Quetame. Revista del Instituto de Ciencias Naturales y Ecología, 2(1): 83–102.

Duque, J.F. 2010. Geocronología (U/Pb y ^{40}Ar/^{39}Ar) y geoquímica de los intrusivos paleógenos de la Sierra Nevada de Santa Marta y sus relaciones con la tectónica del Caribe y el arco magmático Circun–Caribeño. Master thesis, Universidad Nacional Autónoma de México, 189 p. México D. F.

Etayo–Serna, F., Barrero, D., Lozano, H., Espinosa, A., González, H., Orrego, A., Ballesteros, I., Forero, H., Ramírez, C., Zambrano–Ortiz, F., Duque–Caro, H., Vargas, R., Núñez, A., Álvarez, J., Ropaín, C., Cardozo, E., Galvis, N., Sarmiento, L., Alberts, J.P., Case, J.E., Singer, D.A., Bowen, R.W., Berger, B.R., Cox, D.P. & Hodges, C.A. 1983. Mapa de terrenos geológicos de Colombia. Publicaciones Geológicas Especiales del Ingeominas, 14(1), p. 1–135. Bogotá.

Feininger, T. 1970. The Palestina Fault, Colombia. Geological Society of America Bulletin, 81(4): 1201–1216. https://doi.org/10.1130/0016-7606(1970)81[1201:TPFC]2.0.CO;2

Feininger, T. & Botero, G. 1982. The Antioquian Batholith, Colombia. Publicaciones Geológicas Especiales del Ingeominas, 12, p. 1–50. Bogotá.

Feininger, T., Barrero, D. & Castro, N. 1972. Geología de parte de los departamentos de Antioquia y Caldas (Sub–Zona II–B). Boletín Geológico, 20(2): p. 1–67.

Forero, A. 1970. Estratigrafía del Precretácico en el flanco occidental de la serranía de Perijá. Geología Colombiana, 7: 7–77.

Forero, A. 1984. Remanentes de la provincia paleobiogeográfica Frasniano–Fameniana del viejo mundo en Los Andes septentrionales. Geología Norandina, (10): 35–38.

Galvis, J., Huguett, A. & Ruge, P. 1979. Geología de la Amazonía colombiana. Boletín Geológico, 22(3): 3–86.

García–Chinchilla, D. & Vlach, S.R.F. 2017. Datación U–Pb in situ, isotopos de Hf en zircón y geoquímica de granitos y rocas relacionadas de la región de Garzón, Cordillera Oriental. XVI Congreso Colombiano de Geología. Memoirs, p. 1238–1241. Santa Marta.

Gaudette, H.E., Mendoza, V., Hurley, P.M. & Fairbairn, H.W. 1978. Geology and age of the Parguaza rapakivi granite, Venezuela. Geological Society of America Bulletin, 89(9): 1335-1340. https://doi.org/10.1130/0016-7606(1978)89<1335:GAAOTP>2.0.CO;2

Geyer, O.F. 1973. Das präkretazische Mesozoikum von Kolumbien. Geologisches Jahrbuch, 5: 1–155.

Giraldo–Ramírez, W.E. 2017. Novas idades U–Pb (LA–ICP–MS) de rochas granitoides na região de Sabanalarga (Colômbia) e sua correlação com a evolução da Placa do Caribe. Master thesis, Universidade do Estado do Rio de Janeiro, 88 p. Río de Janeiro, Brazil.

Giraldo, W., Patarroyo, P. & Restrepo, J.J. 2015. Sedimentitas de Aquitania, Antioquia: Edad y correlaciones. XV Congreso Colombiano de Geología. Memoirs, p. 1138–1140. Bucaramanga.

Goldsmith, R., Marvin, R.F. & Mehnert, H.H. 1971. Radiometric ages in the Santander Massif, Eastern Cordillera, Colombian Andes. United States Geological Survey Professional Paper, 750–D, p. D44–D49.

Gómez, J., Montes, N.E., Nivia, Á. & Diederix, H., compilers. 2015. Geological Map of Colombia 2015. Scale 1:1 000 000. Servicio Geológico Colombiano, 2 sheets. Bogotá. https://doi.org/10.32685/10.143.2015.936

Gómez, J., Montes, N.E., Alcárcel, F.A. & Ceballos, J.A. 2015b. Catálogo de dataciones radiométricas de Colombia en ArcGIS y Google Earth. In: Gómez–Tapias, J. & Almanza, M.F. (editors), Compilando la geología de Colombia: Una visión a 2015. Servicio Geológico Colombiano, Publicaciones Geológicas Especiales, 33, p. 63–419. Bogotá.

González, H. 1980. Geología de las planchas 167 Sonsón y 187 Salamina. Scale 1:100 000. Boletín Geológico, 23(1): 1–174.

González, H. 1989. Descripción petrográfica de las unidades litológicas de la serranía de Naquén (Colombia) y posibles correlaciones estratigráficas. V Congreso Colombiano de Geología. Memoirs, I, p. 31–49. Bucaramanga.

González, H., Lemoigne, I. & Martínez, J.O. 1977. Flora de la Formación Valle Alto, Jurásico en la Cordillera Central de Colombia. Boletín de Ciencias de la Tierra, 2: 107–122.

González–Ospina, L.J. 2016. Petrogénesis de los complejos ultramáficos de Heliconia–Angelópolis y del oriente de Medellín,

Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Proterozoic

Antioquia, Colombia. Master thesis, Universidad Nacional de Colombia, 108 p. Bogotá.

Hall, R.B., Álvarez, J. & Rico, H. 1972. Geología de parte de los departamentos de Antioquia y Caldas (Sub–Zona II–A. Boletín Geológico, 20(1): 1–85.

Harrington, H.J. & Kay, M. 1951. Cambrian and Ordovician faunas of eastern Colombia. Journal of Paleontology, 25(5): 655–668.

Hernández–González, J.S. & Urueña–Suárez, C.L. 2017. Aspectos geocronológicos y petrogenéticos del Complejo Aleluya: Implicaciones en la exploración de Mg en el norte del departamento del Huila, Colombia. XVI Congreso Colombiano de Geología. Memoirs, p. 832–838. Santa Marta.

Herrera, A. & Velásquez, B.E. 1978. Estratigrafía de la sección de Araracuara (Amazonía). Bachelor thesis, Universidad Nacional de Colombia, 82 p. Bogotá.

Ibañez–Mejia, M., Tassinari, C.C.G. & Jaramillo–Mejia, J.M. 2007. U–Pb zircon ages of the "Antioquian Batholith": Geochronological constraints of late Cretaceous magmatism in the central Andes of Colombia. XI Congreso Colombiano de Geología. Memoirs. 11 p. Bucaramanga.

Ibañez–Mejia, M., Jaramillo–Mejía, J.M. & Valencia, V. 2008. U–Th/Pb zircon geochronology by multicollector LA–ICP–MS of the Samaná Gneiss: A middle Triassic syn–tectonic body in the central Andes of Colombia related to the latter stages of Pangea assembly. VI South American Symposium on Isotope Geology San Carlos de Bariloche. Abstracts in CD ROM, p. 1–4. San Carlos de Bariloche, Argentina.

Ibañez–Mejia, M., Ruiz, J., Valencia, V.a., Cardona, A., Gehrels, G.E. & Mora, A.R. 2011. The Putumayo Orogen of Amazonia and its implications for Rodinia reconstructions: New U–Pb geochronological insights into the Proterozoic tectonic evolution of northwestern South America. Precambrian Research, 191(1–2): 58–77. https://doi.org/10.1016/j.precamres.2011.09.005

Ibañez–Mejia, M., Pullen, A., Arenstein, J., Gehrels, G.E., Valley, J., Ducea, M.N., Mora, A.R., Pecha, M. & Ruiz, J. 2015. Unraveling crustal growth and reworking processes in complex zircons from orogenic lower–crust: The Proterozoic Putumayo Orogen of Amazonia. Precambrian Research, 267: 285–310. https://doi.org/10.1016/j.precamres.2015.06.014

Ibañez–Mejia, M. & Cordani, U.G. 2020. Zircon U–Pb geochronology and Hf–Nd–O isotope geochemistry of the Paleoproterozoic to Mesoproterozoic basement in the westernmost Guiana Shield. In: Gómez, J. & Mateus–Zabala, D. (editors), The Geology of Colombia, Volume 1 Proterozoic – Paleozoic. Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 35, p. 65–90. Bogotá. https://doi.org/10.32685/pub.esp.35.2019.04

Idárraga–García, J. & Martínez–Uribe, L. 2005. Petrografía y geoquímica de la Migmatita de Manizales entre el cerro Morro Gordo y el río Chinchiná, al occidente de Manizales (Caldas). Bachelor thesis, Universidad de Caldas, 63 p. Manizales.

Jaramillo, L., Escovar, R. & Vesga, C.J. 1980. Edades K/Ar de rocas con alteración hidrotermal asociadas al sistema de pórfido de cobre y molibdeno de Mocoa, Intendencia del Putumayo, Colombia. Geología Norandina, (1): 11–18.

Kennan, L. & Pindell, J.L. 2009. Dextral shear, terrane accretion and basin formation in the northern Andes: Best explained by interaction with a Pacific–derived Caribbean Plate? In: James, K.H., Lorente, M.A. & Pindell, J.L. (editors), The origin and evolution of the Caribbean Plate. Geological Society of London, Special Publication 328, p. 487–531. https://doi.org/10.1144/SP328.20

Kroonenberg, S.B. 1982a. A Grenvillian granulite belt in the Colombian Andes and its relation to the Guiana Shield. Geologie en Mijnbouw, 61(4): 325–333.

Kroonenberg, S.B. 1982b. Litología, metamorfismo y origen de las granulitas del Macizo de Garzón, Cordillera Oriental (Colombia). Geología Norandina, (6): 39–46.

Leal–Mejía, H. 2011. Phanerozoic gold metallogeny in the Colombian Andes: A tectono–magmatic approach. Doctorade thesis, Universitat de Barcelona, 989 p. Barcelona.

Litherland, M., Aspden, J.A. & Jemielita, R.A. 1994. The metamorphic belts of Ecuador. Overseas Memoir of the British Geological Survey 11, 147 p. Nottingham, England.

López, J.A.; Khurama, S.; Bernal, L.E. & Cuellar, M.A. 2007. El Complejo Mitú: Una nueva perspectiva. XI Congreso Colombiano de Geología. Memoirs, 16 p. Bucaramanga.

Manosalva, S., Mariño, J., Vlach, S., Naranjo, W. & Castillo, H. 2017. Metamorfismo de rocas pelíticas en el Macizo de Floresta, Cordillera Oriental de Colombia. XIV Congreso Latinoamericano de Geología – XIII Congreso Colombiano de Geología. Memoirs, p. 115. Medellín.

Mantilla–Figueroa, L.C., García–Ramírez, C.A. & Valencia, V.A. 2016. Propuesta de escisión de la denominada 'Formación Silgará' (Macizo de Santander, Colombia), a partir de edades U–Pb en zircones detríticos. Boletín de Geología, 38(1): 33–50. http://dx.doi.org/10.18273/revbol.v38n1-2016002

Martens, U.C., Restrepo, J.J. & Solari, L.A. 2012. Sinifaná Metasedimentites and relations with Cajamarca Paragneisses of the Central Cordillera of Colombia. Boletín de Ciencias de la Tierra, 32: 99–110.

Martens, U., Restrepo, J.J., Ordóñez–Carmona, O. & Correa–Martínez, A.M. 2014. The Tahamí and Anacona Terranes of the Colombian Andes: Missing links between South American and Mexican Gondwana margins. The Journal of Geology, 122(5): 507–530. https://doi.org/10.1086/677177

Maya, M. & González, H. 1995. Unidades litodémicas en la Cordillera Central de Colombia. Boletín Geológico, 35(2–3): 43–57.

Mojica, J. 1980. Observaciones acerca del estado actual del conocimiento de la Formación Payandé (Triásico Superior), Valle Superior del Río Magdalena, Colombia. Geología Colombiana, 11: 67–88.

Mojica, J. & Macía, C. 1981. Características estratigráficas de la Formación Yaví, Mesozoico de la región entre Prado y Dolores, Tolima, Colombia. Geología Colombiana, 12: 7–32.

Mojica, J.; Villarroel, C. & Macía, C. 1988. Nuevos afloramientos fosilíferos del Ordovícico Medio (Fm. El Hígado) al oeste de Tarqui, Valle Superior del Magdalena (Huila, Colombia). Geología Colombiana 16: 95-97.

Montes, L.F. & Restrepo, J.J. 2005. Relación entre las metamorfitas de alto y bajo grado en el sur del Valle de Aburrá, Antioquia. Boletín de Ciencias de la Tierra, (17): 9–18.

Mora–Bohórquez, J.A., Ibañez–Mejia, M., Oncken, O., de Freitas, M., Vélez, V., Mesa, A. & Serna, L. 2017. Structure and age of the lower Magdalena Valley Basin basement, northern Colombia: New reflection–seismic and U–Pb–Hf insights into the termination of the central Andes against the Caribbean Basin. Journal of South American Earth Sciences, 74: 1–26. https://doi.org/10.1016/j.jsames.2017.01.001

Moreno–Sánchez, M. & Pardo–Trujillo, A. 2003. Stratigraphical and sedimentological constraints on western Colombia: Implications on the evolution of the Caribbean Plate. In: Bartolini, C., Buffler, R.T. & Blickwede, J. (editors), The circum–Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics. American Association of Petroleum Geologists Memoir 79, p. 891–924. Tulsa, USA.

Moreno–Sánchez, M., Gómez–Cruz, A.J. & Castillo–González, H. 2007. Ocurrencias de fósiles paleozoicos al este de la parte norte de la Cordillera Central y discusión sobre su significado geológico. Boletín Ciencias de la Tierra, (22): 39–48.

Mosquera, D. 1978. Geología del cuadrángulo K–8 Manizales. Ingeominas, Internal report 1763, 63 p. Bogotá.

Muñoz, J. 1980. Estudio petrológico del Grupo Valdivia. Bachelor thesis, Universidad Nacional de Colombia, 108 p. Medellín.

Nelson, W.H. 1962. Contribución al conocimiento de la Cordillera Central de Colombia, sección entre Ibagué y Armenia. Boletín Geológico, 10(1–3): 161–202.

Nivia, A., Marriner, G.F., Kerr, A.C. & Tarney, J. 2006. The Quebradagrande Complex: A Lower Cretaceous ensialic marginal basin in the Central Cordillera of the Colombian Andes. Journal of South American Earth Sciences, 21(4): 423–436. https://doi.org/10.1016/j.jsames.2006.07.002

Núñez, A., Macía, C. & Mojica, J. 1984. La Fm. Amoyá: Una nueva unidad post–Precámbrica – pre–Jurásica de la Cordillera Central, al W de Chaparral, Tolima, Colombia. Newsletters on Stratigraphy, 13(2): 77. https://doi.org/10.1127/nos/13/1984/77

Ochoa, A., Ríos, P., Cardozo, A.M., Cubides, J.V., Giraldo, D.F., Rincón, H.D. & Mendivelso, D. 2012. Memoria explicativa: Cartografía geológica y muestreo geoquímico de las planchas 159, 160, 161, 179, 180 y 181 Puerto Carreño, Vichada. Servicio Geológico Colombiano, 126 p. Bogotá.

Ordóñez–Carmona, O. 2001. Caracterização isotópica Rb–Sr e Sm–Nd dos principais eventos magmáticos nos Andes colombianos. Doctorade thesis, Universidad de Brasilia, 176 p. Brasilia.

Ordóñez–Carmona, O. & Pimentel, M.M. 2002. Rb–Sr and Sm–Nd isotopic study of the Puquí Complex, Colombian Andes. Journal of South American Earth Sciences, 15(2): 173–182. https://doi.org/10.1016/S0895-9811(02)00017-2

Ordóñez–Carmona, O., Pimentel, M.M., de Moraes, R. & Restrepo, J.J. 1999. Rocas Grenvillianas en la región de Puerto Berrío–Antioquia. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 23(87): 225–232.

Ordóñez–Carmona, O., Pimentel, M.M. & de Moraes, R. 2002. Granulitas de Los Mangos, un fragmento Grenvilliano en la parte oriental de la Sierra Nevada de Santa Marta. Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales, 26(99): 169–179.

Ordóñez, O., Pimentel, M.M. & Laux, J.H. 2008. Edades U–Pb del Batolito Antioqueño. Boletín de Ciencias de la Tierra, 1(22): 129–130.

Ordóñez–Carmona, O., Restrepo, J.J., de Brito, R.S.C., Martens, U. & Rodrigues, J.B. 2011. The late Paleocene age of the Santa Bárbara Batholith (Valle, Colombia) and its implications on the evolution of the Arquía Complex. XIV Congreso Latinoamericano de Geología – XIII Congreso Colombiano de Geología. Memoirs, p. 109. Medellín.

Patarroyo, P., Restrepo, J.J. & Giraldo, W. 2017. Posible presencia de fósiles de crinoides en mármoles del Complejo Cajamarca. XVI Congreso Colombiano de Geología. Memoirs, p. 428. Santa Marta.

Pindell, J., Maresch, W.V., Martens, U. & Stanek, K. 2012. The greater Antillean Arc: Early Cretaceous origin and proposed relationship to Central American subduction mélanges: Implications for models of Caribbean evolution. International Geology Review, 54(2): 131–143. https://doi.org/10.1080/00206814.2010.510008

Priem, H.N.A., Andriessen, P.A.M., Boelrijk, N.A.I.M., De Boorder, H., Hebeda, E.H., Huguett, A., Verdurmen, E.A.T. & Verschure, R.H. 1982. Geochronology of the Precambrian in the Amazonas region of southeastern Colombia (western Guiana Shield). Geologie in Mijnbouw, 61(3): 229–242.

Priem, H.N.A., Kroonenberg, S.B., Boelrijk, N.A.I.M. & Hebeda, E.H. 1989. Rb–Sr and K–Ar evidence for the presence of a 1.6 Ga basement underlying the 1.2 Ga Garzón–Santa Marta granulite belt in the Colombian Andes. Precambrian Research, 42(3–4): 315–324. https://doi.org/10.1016/0301-9268(89)90016-8

Puerta–Moreno, J.J. 1990. Estudio petrográfico del metamorfismo regional al oeste de Manizales. Bachelor thesis, Universidad Nacional de Colombia, 117 p. Medellín.

Renz, O. 1960. Geología de la parte sureste de la Península de Guajira (República de Colombia). III Congreso Geológico Venezolano. Memoirs, III, p. 317–346.

Renzoni, G. 1968. Geología del Macizo de Quetame. Geología Colombiana, 5: 75–127.

Renzoni, G. 1989. Comparación entre las secuencias metasedimentarias de la serranía de Naquén y de la Serra da Jacobina. Boletín Geológico, 30(2): 25–42.

Restrepo, J.J & Toussaint, J.F. 1985. Unidades litológicas de los alrededores de Medellín. Instituto de Ciencias Naturales y Ecología, Publicación Especial, 2: 1–31. Medellín.

Restrepo, J.J & Toussaint, J.F. 1988. Terranes and continental accretion in the Colombian Andes. Episodes. 11(3): 189–193.

Restrepo, J.J. & Toussaint, J.F. 1989. Terrenos alóctonos en los Andes colombianos: Explicación de algunas paradojas geológicas. V Congreso Colombiano de Geología. Memoirs, I, p. 92–107. Bucaramanga.

Restrepo, J.J., Toussaint, J.F., González, H., Cordani, U.G., Kawashita, K., Linares, E. & Parica, C. 1991. Precisiones geocronológicas sobre el occidente colombiano. Simposio sobre magmatismo andino y su marco tectónico. Memoirs, I, 21 p. Manizales.

Restrepo, J.J., Frantz, J.C., Ordóñez–Carmona, O., Correa, A.M., Martens, U. & Chemale Jr., F. 2007. Edad triásica de formación de la Ofiolita de Aburrá, flanco occidental de la cordillera Central. XI Congreso Colombiano de Geología. Abstracts, p. 49. Bucaramanga.

Restrepo, J.J., Dunlap, W.J., Martens, U., Ordóñez–Carmona, O. & Correa, A.M. 2008. Ar–Ar ages of amphibolites from the Central Cordillera of Colombia and their implications for tectonostratigraphic terrane evolution in the northwestern Andes. VI South American Symposium on Isotope Geology. Proceedings in CD ROM, p. 1–6. Bariloche, Argentina.

Restrepo, J.J., Ordóñez–Carmona, O., Martens, U. & Correa, A.M. 2009. Terrenos, complejos y provincias en la cordillera Central colombiana. Ingeniería, Investigación y Desarrollo, 9(2): 49–56.

Restrepo, J.J., Ordóñez–Carmona, O., Armstrong, R. & Pimentel, M.M. 2011. Triassic metamorphism in the northern part of the Tahamí Terrane of the Central Cordillera of Colombia. Journal of South American Earth Sciences, 32(4): 497–507. https://doi.org/10.1016/j.jsames.2011.04.009

Restrepo, J.J., Martens, U. & Giraldo–Ramírez, W.E. 2020. The Anacona Terrane: A small early Paleozoic peri–Gondwanan terrane in the Cauca–Romeral Fault System. In: Gómez, J. & Mateus–Zabala, D. (editors), The Geology of Colombia, Volume 1 Proterozoic – Paleozoic. Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 35, p. 149–165. Bogotá. https://doi.org/10.32685/pub.esp.35.2019.08

Restrepo–Moreno, S.A., Foster, D.A. & Kamenov, G.D. 2007. Formation age and magma sources for the Antioqueño Batholith derived from LA–ICP–MS uranium–lead dating and hafnium–isotope analysis of zircon grains. Geological Society of America Annual Meeting. Session 181–28 # 186. Denver, USA.

Restrepo–Pace, P.A., Ruiz, J., Gehrels, G. & Cosca, M. 1997. Geochronology and Nd isotopic data for Grenville–age rocks in the Colombian Andes: New constraints for late Proterozoic – early Paleozoic paleocontinental reconstructions of the Americas. Earth and Planetary Science Letters, 150(3–4): 427–441. https://doi.org/10.1016/S0012-821X(97)00091-5

Rodríguez, G. & Arango, M.I. 2013. Reinterpretación geoquímica y radiométrica de las metabasitas del Complejo Arquía. Boletín de Geología, 35(2): 65–81.

Rodríguez, G., González, H. & Zapata, G. 2005. Geología de la plancha 147 Medellín Oriental. Ingeominas, 300 p. Medellín.

Rodríguez, G., Sepúlveda, J., Ramírez, C., Ortiz, F.H., Ramos, K., Bermúdez, J.G. & Sierra, M.I. 2011. Unidades, petrografía y composición química del Complejo Migmatítico de Mitú en los alrededores de Mitú. Boletín de Geología, 33(1): 27–42.

Rodríguez, G., Obando, G., Correa–Martínez, A.M., Zapata, G. Correa, T., Obando, M., Rincón, A. & Zapata, J.P. 2017. Redefinición del bloque norte del Batolito de Ibagué con base en nuevos datos de petrografía, litogeoquímica y geocronología U–Pb. XVI Congreso Colombiano de Geología. Memoirs, p. 1437–1442. Santa Marta.

Rodríguez–Jiménez, J.V. 2010. Fábrica y emplazamiento de la Diorita de Pueblito, NW Cordillera Central de Colombia: Análisis de fábrica magnética y mineral. Master thesis, Universidad Nacional de Colombia, 68 p. Medellín.

Silva–Tamayo, J.C., Sial, A.N., Ferreira, V.P. & Estrada, J.J. 2004. C–isotope stratigraphy of a Vendian carbonate succession in northwestern Andes: Implications for the NW Andes. IV Reunión de Ciencias de la Tierra. Abstracts, p. 198. Querétaro, México.

Thouret, J.C., Cantagrel, J.M., Salinas, R. & Murcia, A. 1990. Quaternary eruptive history of Nevado del Ruiz (Colombia). Journal of Volcanology and Geothermal Research, 41(1–4): 225–251. https://doi.org/10.1016/0377-0273(90)90090-3

Toussaint, J.F. & Restrepo, J.J. 1989. Acreciones sucesivas en Colombia: Un nuevo modelo de evolución geológica. V Congreso Colombiano de Geología. Memoirs, p. 127–146. Bucaramanga.

Toussaint, J.F. & Restrepo, J.J. 2020. Tectonostratigraphic terranes in Colombia: An update. Second part: Oceanic terranes. In: Gómez, J. & Pinilla–Pachon, A.O. (editors), The Geology of Colombia, Volume 2 Mesozoic. Servicio Geológico Colombiano, Publicaciones Geológicas Especiales 36, p. 237–260. Bogotá. https://doi.org/10.32685/pub.esp.36.2019.07

Trumpy, D. 1943. Pre–Cretaceous of Colombia. Geological Society of America Bulletin, 54(9): 1281–1304. https://doi.org/10.1130/GSAB-54-1281

Tschanz, C.M., Marvin, R.F., Cruz, J., Mehnert, H.H. & Cebula, G.T. 1974. Geologic evolution of the Sierra Nevada de Santa Marta, northeastern Colombia. Geological Society of America Bulletin, 85(2): 273–284. https://doi.org/10.1130/0016-7606(1974)85<273:GEOTSN>2.0.CO;2

Ulloa, C., & Rodríguez, G.I. 1982. Intrusivos ácidos Ordovícicos y post–Devónicos en la Floresta (Boyacá). IV Congreso Colombiano de Geología, Memoirs, p. 23. Cali.

Ulloa, C., Pérez, V.E. & Baldis, B. 1982. Unidades litoestratigráficas del Ordovícico de los Llanos Orientales de Colombia. V Congreso Latinoamericano de Geología. Memoirs, I, p. 109–112. Buenos Aires.

Villagómez, D.R. 2010. Thermochronology, geochronology and geochemistry of the Western and Central Cordilleras and Sierra Nevada de Santa Marta, Colombia: The tectonic evolution of NW South America. Doctorade thesis, Université de Genève, 143 p. Geneva, Switzerland. https://doi.org/10.13097/archive-ouverte/unige:14270

Villagómez, D., Spikings, R., Magna, T., Kammer, A., Winkler, W. & Beltrán, A. 2011. Geochronology, geochemistry and tectonic evolution of the Western and Central cordilleras of Colombia. Lithos, 125(3–4): 875–896. https://doi.org/10.1016/j.lithos.2011.05.003

Vinasco, C.J., Cordani, U.G., González, H., Weber, M. & Pelaez, C. 2006. Geochronological, isotopic, and geochemical data from Permo–Triassic granitic gneisses and granitoids of the Colombian central Andes. Journal of South American Earth Sciences, 21(4): 355–371. https://doi.org/10.1016/j.jsames.2006.07.007

Ward, D.E., Goldsmith, R., Cruz, J. & Restrepo, H. 1973. Geología de los cuadrángulos H–12 Bucaramanga y H–13 Pamplona, Departamento de Santander. Boletín Geológico, 21(1–3): 1–132.

Weber, M., Cardona, A., Valencia, V., García–Casco, A., Tobón, M. & Zapata, S. 2010. U/Pb detrital zircon provenance from late Cretaceous metamorphic units of the Guajira Peninsula, Colombia: Tectonic implications on the collision between the Caribbean arc and the South American margin. Journal of South American Earth Sciences, 29(4): 805–816. https://doi.org/10.1016/j.jsames.2009.10.004

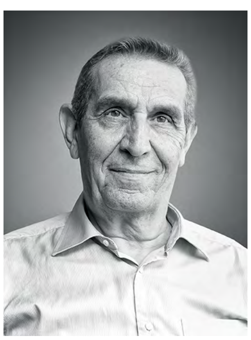
Zapata, G., Rodríguez, G., Arango, M.I. & Bermúdez, J.G. 2015. Catálogo de unidades litoestratigráficas de Colombia: Cuarzomonzodiorita de Páeza. Servicio Geológico Colombiano, 51 p. Bogotá.

Zapata, G., Rodríguez, G. & Arango, M.I. 2017. Petrografía, geoquímica y geocronología de rocas metamórficas aflorantes en San Francisco Putumayo y la vía Palermo–San Luis asociadas a los complejos La Cocha–Río Téllez y Aleluya. Boletín de Ciencias de la Tierra, (41): 48–65. https://doi.org/10.15446/rbct.n41.58630

Explanation of Acronyms, Abbreviations, and Symbols:

CRFZ	Cauca–Romeral Fault Zone
LA–ICP–MS	Laser ablation inductively coupled plasma mass spectrometry
LA–MC–ICP–MS	Laser ablation multi–collector inductively coupled plasma mass spectrometry
LGP	La Guajira Peninsula
SGC	Servicio Geológico Colombiano
SHRIMP	Sensitive high–resolution ion microprobe
SNSM	Sierra Nevada de Santa Marta

Authors' Biographical Notes



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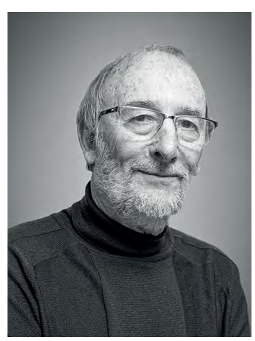

Jean–François TOUSSAINT has a Doctorate degree from the Université de Paris. After working in Bolivia for some time, he arrived at Medellín to teach at the Universidad Nacional de Colombia, Sede Medellín, where he taught courses such as Structural Geology, Geotectonics, Regional Geology, and Geology of Colombia for approximately 35 years. He was awarded the titles of Honorary Professor and "Maestro Universitario" by the Universidad Nacional. Some of his interests are the geological evolution of the Colombian Andes in terms of plate tectonics and tectonostratigraphic terranes, playing tennis, and the history of human evolution.