Geoheritage (2024) 16:94
https://doi.org/10.1007/s12371-024-00974-6

ORIGINAL ARTICLE

Geotourism and Geoeducation: A Holistic Approach for Socioeconomic Development in Rural Areas of Los Santos Municipality, Santander, Colombia

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Received: 23 January 2024 / Accepted: 4 June 2024

Abstract
This study emphasizes the untapped geotourism and geoeducation potential in the Mesa de Los Santos region, situated within the Chicamocha Canyon in Colombia, renowned for its abundant geoheritage. Despite the region's geological richness, geotourism development opportunities have been overlooked, leaving its geoheritage largely unexplored for tourism. Focused on the georoute Refugio La Roca—Los Santos, the study identifies key geosites with significant potential for future geotourism endeavors. The Mesa de Los Santos region boasts a complex geological history and diverse geodiversity shaped by various natural phenomena. However, its full geotourism potential remains undiscovered. The georoute, incorporating natural and cultural heritage, is strategically designed for geotourism and geoeducation, aiming at fostering geoconservation in rural areas. Educational and interpretive panels are employed as didactic resources to enlighten tourists about the natural phenomena shaping the landscape, enhancing their overall experience and understanding. By integrating geoethical considerations into geosite management, the study proposes achieving sustainable geoconservation in the Chicamocha Canyon territory. This approach not only contributes to preserving the region's geological uniqueness but also provides a platform for socio-economic development in rural areas. The study envisions creating meaningful experiences that attract tourists while benefiting local communities, thereby promoting holistic and sustainable rural development.

Keywords Georoute · Mesa de Los Santos · Natural and Cultural Heritage · Didactic · Landscape

Introduction

The global tourism industry is a multifaceted economic sector encompassing a wide range of activities and services associated with the movement of people across international borders for various purposes. It encompasses both public and private enterprises operating in various sectors, including transportation, accommodation, food services, entertainment, specialized tourism services, and others. Geotourism is a specialized form of tourism that specifically focuses on the unique geological features of a location and aims to provide educational and sustainable experiences for visitors. The term "geotourism" was introduced by the National Geographic Society (NGS) and is a relatively new concept in the tourism industry that has emerged worldwide as a rapidly growing form of tourism (Turner 2006). Geotourism has been a rapidly growing global activity (e.g., Dowling and Newsome 2010; Hose and Vasiljević 2012). Geotourism is a form of tourism that emphasizes geology and landscape as central elements of the tourist experience. In this context, various types of geotourism can be identified (Fig. 1). Cultural geotourism focuses on visiting geological sites with a strong emphasis on the cultural history associated with those places (e.g., Freire-Lista et al. 2022). Adventure geotourism involves active exploration of challenging geological areas, such as karstic caves, mountains, and canyons (e.g., Garofano and Govoni 2012). Educational geotourism imparts geological knowledge to visitors through guided tours, interpretative exhibits, and educational activities (e.g., Lovendianto and Defiana 2023). Sustainable geotourism highlights the conservation and preservation of geological and natural resources, with a focus on sustainability (e.g., Martínez-Graña et al. 2017). Recreational geotourism includes leisure and recreational activities in geological

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Published online: 07 September 2024

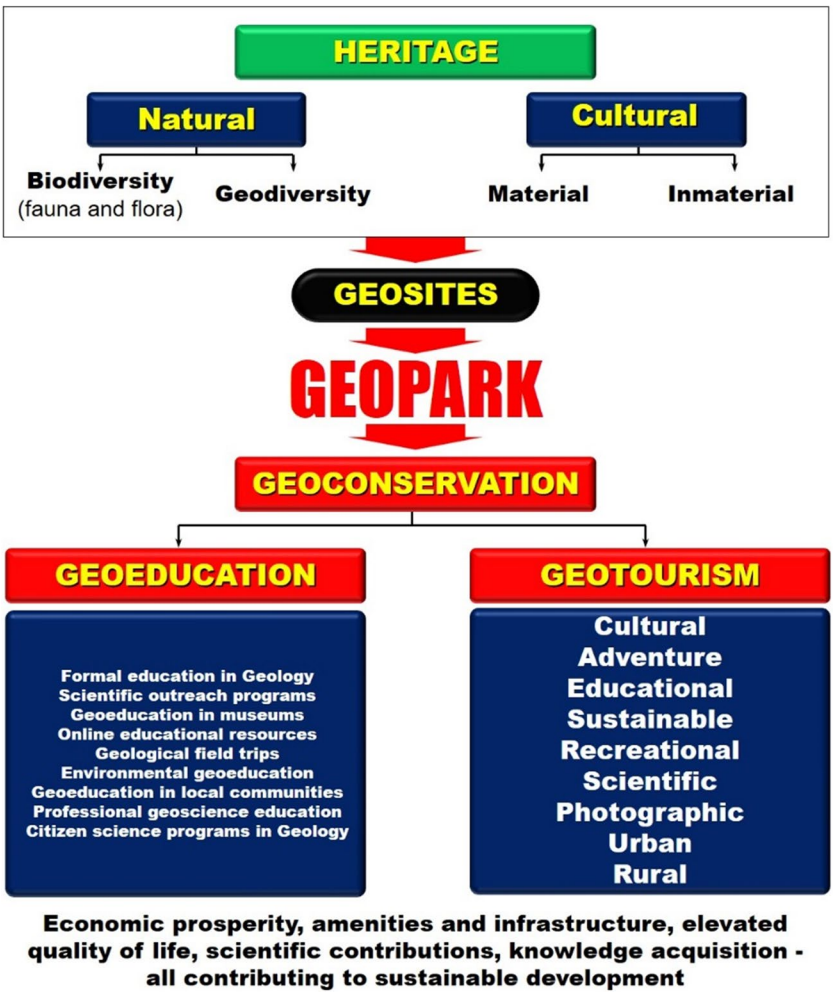

Fig. 1 A relationship between heritage, geopark, geosites, research topics for geotourism, and sustainable development (adapted and modified after Çelik-Ateş and Ateş 2019)

environments, such as visiting geological parks and natural areas (e.g., Ogezi et al. 2010). Scientific geotourism entails the active participation of geologists and professionals in the research and study of specific areas (e.g., Tomić et al. 2020). Photographic geotourism focuses on visually capturing the beauty and uniqueness of geological landscapes through photography (e.g., Larwood 2014). Urban geotourism is centered on exploring geology within urban environments, highlighting geological features present in buildings and monuments (e.g., Liccardo et al. 2012; Dóniz-Páez et al. 2015; Kubalíková et al. 2021). These typologies encompass a wide variety of geotouristic experiences, from outdoor adventures to urban explorations, reflecting the diversity of geodiversity that can be found in different places and contexts. Nekouie-Sadry and Hajalilu (2009) proposed a comprehensive classification of geotourism, categorizing it into seven distinct segments: adventure and sport geotourism, geology and geomorphology, road outcrops, rocky and stone monuments (encompassing caving art), mine geotourism, and human fossils exploration. However, it is essential to highlight that the ensuing category of geotourism aligns more cohesively with thematic tourism products. One of the geotourism products which is growing under the umbrella of rural tourism is the recently named "rural geotourism", which is a specific variant of tourism that combines the principles of geotourism with rural settings. Similar to geotourism, the focus is on appreciating and conserving geological heritage, but it takes place in rural areas where the connection with nature and rural life is paramount. According to Lane (1994), it is defined as tourism that unfolds in the countryside. It is emphasized that, at the local level, a prerequisite for rural settings is a population density of 150 persons per square kilometer (OECD 1993). However, it's important to note that the criteria and settlement sizes for rural areas may vary between countries. Moreover, rural tourism is dedicated to the conservation of landscapes, as well as the preservation of natural and cultural heritage. In this context, it is pertinent to assert that rural geotourism, occurring in rural areas, adheres to these criteria. Rural geotourism, a subset of nature tourism, unfolds in the countryside and encompasses unique geological and geomorphological landscapes. This type of tourism aims to provide

enriching and educational experiences while highlighting the distinctive geological features of a rural environment. Key features of rural geotourism include geological heritage, local community involvement, educational experiences, sustainability and specific geotourism activities. Emphasis is placed on the presence of unique geological features in rural areas, such as rock formations, karstic cavities, minerals, and other notable geological elements. Similar to rural tourism, there is a focus on the active participation of local communities, allowing visitors to interact with residents and learn about the interconnections between geology and everyday life. It provides educational information about the geological history of the area, the processes that have shaped the landscape, and the importance of conserving geological heritage, seeks sustainable tourism practices that preserve both geological richness and the rural environment, minimizing environmental impact, and includes specific geotourism activities such as visits to geological sites, interpretative hiking focused on geology, and other experiences that highlight the significance of geodiversity. Therefore, rural geotourism offers visitors the opportunity to explore and understand the relationship between geology and life in rural environments, creating a comprehensive tourist experience that combines the appreciation of geological heritage with the natural and cultural richness of local communities in rural areas. Rural geotourism and georoutes are closely linked, as both focus on the connection between the appreciation of geological heritage and life in rural environments. In Colombia, there are thousands of kilometers of historical paths built since pre-Hispanic and colonial times to facilitate product exchange. Some of these paths have been adapted as natural routes with varying levels of difficulty to promote hiking, a sports activity aimed at exploring routes that offer tourists the opportunity to enjoy nature and diverse landscapes. Hiking has been gaining importance in Colombia as it promotes nature tourism and allows visitors to explore the remarkable diversity the country has to offer, becoming an attraction for international tourists as the tourism offering expands. Colombia is moving towards sustainable tourism, which could become one of the main drivers of the country's economy in the coming years. The natural and cultural heritage is an undeniable national asset, with isolated initiatives focused on improving infrastructure and strengthening the production chain, generating an increasingly diverse offering that will favor the increase in tourist flow to the country. Geological heritage is part of the natural and cultural heritage of humanity, becoming more than just a scientific and educational resource. Globally, numerous georoutes have been developed (e.g., Tavera-Escobar et al. 2017; Ibañez et al. 2018; Spyrou et al. 2022; Herrera-Franco et al. 2022; Rivera and Tassara 2023). Geological points of interest in the georoute have, in addition to their scientific and educational value, an added value due to their scenic appeal, making the region a significant destination to be leveraged as a geotourism resource. The main objective of this work is to bring tourists closer to the geological heritage as a valuable resource for the development of geotourism and the teaching of geosciences, contributing to socioeconomic development in rural areas.

Research Methods

The methodology employed in this research is grounded in field geology, involving extensive visits to geosites across various regions, with a particular focus on the Mesa de Los Santos. The research delves into the touristic attractions within these geosites, emphasizing their geological, cultural, and historical significance. Additionally, the study examines potential risks related to the destruction and pollution of these valuable sites. To comprehensively understand and recommend suitable sites for geotourism development, a multifaceted approach is adopted. This includes a variety of research methods such as library-documentation studies, field studies, direct observations, and surveys. The evaluation encompasses an in-depth analysis of the region's geological, cultural, historical, and economic conditions. By synthesizing information from published documents, the research identifies the advantages of establishing geotourism in the Mesa de Los Santos region, aligning with the broader goal of contributing to its sustainable development. The research draws inspiration from the untapped geotourism potential highlighted in the overarching study. Focused on the georoute Refugio La Roca—Los Santos, key geosites with promising prospects for future geotourism are pinpointed. The study recognizes the complex geological history of the Mesa de Los Santos region, emphasizing its rich geodiversity shaped by various natural phenomena. Despite this richness, the full extent of geotourism potential in the region remains largely unexplored. The georoute, specifically designed to encompass the significant natural and cultural heritage attributes of the region, serves as a focal point for fostering geotourism and geoeducation. Didactic resources, including educational and interpretive panels, are strategically utilized to enhance the experience of tourists and promote an understanding of the natural phenomena that have shaped the landscape. The study incorporates a geoethical perspective into the management of geosites, advocating for sustainable geoconservation in the Chicamocha Canyon territory. This approach not only contributes to preserving the geological uniqueness of the region but also provides a foundation for socio-economic development in rural areas. The research envisions creating meaningful and enlightening experiences for tourists while simultaneously benefiting local communities, thereby paving the way for holistic and sustainable rural development.

Geology of the Georoute

The region traversed by the georoute lies on the western flank of the Eastern Cordillera, specifically in the Mesa de Los Santos region, situated south of Bucaramanga and bounded in that direction by the Chicamocha River Canyon, which flows southwest and then west (Fig. 2). The geology of Mesa de Los Santos has been extensively studied by various authors since the 1930s. In the regional geological context, this region is part of the Mesas and Cuestas Zone located west of the Santander Massif (SM). Mesa de Los Santos is characterized by a flat surface, representing a structural surface; towards the west, a flexure appears, leading to westward dip angles until reaching the Suarez Fault (Julivert 1958). Among the structures that limit and exert significant influence in the study area, the Bucaramanga Fault stands out as a major regional structure, representing the most evident and extensive structural feature crossing the central-eastern region of the Department of Santander, with a N20ºW direction and a straight trace. Velandia and Bermúdez (2018) have provided valuable insights into the transpressive southern termination of the Bucaramanga Fault, shedding light on the complex tectonic processes shaping the geological landscape of the region. Their research employed geological mapping, stress tensor analysis, and fractal analysis to elucidate the structural characteristics and deformation patterns associated with this significant geological feature. Julivert (1968) conducted an analysis and synthesis of the stratigraphy of this region based on the nomenclature established by Morales (1958), which has been adapted and modified in subsequent studies (e.g., Ward et al. 1977; Royero and Vargas 1999). Metamorphic rocks predating the Devonian, constituting part of the crystalline basement of the SM, sedimentary rocks of Jurassic-Cretaceous age, and Quaternary deposits outcrop in the study area. The oldest rocks of the SM correspond to quartz-feldspar paragneisses, hornblende,

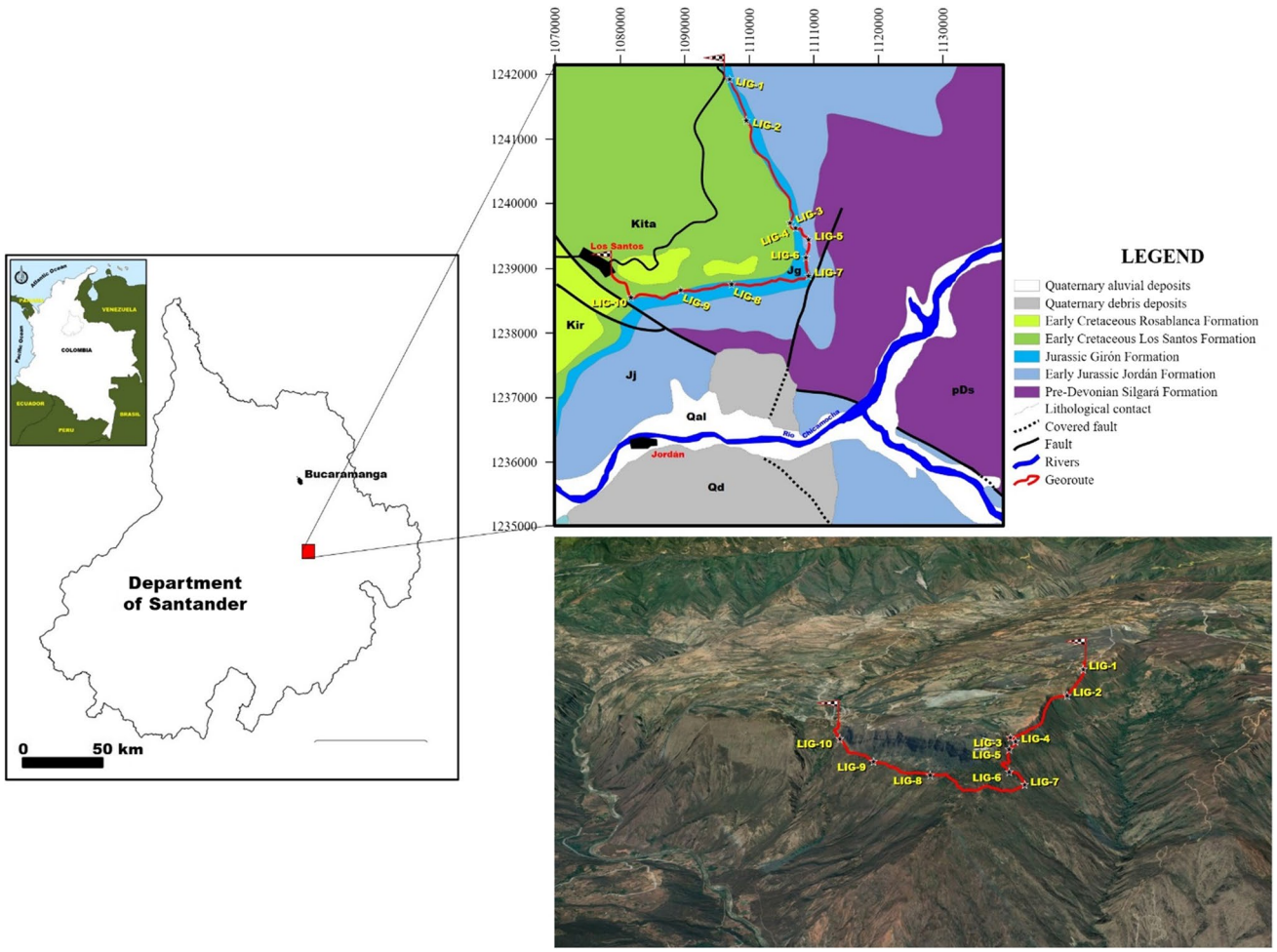

Fig. 2 Left, location of the study area in the Department of Santander (Colombia). Top right, geological map of the study area showing the location of the georoute in the region of Mesa de Los Santos. Bottom right, 3D model of the georoute (adapted and modified from Google Earth—http://earth.google.com)

mica, and garnet-bearing rocks, with subordinate amounts of amphibolites, migmatites, quartzites, marbles, and sporadically Precambrian granulites from the Bucaramanga Neis Complex (Royero and Clavijo 2001). The Silgara Formation was affected by a regional metamorphic event during the Caledonian (e.g., Mantilla et al. 2003; Ríos et al. 2003; Castellanos et al. 2010; Castellanos and Ríos 2015), which was probably superimposed by a thermal event (e.g., Ríos et al. 2003; Castellanos and Ríos 2015). These rocks are intruded by Paleozoic-Jurassic and Cretaceous intrusive bodies (e.g., Dörr et al. 1995; Ordóñez and Mantilla 2004), including the Pescadero Granite and the La Corcova Quartz Monzonite from the Triassic-Jurassic (e.g., Dörr et al. 1995) that are part of the Santander Plutonic Group. Rocks from the crystalline basement are overlain by geological units from the Jurassic-Cretaceous-Quaternary. Osorio-Naranjo et al. (2008) provides a significant contribution to understanding the geological and structural evolution of the SM region in Colombia, focuses on analyzing the mechanisms and forces that have influenced the geological configuration of this ancient massif, including the formation of tectonic structures, the distribution of geological materials, and deformation processes in the region. Arcila et al. (2020) provide a national seismic hazard model for Colombia, which may be relevant for understanding associated geological risks in regions such as Mesa de los Santos, where the georoute is located. The Chicamocha Canyon region has experienced significant tectonic activity, resulting in the presence of numerous faults and areas with elevated seismic activity (although not posing major risks) in Mesa de Los Santos (Ríos et al. 2020). Valencia-Ortiz and Martínez-Graña (2023) focus on morphometric evaluations and the calculation of precipitation and seismicity thresholds as triggers for mass movements, which are crucial factors for understanding the geological and geomorphological characteristics of the area. The morphometric evaluation study provides insights into the landforms and terrain characteristics of the Chicamocha Canyon region, which encompasses the Mesa de Los Santos region. Understanding the morphology of the terrain is essential for assessing the susceptibility of the area to mass movements such as landslides and rockfalls, which can impact the safety and accessibility of the georoute. Their findings contribute not only to the scientific understanding of regional geology but also to hazard assessment and risk mitigation strategies, providing crucial information for geotourism development and the teaching of geological sciences, contributing to socioeconomic development in rural areas.

General Description of the Georoute

The starting point of the georoute (Refugio La Roca) is located approximately 53 km from the city of Bucaramanga, with a travel time of 1 h and 20 min drive. Initially, you take the national route 45A that leads from Bucaramanga to Bogotá until reaching the "Y" junction located 21.8 km from Bucaramanga, a few meters before the El Bwey Restaurant, with a travel time of 35 min drive. From that point, you take the road to the right leading to Mesa de Los Santos until reaching Refugio La Roca in La Mojarra village located 31.2 km from the referred junction, with a travel time of 45 min drive. The roads are in good condition and accessible for vehicles of all types. Throughout this route, there are no significant obstacles affecting accessibility, allowing easy access to the starting point of the georoute.

The georoute (Fig. 3) unfolds along the eastern side of Mesa de Los Santos in a one-way direction, starting and ending at different points, and it has a length of 7.3 km, which is covered by approximately a 2.5-h hike. The trail is well-marked and usually frequented by hikers, climbers, and nature enthusiasts. It presents a moderate level of difficulty, with an elevation gain of 476 m and an elevation loss of -766 m, respectively. The maximum positive incline is 69.2%, the maximum negative incline is -64.9%, and the average incline is 15.2% and -16.7%. Some physical effort is required due to the length of the route and the steeper sections. The route descends from 1,576 m (Refugio La Roca) to 1,285 m (municipality of Los Santos). Along the georoute, visitors will encounter various points of interest, including stunning panoramic views of the Chicamocha River Canyon, unique geological formations, and historical landmarks. This georoute serves multiple purposes aimed at enriching visitors' experiences and contributing to the local community. Firstly, it provides an opportunity to explore and appreciate the geological diversity of the Chicamocha River Canyon and the Mesa de Los Santos region, showcasing some of the area's most remarkable natural features and cultural heritage sites. Moreover, the georoute is designed to promote geotourism in the region by offering visitors meaningful educational experiences focused on conservation and sustainability. Through engaging activities and interpretation, it aims to instill a deeper understanding of the importance of preserving these natural wonders for future generations. Additionally, the georoute serves as a platform for the dissemination of geoscientific knowledge in an accessible and engaging manner. Through interactive exhibits, guided tours, and educational materials, visitors have the opportunity to learn about the geological processes that have shaped the landscape over millions of years. This educational component, known as geoeducation, plays a vital role in fostering a sense of curiosity and appreciation for the natural world. Furthermore, the georoute seeks to raise awareness about the cultural and historical significance of the region, fostering a greater sense of connection and pride among local residents. By highlighting the rich heritage of the area, including its indigenous roots and colonial history, the georoute helps to

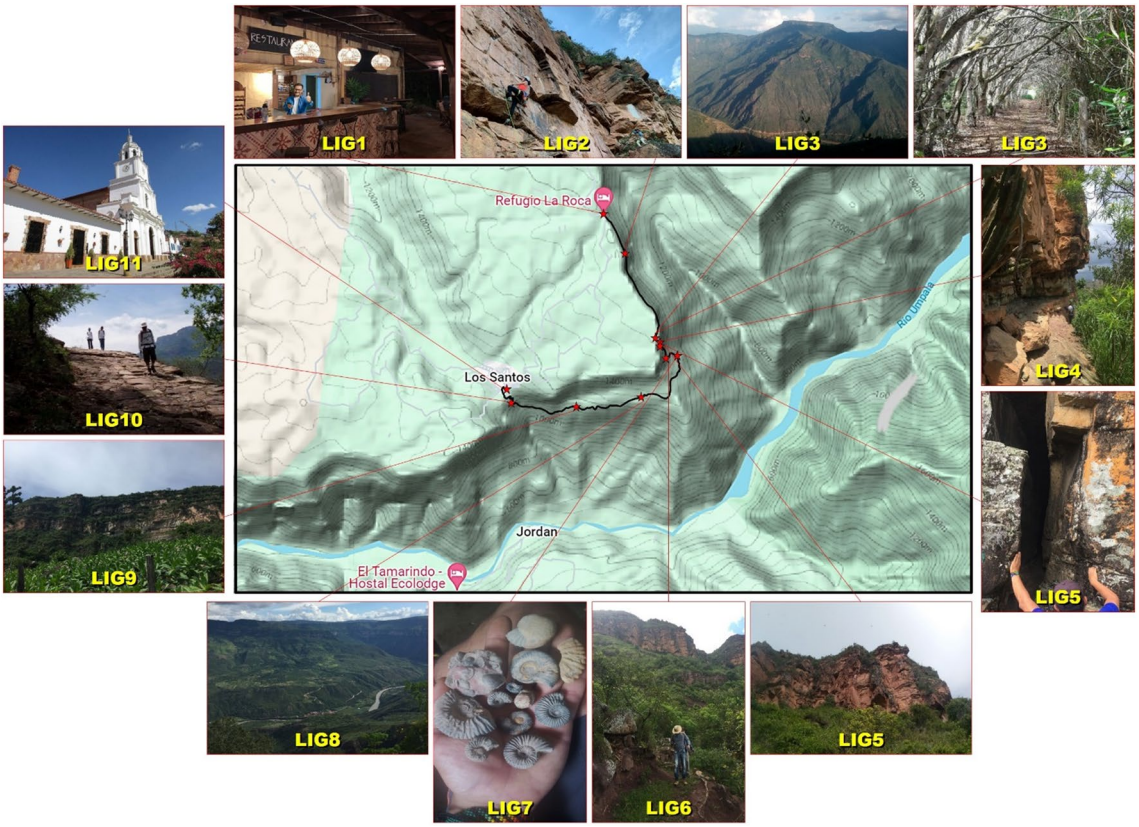

Fig. 3 Points of Geological Interest (red stars) along the Georoute (black line)

strengthen the community's sense of identity and belonging. Finally, the georoute aims to make a positive impact on the socio-economic development of rural areas within the Municipality of Los Santos. By attracting visitors and generating tourism revenue, it creates opportunities for local businesses and entrepreneurs, contributing to job creation and economic growth. Additionally, by showcasing the natural and cultural heritage of the region, the georoute helps to promote sustainable tourism practices that benefit both visitors and the local community alike.

LIG1—Refugio La Roca Eco Retreat

Refugio La Roca stands out as an eco-friendly hostel committed to respecting the environment and adopting sustainable practices. In this regard, it implements various measures to minimize its environmental footprint, such as the use of renewable energy, efficient waste management, and the promotion of conservation practices. The establishment features rustic rooms that seamlessly blend with the natural surroundings, constructed with eco-sustainable materials like earth, stone, wood, palm, and cane (Figs. 4a-d). These environmentally friendly materials preserve the scenic beauty without altering it. At Refugio La Roca, we consider tolerance towards diversity and respect for fauna and flora as fundamental principles. Our mission is to preserve, maintain, and care for the environment without causing harm. The refuge promotes harmony and respect for the natural surroundings, as well as local traditions and culture. Additionally, sustainable practices like rainwater harvesting, greywater reuse, domestic composting, renewable energy use, ecological education, and intelligent management of basic services are encouraged, along with the use of biodegradable products. The significance of Refugio La Roca extends across various dimensions in the context of the Chicamocha Canyon. Not only does it adopt environmentally friendly practices, such as efficient waste management and water conservation, but it also contributes to the protection of the natural environment and the reduction of the ecological footprint. Furthermore, it is dedicated to environmental education, providing information about local biodiversity and promoting sustainable travel practices among its guests. The refuge plays a crucial role in preserving and promoting local culture, traditions, and historical heritage. It actively engages in local sustainable development initiatives, working closely with communities to promote sustainable agricultural practices and conserve cultural identity. Ultimately, Refugio La Roca embraces responsible tourism by offering

Fig. 4 Refugio La Roca eco retreat and surrounding activities

visitors authentic and culturally enriching experiences while minimizing negative impacts on the environment and the local community. Its commitment contributes to the resilience of local ecosystems, protecting them from the harmful effects of unsustainable tourism. From Refugio La Roca, a descent begins through a steep trail (Fig. 4e) until reaching the La Mojarra climbing park campsite, from where it is possible not only to admire the wonderful and rugged landscape of the Chicamocha Canyon but also the characteristic fauna and flora (Fig. 4f). Hiking in terrain like this presents additional challenges that require attention and special care from hikers. Before starting the hike, proper planning is essential, including understanding the length and difficulty of the trail, as well as the weather conditions. It is important to wear suitable clothing and footwear for steep terrain, providing good grip and support for the feet. While walking, carefully observing the terrain and maintaining a proper posture is crucial. Using arms to balance and leaning on handrails or solid surfaces when available, as well as taking short and firm steps, is advised. During ascents, taking short breaks to catch one's breath and rest the legs is beneficial. When descending, controlling speed is important to prevent falls. Staying aware of the surroundings and adhering to good hiking practices ensures a safe and enjoyable experience.

LIG2—Rock-Climbing Park La Mojarra

Hiking along the georoute (Fig. 5a) leads us to La Mojarra, a natural reserve and rock-climbing park (Fig. 5b-d) that undoubtedly stands as the premier sports climbing destination in Colombia. Boasting the highest potential for new route openings, the park features over 400 equipped routes on the sandstone cliffs of the Los Santos Formation, stretching for more than a kilometer and a half. This extensive range provides climbers with opportunities for various climbing styles and movements. The significance of La Mojarra extends beyond national borders, attracting both local and international rock climbers who take on the challenges presented by the magnificent cliffs of the Los Santos Formation. The park hosts competitions organized by Santander X-Tremo, showcasing the skills and prowess of climbers (Fig. 5b). As this is an extreme sport, it is strongly recommended that participants come well-prepared with the necessary attire and equipment. The allure of La Mojarra extends beyond rock climbing, offering an equally enchanting experience for hiking enthusiasts. The trail that traverses the park provides a beautiful backdrop for this recreational activity. The journey becomes particularly intriguing in a section where traditional walking is not feasible, and the only way forward is via the via ferrata – a system of steel cables and anchor points embedded in the rock. For those who venture into this park, the opportunity to savor each sunset and sunrise is nothing short of marvelous. The captivating beauty of the natural surroundings, coupled with the adrenaline of rock climbing and the tranquility of hiking, makes La Mojarra a multifaceted destination that caters to both adventure seekers and nature lovers alike.

Fig. 5 Rock-climbing park La Mojarra

Fig. 6 Tree tunnel along the path trail

LIG3—Chicamocha River Canyon Viewpoint

One of the prime attractions at this viewpoint, offering a feast for nature enthusiasts and landscape admirers, is the tunnel of bare and intertwined trees leading to this geological point of interest. Here, nature becomes an artistic expression through a captivating tunnel of trees (Fig. 6). This tree tunnel serves as a passage where trees on either side create an almost continuous canopy overhead, producing the effect of a tunnel or even an underground passage. Thus, with their trunks and branches, the trees in this forest have sculpted a beautiful passageway where the sky is barely visible. Globally, tree tunnels have inspired landscape artists, and this natural wonder stands as a testament to the artistry inherent in nature. This unique tree tunnel not only showcases the ingenuity of nature but also serves as a global inspiration for landscape art. The artistic expression displayed by the intertwined trees forms an enchanting passageway, contributing to the aesthetic appeal of the geological route. The site highlights the intersection of natural beauty and artistic inspiration, emphasizing the significance of preserving such remarkable landscapes for both local appreciation and global artistic influence.

From this viewpoint you can marvel at the breathtaking Chicamocha River Canyon (Fig. 7), a geological masterpiece shaped by fluvial erosion and denudational processes driven by surface water flow. These processes persistently sculpt the riverbed, creating majestic gorges and drainage basins on both banks (Fig. 7a). Figures 7b-c depict the remarkable geomorphological features visible from this station, prominently featuring the Mesa de San Pedro. Here, Jurassic-Cretaceous rocks rest unconformably atop metamorphic rocks from the Silgará Formation, dating back to the pre-Devonian era. In Fig. 7d, the sedimentary cover of the Mesa de Los Santos is evident, showcasing towering cliffs formed by the Los Santos Formation (Lower Cretaceous). This formation unconformably overlies rocks from the Girón Formation of Jurassic age. Figure 7e illustrates an outcrop of sandstones from the Los Santos Formation, characterized by tabular geometry and blocky jointing. The sedimentary sequence of the Los Santos Formation reflects a fluvial environment comprising channel deposits, channel bar deposits, and abandoned channel deposits. The Chicamocha River Canyon, visible from this starting point, stands as a testament to the dynamic geological processes that have shaped the landscape. The diverse rock formations, spanning different geological eras, offer a unique opportunity to witness the intricate geological history of the region. This site not only provides valuable insights into the Earth's geological evolution but also serves as an educational and interpretative resource for visitors, highlighting the importance of preserving and understanding our geological heritage.

LIG4—Los Santos Formation Cliff

From a geoeducational standpoint, it's worth illustrating the concepts of continuity and discontinuity here, which apply

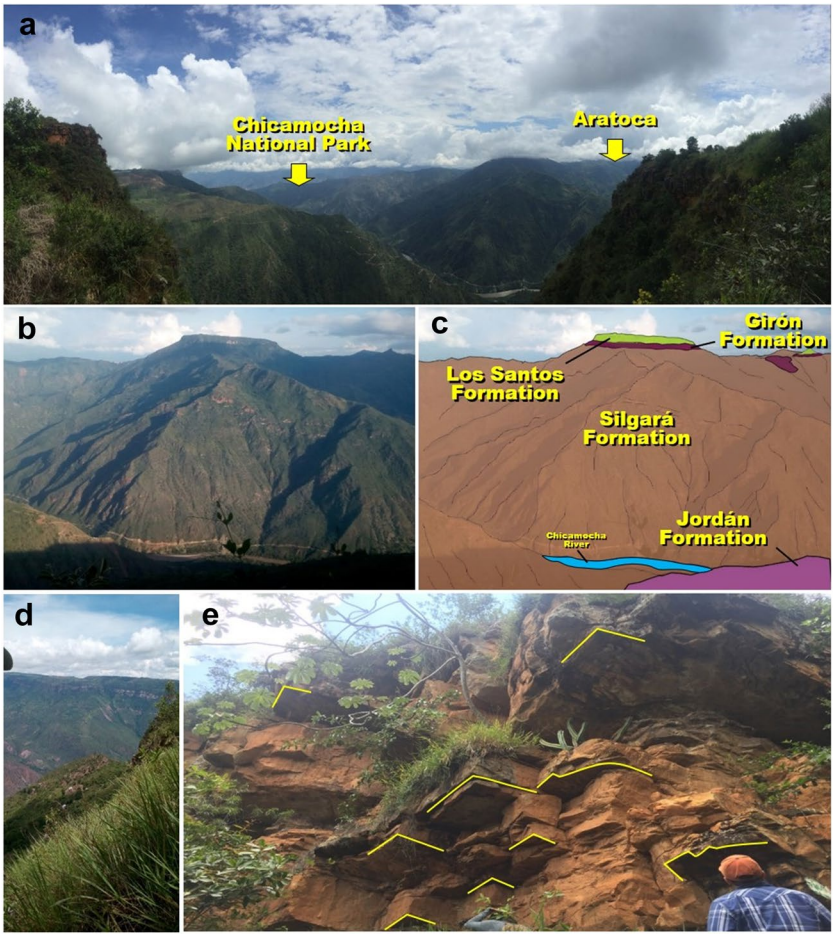

Fig. 7 (**a**) Chicamocha River Canyon. (**b**)-(**c**) San Pedro Mesa. (**d**) Sedimentary cover of Los Santos Mesa. (**e**) Tabular geometry and block fracturing of Los Santos Formation sandstones

to the genetic relationships between overlapping parts of a stratigraphic section, often coinciding with the boundary between two units. This cliff of sedimentary rocks provides an opportunity to study the stratigraphic record revealed by the outcropping geological units. The stratigraphic record (Fig. 8) doesn't always show continuity (Fig. 8a), as interruptions in sedimentation can occur. Stratigraphic discontinuities can be of three types: (1) unconformity (discontinuity between an older stratigraphic succession, which underwent erosion, and a more recent one, Fig. 8b); (2) discordance (discontinuity between an older stratigraphic succession, which underwent folding and erosion, and a more recent one, Fig. 8c); (3) nonconformity (discontinuity between an ancient crystalline basement composed of igneous and/or metamorphic rocks and a more recent stratigraphic succession, Fig. 8d). This geological site, characterized by the impressive cliffs of the Los Santos Formation, offers a unique opportunity to explore and understand the complex history of sedimentation and tectonic processes shaping the region over geological time. The exposed layers provide a tangible record of Earth's dynamic past, making it a valuable resource for both geological education and the appreciation of the Earth's geological heritage.

The Lower Cretaceous Los Santos Formation, with an assigned age of 145–139 Ma (Berriasian—Lower Valanginian), rests here discordantly over the Jurassic Girón Formation. The sedimentary rocks of the Los Santos Formation generally exhibit tabular geometry with layers of varying thickness (Figs. 9a-b). Cliffs of this sedimentary unit stand out in the Mesa de Los Santos region. Evidence of the discontinuity between these geological units is observed in Figs. 9c-d, with younger rocks (Los Santos Formation) overlying inclined older rocks (Girón Formation), as reported by Julivert et al. (1964) in the surroundings of the Mesa de Los Santos region. Previous studies regarding the stratigraphic relationship between the Girón and Los Santos formations demonstrate that it hasn't been definitively established whether the contact between these formations is unconformable or transitional (e.g., Ward et al. 1973; Royero and Clavijo 2001). However, the stratigraphic relationship between the Girón and Los Santos formations reveals that the boundary between these two geological units is marked by a disconformity within the stratigraphic sequence of the Girón Formation, which underwent erosion before the deposition of the Los Santos Formation. This geological feature not only provides insights into the geological history of the

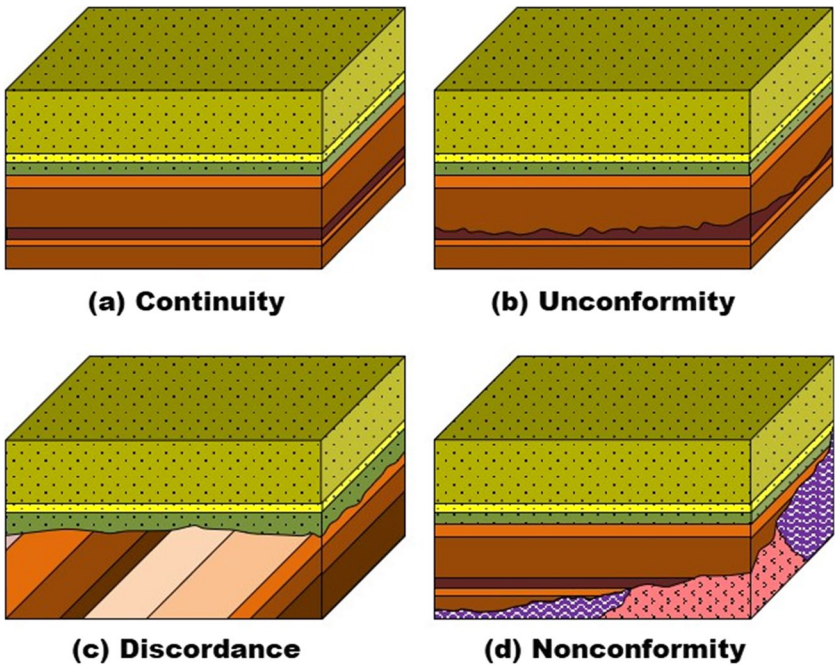

Fig. 8 Stratigraphic continuity and discontinuities in the geological record

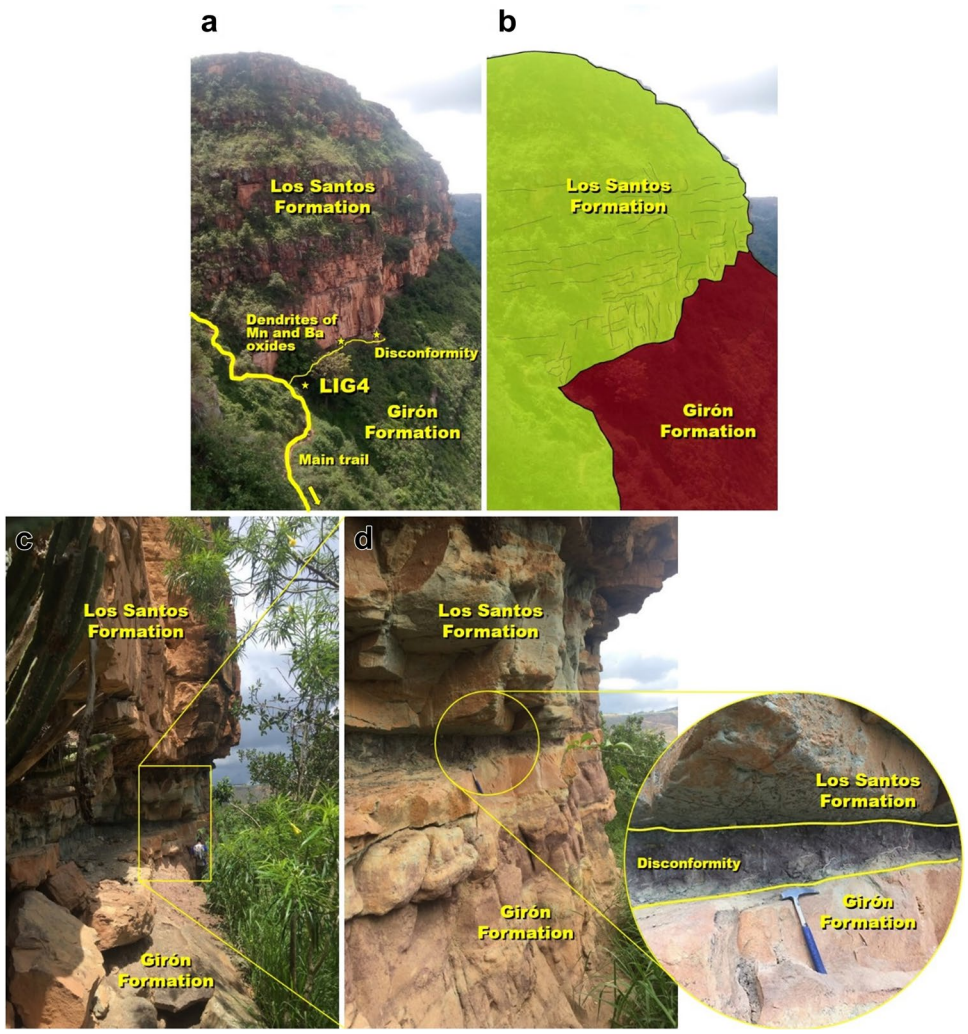

Fig. 9 (**a**)-(**b**) Disconformity between the Los Santos and Girón formations. (**c**) Tabular geometry and cross-bedding, flat-parallel and trough bedding of the sandstones of the Los Santos Formation

region but also offers a tangible record of past environmental conditions, contributing significantly to the understanding of the dynamic Earth processes that shaped the landscape over millions of years.

Here, the Upper Member of the Los Santos Formation outcrops, corresponding to quartzarenites and sublitharenites in medium to thick layers with tabular to wedge-shaped geometry, ranging from gray to pale yellow, exhibiting cross-bedding, flat-parallel, and trough bedding (Fig. 10a). In Fig. 10b, the development of numerous cavities and centimeter-sized recesses is observed, displaying a pattern of orientation, although typically not interconnected and locally clustered. The mechanism behind the formation of these cavities and recesses could be attributed to diffusion and convection of intergranular solutions emerging along the external walls of the rock (Galán et al. 2019) or to differential dissolution (García-Garmilla 1990). This geological feature not only contributes to the scientific understanding of sedimentary processes but also provides a recreational outlet, attracting rock climbing enthusiasts and adventure seekers to experience the unique geological formations of the region. The integration of extreme sports with geological exploration adds an extra layer of significance to the geological heritage, making it accessible and engaging for a broader audience.

At this location, a groundwater seep emerges through the joints and fractures of the clear medium to coarse-grained quartzose sandstones with intercalations of gray to brown limolites of this Lower Cretaceous sedimentary unit, assigned an age of 145–139 Ma (Berriasian—Lower Valanginian). How can groundwater flow through rocks? Rainwater infiltrated into the subsurface until reaching a layer of sandstone from the Los Santos Formation, porous and fractured enough to allow water to move horizontally due to its permeability through the more porous rock layer. The presence of fractures in this layer has facilitated the emergence of groundwater (Fig. 11). The Los Santos Formation has been of interest in the Mesa de Los Santos region to

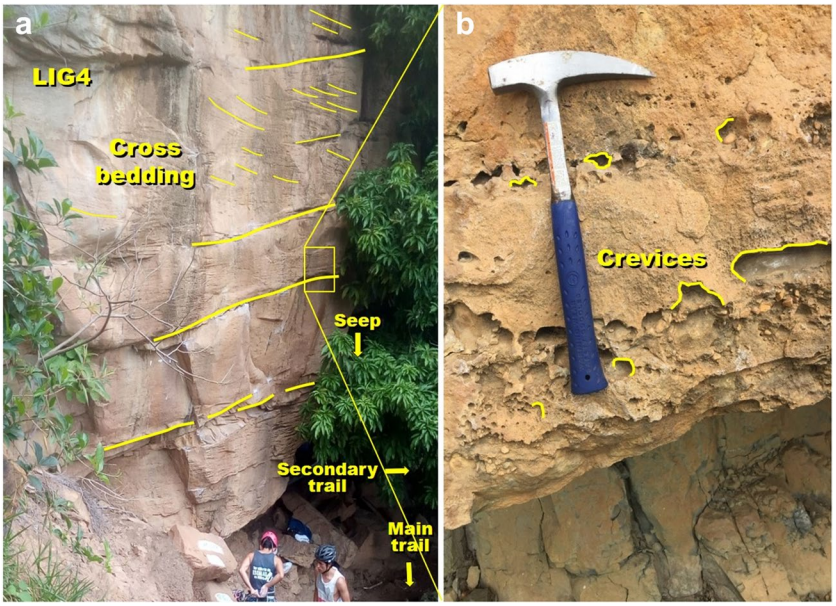

Fig. 10 (**a**) Cross-bedding and tabular geometry in sandstones of the Los Santos Formation. (**b**) Development of recesses due to the physical and chemical weathering of the sandstones

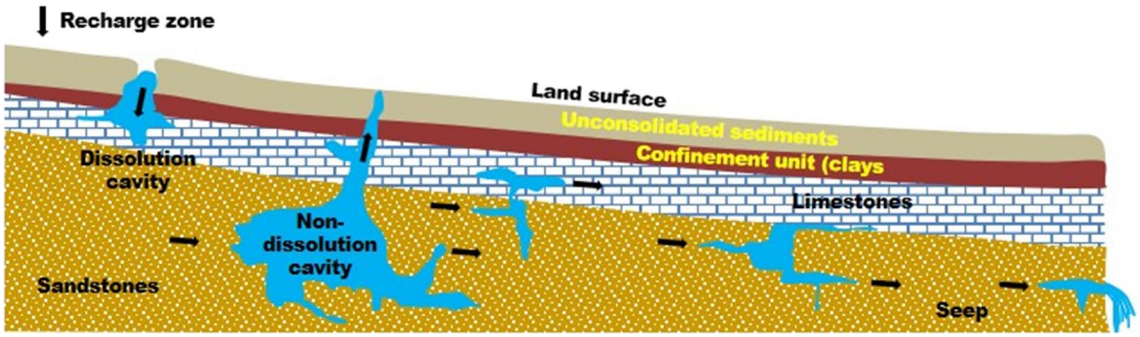

Fig. 11 Generalized scheme of aquifer formation and seepage in sandstones of the Los Santos Formation

assess the hydrogeological potential (e.g., Díaz et al. 2009) for providing new water supply alternatives to local communities. Understanding the hydrogeological features of this site not only contributes to the scientific understanding of groundwater flow in geological formations but also has practical implications for local water supply strategies. This geological formation serves as a natural reservoir, showcasing the intersection of geological processes, water dynamics, and human needs in the region.

Another notable feature found within the sandstones of the Los Santos Formation is the presence of oxide dendrites (Fig. 10). Historically, they have often been mistaken for tree-like branches, commonly referred to as pseudofossils (Fig. 10a). In certain instances, they have been erroneously labeled as pyrolusite dendrites, a term that lacks scientific validity (e.g., Xu et al. 2010). Figures 10b-c showcase SEM backscatter electron images of these dendrites at varying magnifications, revealing them as lighter areas within the grayscale, indicative of a higher density of backscattered electrons. However, a comprehensive analysis of the chemical composition of this type of mineral occurrence suggests that the dendrites correspond to manganese and barium oxides, likely hollandite or romanechite. This identification is supported by the EDS spectrum (Fig. 10d) obtained through scanning electron microscopy. The formation mechanism of these Mn and Ba dendrites is believed to be linked to the presence of natural fractures within the rock. These fractures serve as conduits for the accumulation of manganese and barium-rich solutions, which permeate through the rock and precipitate crystals. Over time, these crystals develop into dendritic aggregates, contributing to the intricate formations observed (Figs. 12a-d).

LIG5—Pseudokarst

In this LIG, tectonic efforts causing the development of joints and fractures in sandstones of the Los Santos Formation are evident (Figs. 13a-b), as well as the detachment of tabular blocks, mechanically creating cavities in the form of cracks or caves, classified as "pseudokarst." This term refers to a karstic morphology produced by processes not associated with dissolution phenomena in siliceous rocks

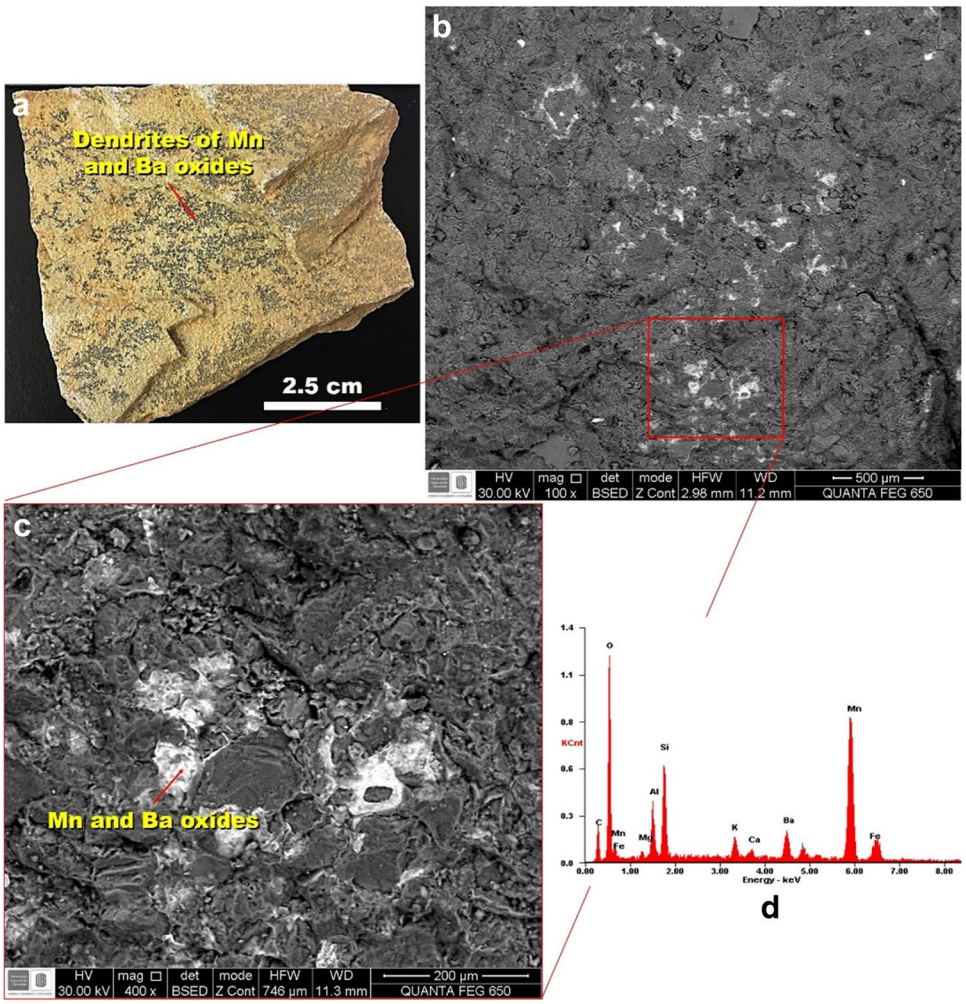

Fig. 12 (**a**) Hand specimen. (**b**)-(**c**) SEM images. (**d**) EDS spectrum of oxide dendrites

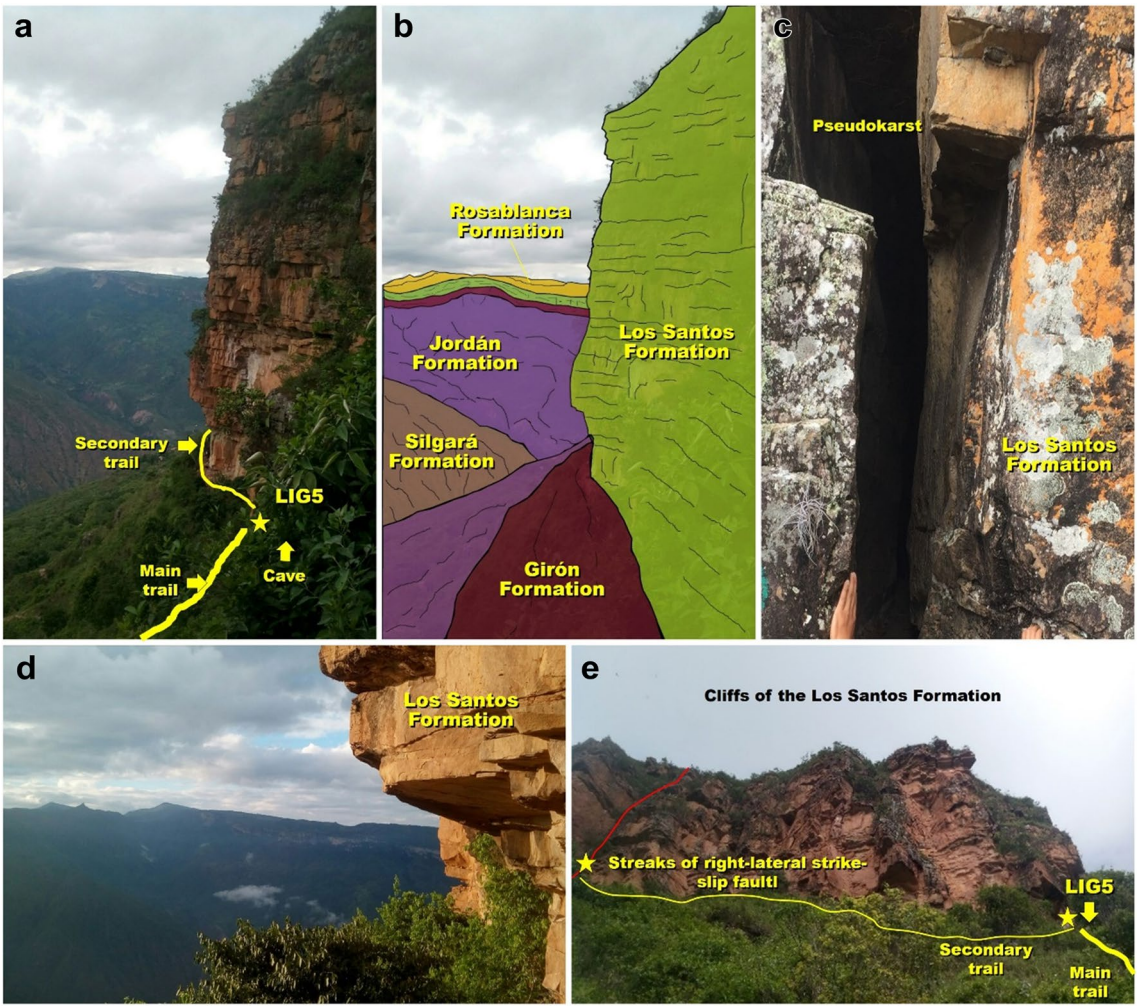

Fig. 13 (**a**)-(**b**) Field relationships between observable geological units. (**c**) Pseudokarst. (**d**) Panoramic view towards Alto de Aratoca. (**e**) Cliffs of the Los Santos Formation

like the sandstones of this geological unit (e.g., Balado-Piedra and Molerio-León 2017). The sandstones of the Los Santos Formation are essentially composed of quartz grains (more than 90%) in a matrix or intergranular cement mainly of siliceous composition. Here, "pseudokarst" cavities are observed with dimensions of up to 1 m thick, 3 m in height, and 6 m in length (Fig. 13c). From here, it is possible to observe the Alto de Aratoca (Fig. 13d), and throughout the route, the cliffs of the Los Santos Formation are highly attractive (Fig. 13e), which has been affected by tectonism, with the development of fault striae, and intense jointing and fracturing.

LIG6—Disconformity Between the Girón and Los Santos Formations

During the descent, it is possible to observe not only the change in slope but also lithological features of the outcropping sedimentary rocks (Fig. 14). The abrupt change in slope is a direct result of differential erosion responsible for the loss of solid material in rocks of lower relative resistance. Here, it is possible to establish the discordant contact between the yellow-reddish fine-grained sandstones of the Lower Cretaceous Los Santos Formation, at the top, which develops a vertical scarp appealing to those who practice rappelling, and the Upper Jurassic Girón Formation. The Girón Formation stands out for the presence of a thick set of red, conglomeratic, and white and green-spotted clayey sandstones, as well as intercalations of reddish-brown mudstones. The Los Santos Formation rests discordantly over the Girón Formation, developing a slightly discordant surface in the La Mesa de los Santos area (Julivert et al. 1964). Etayo-Serna and Rodríguez (1985) assign it a Berriasian age. According to Ward et al. (1973), the Girón Formation rests discordantly at a low angle (10-15º) over the Jordán Formation. The Girón Formation is assigned an Upper Jurassic age

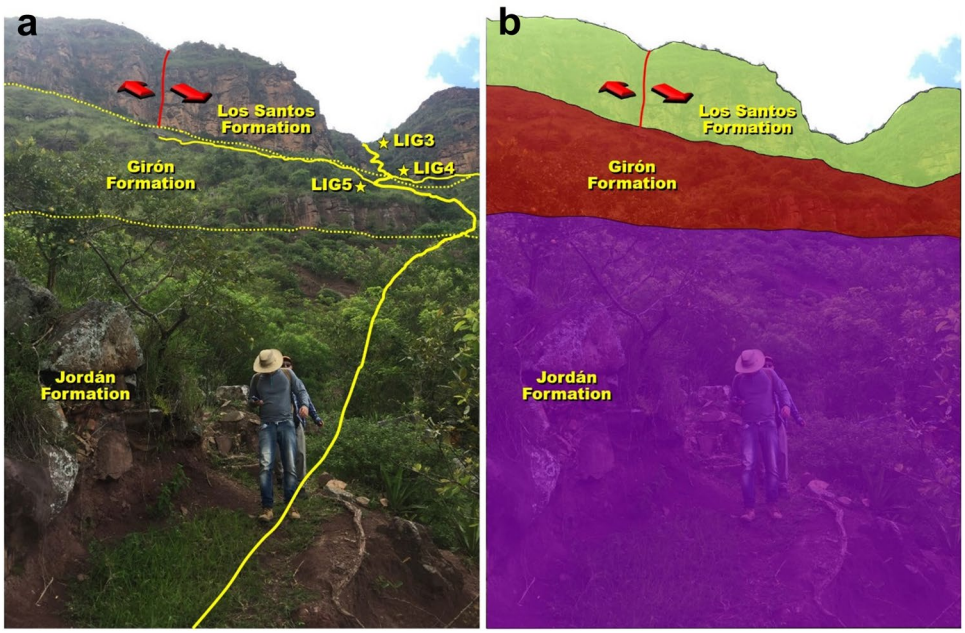

Fig. 14 (**a**)-(**b**) Discordant contact between the Los Santos Formation (upper part) and the Girón Formation (lower part)

based on ostracods (Rabe 1977) and palynomorphs (Pons 1982). A dextral strike-slip fault associated with the Los Santos Fault is also observed, which seems to coincide with the Aratoca Fault.

LIG7—Paleontological and Archaeological Heritage

This point of geological interest offers a fascinating glimpse into the world of paleontology through the examination of mollusk fossils, prominently featuring ammonites and gastropods (Figs. 15a-d). While these specimens may not have been directly collected along the route, they originate from the Paja Formation (ammonites) and Rosablanca Formation (gastropods), both of which are integral to the geological landscape of the region. The Rosablanca Formation overlies the Los Santos Formation and is composed, towards its base, of limestones and dolomitic limestones with few intercalations of terrigenous rocks, in the middle part by biomicrites, marls, and shales, and towards the top by oolitic limestones of grayish-brown color. The Paja Formation is stratigraphically above the Rosablanca Formation, and its age range extends from the Lower Barremian to the Upper Aptian (according to the fossil record). It is predominantly composed of black fissile mudstones with planar-parallel lamination and, to a lesser extent, thin intercalations, very occasionally thick, of micrites and biomicrites. The occurrence of fossiliferous concretions is common, occasionally pyritous, containing ammonites, bivalves, fish, and gastropods (Patarroyo 1997). This geological unit also presents dark brown to black, organic-rich shales, slightly calcareous to calcareous, quite hard, and in some cases with the presence of micas and pyrites as accessory minerals. Beyond their scientific significance, these fossils hold cultural and recreational importance within the local community. It's worth noting that many inhabitants of the region and avid fossil enthusiasts often encounter such specimens in their everyday lives, leading to the formation of informal personal collections. These fossils serve as tangible connections to

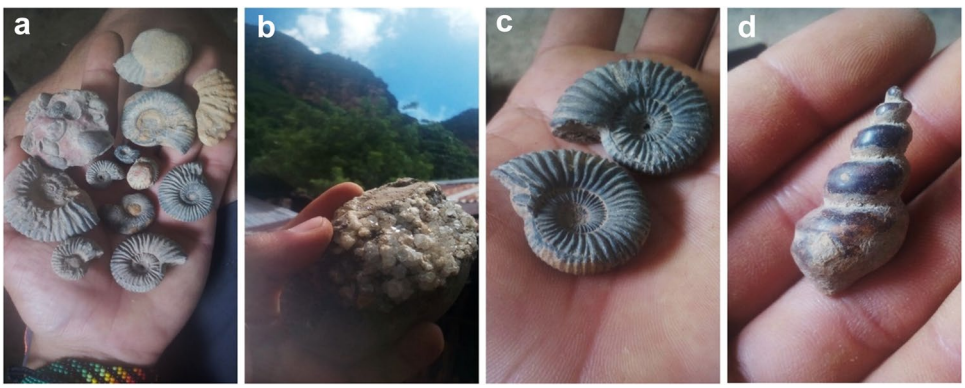

Fig. 15 (**a**) Fossilized ammonites and gastropods, held in hand for examination. (**b**) Faunal association ammonites and gastropods in a Cretaceous sedimentary rock. Fossilized (**c**) ammonites and (**d**) gastropod, held in hand for detailed study

the geological history of the area, fostering a sense of pride and stewardship among residents. Additionally, the geological unit also presents dark brown to black, organic-rich shales, slightly calcareous to calcareous, often exhibiting hardness and occasionally containing accessory minerals such as micas and pyrites. Such mineralogical diversity further enriches the geological narrative of the region, providing a multifaceted lens through which to explore its natural heritage.

The understanding of paleontology allows for the reconstruction of the life of organisms from the past, their physiological and morphological characteristics, and the environment in which they interacted. Figure 16 illustrates a diagram of the fossilization process of ammonites and gastropods. Figure 16a shows how ammonites and gastropods, which are marine organisms, lived in their habitat, such as oceans, seas, or lakes, during their active life. When the ammonites and gastropods die, their remains are deposited in an area where sediments accumulate, such as the seafloor or the bottom of a lake (Fig. 16b). This is the initial stage of the fossilization process. Over time, the remains of the ammonites and gastropods become buried under successive layers of sediment (Fig. 16c). During this process, the soft parts of the body decompose or disintegrate, leaving behind mineralized skeletons or shells. As minerals infiltrate the organic remains, they petrify and turn into rock. Once the remains of the ammonites and gastropods have petrified and become fossils, they become part of the Earth's stratigraphic record (Fig. 16d). These fossils provide evidence of past life and help scientists understand the Earth's history and the evolution of life over time. Geoeducation regarding the study of fossils enables a fantastic journey into the past of our planet, understanding their preservation in the stratigraphic record and establishing the environmental conditions in which an organism lived or died.

In the Mesa de Los Santos region, archaeologists have unearthed a wealth of significant discoveries spanning various aspects of Guane culture (Fig. 17), including ceramic, lithic, textile, metallurgical, and funerary artifacts. These findings offer valuable insights into the lifestyle and practices of the Guane people, shedding light on their agricultural techniques, hunting and fishing methods, domestic activities, decorative arts, and even their religious and ceremonial practices, as evidenced by the presence of rock art. The Guane culture flourished in the region following the arrival of European colonizers, and archaeological research conducted (e.g., Morales and Cadavid 1984; Moreno-González 2012; Echeverry 2017), which has helped piece together the story of this ancient civilization. Despite the extensive excavation and research efforts, there remains a trove of cultural and historical treasures yet to be uncovered, representing the largest collection of archaeological remains from an extinct culture in the area. Indeed, the Mesa de Los Santos region is teeming with customs and traditions that serve as a testament to the enduring legacy of our ancestors. Techniques like stepped walls, found in the architectural remnants, offer a glimpse into the construction methods employed by the Guane people. Additionally, the region boasts a rich gastronomic heritage, with culinary practices passed down through generations, providing a taste of the past. In recent years, Echeverry (2017) conducted a comprehensive virtual inventory and documentation of the

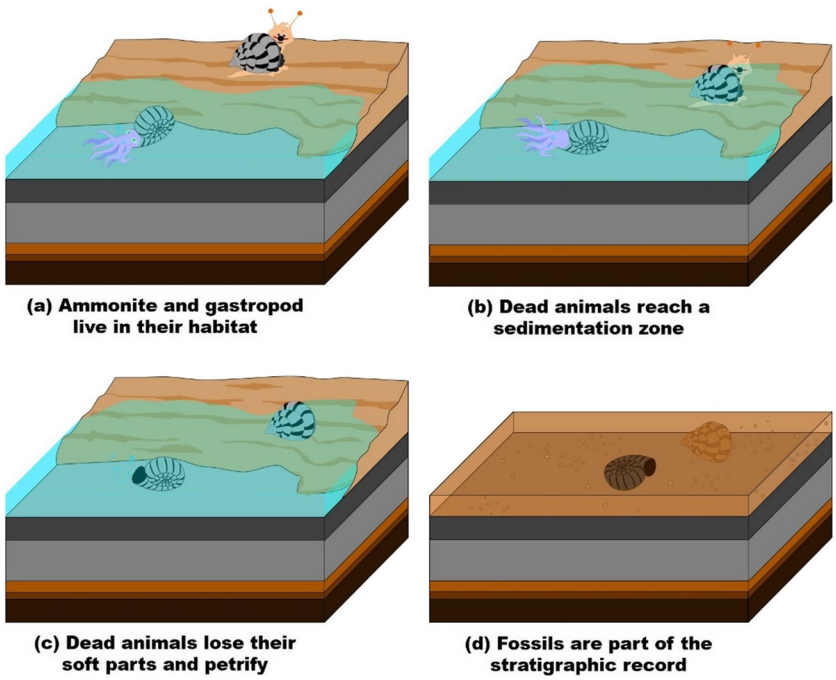

Fig. 16 Fossilization process of ammonites and gastropods

Fig. 17 (**a**)-(**b**) Archaeological findings of the Guane culture

region's rock art, including petroglyphs and pictographs found in caves and fractures within the sedimentary rocks of the Los Santos Formation at the top of the Mesa de Los Santos region. These ancient artworks offer invaluable insights into the spiritual and cultural beliefs of the Guane people, enriching our understanding of their way of life and leaving an indelible mark on the landscape of the region.

LIG8—Panoramic View Towards Jordán

This stunning panoramic view (Fig. 18) offers a unique opportunity to observe the breathtaking Chicamocha River Canyon, track the stratigraphic succession on both sides of the river with the aid of diagrams and geological maps, and witness fault systems extending for kilometers. Along the valley floor, where the base of the canyon is not exposed, one can see the sedimentary rocks of the Jordán Formation, which was initially described by Cediel (1968), who established its type section on the northern slope of the Chicamocha River Canyon, 1 km west of the municipality of Jordán. It is characterized from base to top by greenish-gray, coarse to slightly conglomeratic sandstones with cross-stratification. Interbedded at the base are greenish-gray mudstones, while reddish-brown to grayish-red mudstones and fine-grained sandstones with volcaniclastic input occur towards the top. Near Jordán, it is distinguished by the presence of strongly jointed siliceous mudstones intersected by a diabase dike. The Jordán Formation exhibits an unconformable and faulted contact with the underlying Silgará Formation and is considered to be of Early to Middle Jurassic age based on its stratigraphic relationships (Royero and Clavijo 2001). It unconformably underlies the Girón and Los Santos formations and overlays concordantly the Bocas Formation. Additionally, the Cretaceous sedimentary sequence, including the

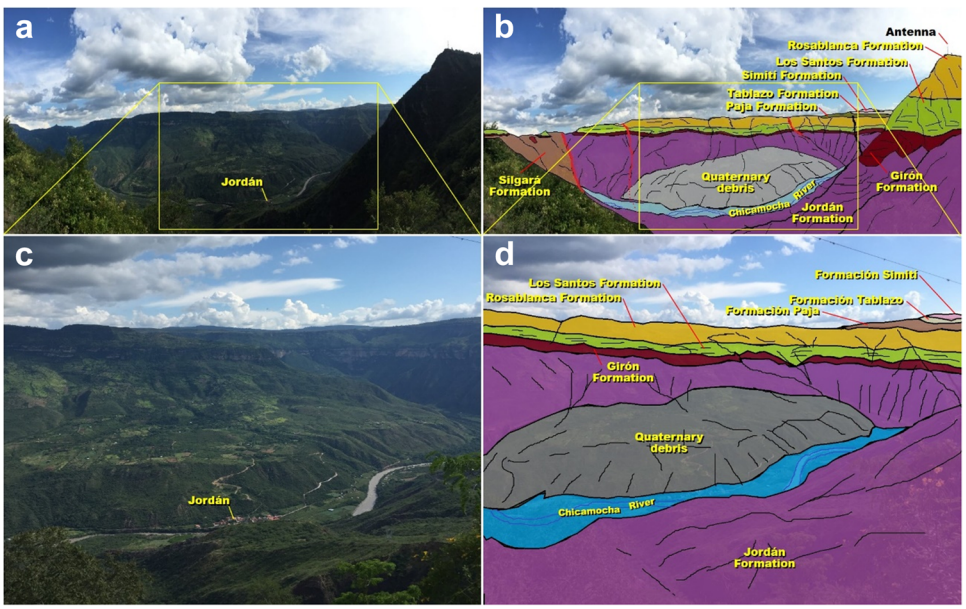

Fig. 18 (**a**)-(**b**) Panoramic views towards Jordán, showing the lithoestratigraphic sequence. (**c**)-(**d**) Closer and more detailed panoramic views of (a) and (b), respectively

Los Santos, Rosablanca, Paja, Tablazo, and Simití formations, is observable in this area.

LIG9—Gypsum Stalactites

From this point, gypsum speleothems in cavities of the Los Santos Formation can be observed (Fig. 19a), whose preservation is important in paleoclimatic reconstruction. Evidently, the intergranular cement of the Los Santos Formation sandstones is not calcareous enough to consider it as the source of Ca for the precipitation of gypsum speleothems. Therefore, their formation can be attributed to the percolation of solutions from the overlying Rosablanca and Paja formations, which contain rocks of calcareous composition, providing the necessary Ca to promote calcium sulfate precipitation. Previous studies indicate that in non-soluble sandstones like those of the Los Santos Formation, the mineralogy of speleothems could be represented by a silica polymorph (opal A) of extensive occurrence worldwide (e.g., Sanjurjo et al. 2007; Galán et al. 2010), and therefore, their formation is independent of the climate, although the action of water is always required. Gypsum is one of the resources of the municipality of Los Santos, being exploited for several years, mainly from the Paja Formation and the basal part of the Rosablanca Formation. Figures 19b-c show the gypsum mining fronts in sedimentary rocks of the Paja Formation, as well as the arrangement of mining waste on the slopes of the Chicamocha River valley, which, along with agriculture and domestic and industrial waste, gradually affect water quality.

LIG10—Seismic Nest and Historical Path of Geo Von Lengerke

According to the National Seismological Network of Colombia of the Colombian Geological Service, in the region of Mesa de Los Santos (Fig. 20a), an average of 5 earthquakes are recorded daily, making this region the second seismic nest in the world (e.g., Sepúlveda-Jaimes and Cabrera-Zambrano 2018). A seismic nest is an area where an unusual concentration of seismic activity can be observed more or less continuously, with hypocenters concentrated at depths of 50–250 km and with greater intensity than in adjacent areas (Zarifi and Havskov 2003). Deep and intermediate nests are related to subduction zones (Tryggvason and Lawson 1970), among which is the seismic nest of Mesa de Los Santos. Most of the earthquakes that occur there are of intermediate depth and generally are not associated with destructive earthquakes, with magnitudes usually below 6.5 on the Richter scale. Therefore, the municipality of Los Santos constitutes an ideal scenario for teaching how to cope with seismic activity, where the key is to avoid panic,

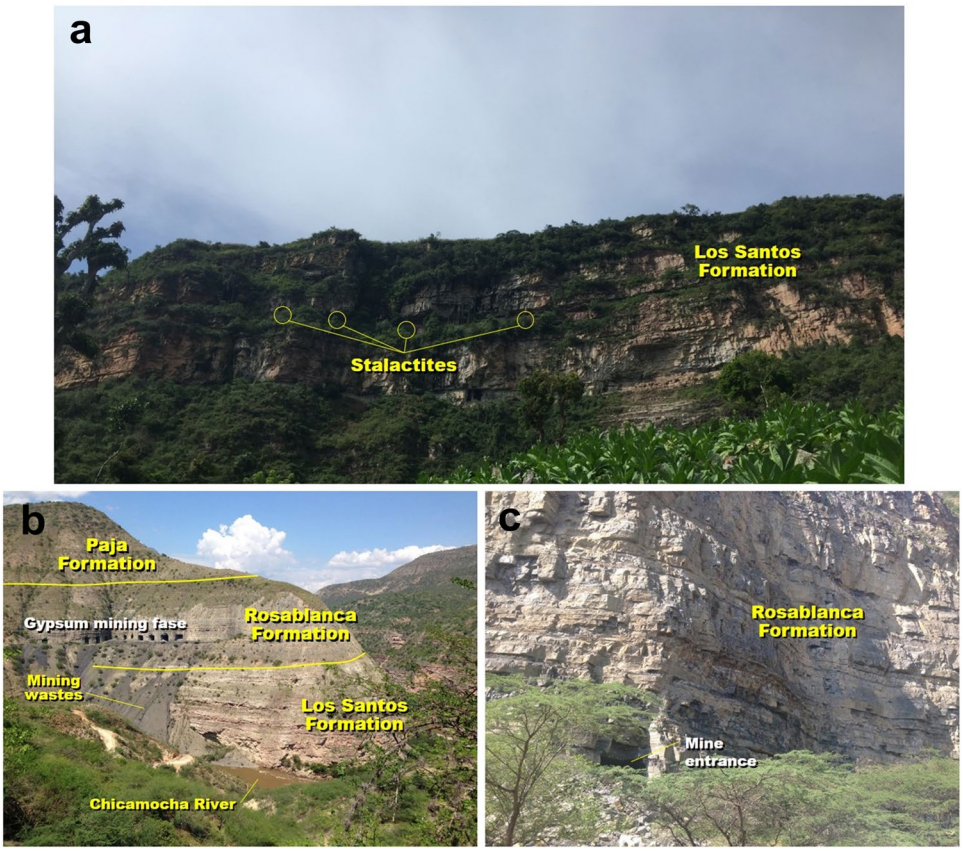

Fig. 19 (**a**) Gypsum stalactites in sandstones of the Los Santos Formation. (**b**)-(**c**) Gypsum mining operations in limestones of the Rosablanca Formation

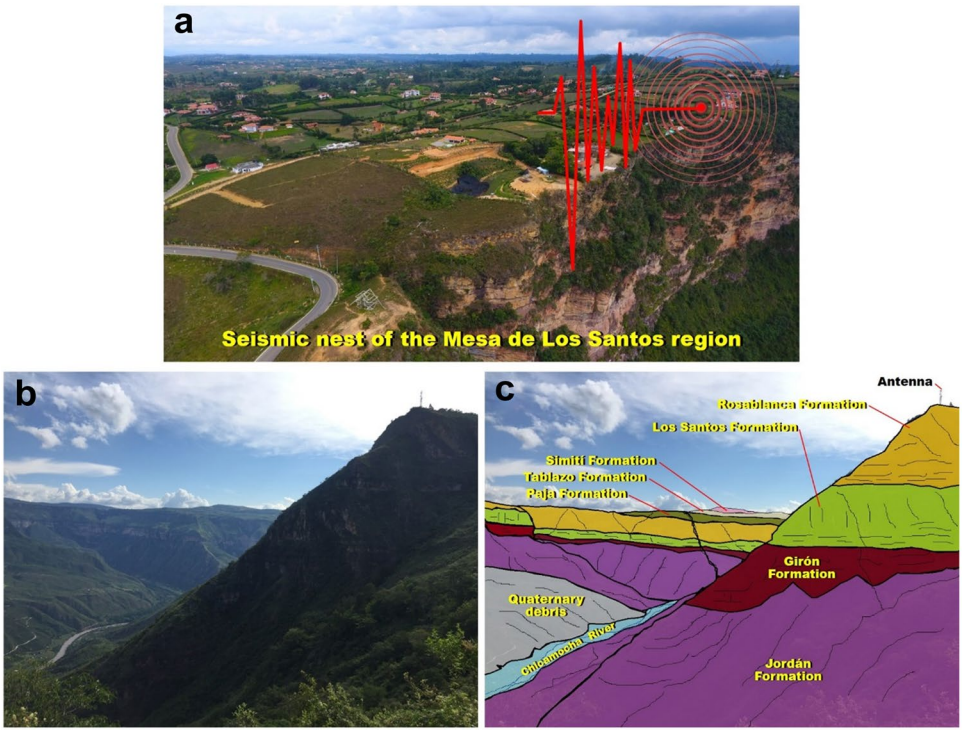

Fig. 20 (**a**) Mesa de Los Santos region. (**b**)-(**c**) Panoramic view of the Chicamocha River Canyon

educating the population about this natural phenomenon and how to coexist with it. Here, it is possible to enjoy another excellent panoramic view of the Chicamocha River Canyon (Figs. 20b-c), from which it is possible to observe the course of the imposing Chicamocha River, as well as the geological units that its erosive process has excavated over millions of years, highlighting the Jurassic sequence of the Jordán and Girón formations on which rests the sedimentary sequence of the Cretaceous with the Los Santos, Rosablanca, Paja, Tablazo, and Simití formations.

This journey encounters a small section of one of the historical paths of Lengerke leading to Jordán, forming part of a network connecting different cities in Santander along the Chicamocha River Canyon. These hand-built rock roads date back to the mid-nineteenth century and were constructed by Geo Von Lengerke (Fig. 21a), a German merchant (e.g., León 2012), who arrived in this region fleeing injustice in his country, according to historians. Roads built during the colonial period took advantage of pre-existing indigenous trails and remained in use until the first half of the twentieth century when the appearance of modern roads made the trails obsolete. However, these original paths are still used today (Figs. 21b-c), although less frequently, by the region's inhabitants and represent one of Santander's great cultural, historical, and tourist heritages. Some historians have contributed not only to the knowledge of the life and work of road builders such as Lengerke but also to understanding the reasons for their construction as part of the Santander colonization process (e.g., León 2012). The Lengerke suspension bridge (Fig. 21d) over the Chicamocha River is considered one of the country's most iconic suspension viaducts because it was the first toll in Colombia and was crossed by Simón Bolívar during the liberation campaign. However, this bridge, which in 2000 was declared a National Monument, fell into oblivion, lagged behind, anchored in time, in the depths of the Canyon, and its red cedar planks and its four-meter-high railings deteriorated gradually. However, the municipalities of Los Santos and Jordán, which share a common history, recently undertook the task of restoring this architectural relic using period techniques.

LIG11—Los Santos Cultural and Historical Geosite

The georoute ends in the municipality of Los Santos (Fig. 21d), founded in 1750, with a population that mostly lives in rural areas surrounding its urban center. The main economic activities in the municipality are agriculture (tobacco, tomatoes, bell peppers, beans, and watermelon), livestock, and poultry farming, as well as limestone and gypsum mining. Mesa de Los Santos is a region with a tendency toward Catholicism, reflected in the religious architecture and colonial engineering of the Church of Nuestra Señora de Las Nieves (Figs. 21e-f). On the other hand, the Catholic faith is manifested in the identity of the Santander people and is a source of unique cultural heritage due to the architectural beauty of the monuments and related traditions. In this region, various remnants of the Guane culture have been found, along with a historic stone road that connects this

Fig. 21 (**a**)-(**b**) Historical Lengerke Road connecting the municipalities of Los Santos and Jordán. (**c**) Lengerke Bridge. (**d**) Municipality of Los Santos. (**e**)-(**f**) Church of Nuestra Señora de Las Nieves

municipality with Jordán and a stone labyrinth with well-defined streets. The municipality of Los Santos has different tourist attractions. The colonial streets, the beautiful church, and the historical sites of this municipality are full of stories from visitors who passed through on their way to Bucaramanga. Walking to the Monument of San Antonio de Padua to fervently stop at each station of the Via Crucis is an experience that rejoices the spirit and allows visitors to find an oasis of peace and tranquility in a region with fantastic landscapes and cultural and historical richness.

Geotourism as a Strategy of Sustainable Rural Development

Geotourism holds the promise of becoming a significant catalyst for the sustainable development of rural areas in the municipality of Los Santos, which are part of the Chicamocha Canyon territory, Colombia. Future efforts must strongly emphasize promoting geotourism activities in this territory to contribute to sustainable development and the well-being of local communities. These activities not only offer visitors enriching experiences but also have the potential to boost the local economy, generate employment, and promote the conservation of the geological and natural environment. It is crucial to integrate these initiatives with sustainable and preservation practices to ensure a balance between tourism and long-term conservation. Rural geotourism stands out for its focus on an intimate connection with the geography and geology of a specific area, offering visitors a unique experience that seamlessly merges with rural life. It becomes a strategy to universalize Earth sciences. In the Mesa de Los Santos region, the georoute Refugio La Roca—Los Santos, which winds along the cliffs sculpted by the Los Santos Formation from the Cretaceous period, presents extraordinary potential for the development of this unique form of tourism, offering a variety of experiences for visitors to immerse themselves in the authenticity and richness of rural life. This emerging niche seeks to explore and revitalize cultural identities, integrating them with geological knowledge to educate the local communities in this region, which is part of the territory of the Chicamocha Canyon, and to transfer knowledge to visitors. This route not only showcases the natural and cultural heritage of the region but also serves scientific, didactic, and educational purposes by conveying geological knowledge in accessible language for both tourists and rural residents. Furthermore, it fulfills cultural and historical objectives by preserving ancestral culture and reliving the region's history. Moreover, it serves ecological goals by raising public awareness about environmental respect through geological concepts.

On a socio-economic level, it promotes the creation of new businesses and employment opportunities, enhancing the value of local products. The overarching objective is to foster synergies among various stakeholders, including tour operators, hotels, restaurants, and producers, thereby contributing to rural development, increasing tourist traffic, and enhancing the overall visitor experience in rural areas. This, in turn, leads to greater consumption in local establishments, improving environmental quality and preserving the natural and cultural heritage. Clearly, this initiative influences the enhancement of tourism infrastructure, the creation of new businesses and employment opportunities, the formulation of strategies for environmental remediation, and the preservation of natural and cultural heritage and territorial identity. Additionally, it rejuvenates local products such as typical foods, sweets, and handicrafts. Geotourism activities in this region include hiking and landscape interpretation georoutes highlighting unique geological features, as well as guided excursions (geo-adventures) to explore specific geological formations. Educational geo-experiences have been incorporated, including lectures on various geoscience topics and interaction with and participation in educational programs in local rural schools. Themed accommodations such as rock cabins reflecting local culture and history, mountain refuges (Refugio La Roca) with panoramic views of the surrounding landscape, stone accommodations harmoniously integrated with the environment, and glampings (glamorous camps) providing a luxurious camping experience in rural settings stand out. These accommodations focus on providing unique and thematic experiences that reflect local culture, history, or geology. Adventure sports such as rock climbing (traditional, sport, and mixed) in the La Mojarra Climbing Park, which extends along 1.5 km, and cycling through scenic routes represent experiences leveraging the natural and geographical resources of the area, providing participants with opportunities for exploration, challenge, and connection with nature. Local gastronomy is another highlight, with tastings of local products such as coffee (the coffee from the Mesa de Los Santos region is one of the best in Latin America), artisanal chocolate, agricultural products, artisanal cheeses, local spirits, or other handmade products such as bee honey, along with culinary experiences. However, rural areas in this region also offer alternatives for the development of local workshops to learn traditional crafts or attendance at festivals and events celebrating local culture; visits to local farms practicing sustainable agriculture and experiences in harvesting and participating in agricultural activities; and events such as astronomical observation nights in rural settings or celebrations highlighting local traditions. These experiences can enrich tourists' visits, providing opportunities to learn, participate, and appreciate the authenticity of rural life and the natural and cultural richness of the region. It is notable how geological heritage and landscapes integrate with the lifestyle and rural culture. Like in other parts of the world, rural geotourism initiatives in the region not only offer unforgettable experiences but also generate income for local communities. These earnings can be reinvested in the sustainability of traditional activities, the promotion and conservation of local arts and cultures, as well as in preventing rural–urban migration. Rural geotourism also serves as a gateway for the introduction of public and private infrastructures and educational facilities in rural areas, especially in developing countries like Colombia. Thus, this approach not only transfers geological knowledge at a professional level but also educates children, local residents, and visitors, becoming a means to implement sustainable principles and geoconservation methods. The beauty of the Chicamocha Canyon territory extends beyond its breathtaking landscape to encompass a rich geological heritage that harmoniously integrates with the distinctive lifestyle and cultural of the rural population in the municipality of Los Santos. This merging of natural wonders and human traditions creates a unique and immersive experience for both locals and visitors, forging a deep connection between the land and its inhabitants. Table 1 illustrates activities focused on the development of rural geotourism. These initiatives are meticulously designed to not only showcase the geological marvels but also to engage and educate individuals about the significance of the local geological features. By placing a deliberate focus on rural geotourism development, these activities aim to stimulate economic growth, empower local communities, and instill a sense of pride in the region's geological identity. The concerted efforts in rural geotourism align with the mission of the Global Geoparks Network, a driving force in advancing the development of rural geotourism on a global scale, which serves as a platform for the exchange of innovative ideas and experiences, fostering collaborations that transcend geographical boundaries (e.g., Zouros and Mckeever 2009; Mckeever et al. 2010). It exemplifies how shared knowledge and best practices contribute to the enhancement of geological awareness and the sustainable development of rural areas. As a result, the municipality of Los Santos stands poised at the intersection of natural splendor and cultural heritage, ready to unfold its full potential as a beacon for responsible and enriching geotourism experiences.

Empowering Geoscientific Understanding Through Geoeducation

Geotourism through the georoute Refugio La Roca—Los Santos offers a valuable opportunity to provide students from educational institutions in the Mesa de Los Santos region with a deeper understanding of geological heritage, allowing them to narrow the knowledge gap in geoscience-related topics. The georoute provides students with the

Table 1 Diverse geoexperiences and objectives based on rural geotourism

Geoexperiences	Objectives
Geosite exploration	Provide enriching experiences that connect visitors with the geological environment, promoting education, conservation, and sustainable enjoyment of geological resources
Geosport adventures	Combine the thrill and energy of sports activities with educational exploration and appreciation of the geological features of the environment, promoting a deeper connection with nature and an active understanding of geology
Outdoor geostudy	Facilitate hands-on learning experiences in outdoor settings, including observing geoheritage, capturing geolandscapes through photography, and embarking on field trips for geological exploration
Rural geotourism synergy	Support and complement other tourism products such as ecotourism and adventure tourism, promoting a well-rounded and diversified tourist experience
Serene retreats in geological surroundings	Create immersive and relaxing experiences by offering opportunities for visitors to unwind in unique environments, including stone-built establishments, geovillages, rocky villages, georestaurants, geobakeries, and rural accommodations crafted with rocks
Geoconservation endeavors	Promote sustainable practices and actively participate in the preservation of geological sites, ensuring the safeguarding of their unique features
Geoeducation activities	Enhance geological literacy and foster an appreciation for the Earth's processes in rural communities through engaging and accessible geoeducation initiatives
Unique attraction events	Promote community engagement and geological awareness by organizing special events such as geofestivals and geoproduct showcases, fostering a deeper connection between local communities and the geological heritage of the area
Special facilities for geoexploration	Provide facilities for geoexploration to facilitate a comprehensive and enriching experience for individuals seeking to explore and understand the geological features of a particular area
Infusing geoknowledge into local culture	Integrate geoknowledge into local culture to enrich community understanding, promote geological appreciation, and strengthen the connection between the community and its geological heritage
Wellness experiences in geological settings	Promote physical and mental well-being by offering experiences that integrate the beauty and serenity of geological settings, providing participants with a unique connection to nature and fostering a sense of tranquility and rejuvenation
Geoart and cultural expression	Promote artistic expressions inspired by geological features, fostering a creative link between art and the natural landscape
Geological cuisine experiences	Explore and enjoy local culinary experiences that integrate geological themes, highlighting the connection between food and the geological setting
Community engagement and geotourism workshops	Involve local communities in geotourism initiatives through workshops, enhancing community participation and fostering a sense of ownership
Geological storytelling sessions	Share geological stories and local legends, creating a narrative that enriches the visitor's understanding of the region's geological history
Night sky geotourism	Explore the celestial geology by offering stargazing experiences, connecting the geological landscape with the astronomical features of the night sky

opportunity to directly experience and observe geological features in their natural environment, facilitating a deeper and more meaningful understanding of geological concepts that might be abstract in a purely theoretical setting. By linking theory with tangible experiences, students can contextualize and apply the geological concepts learned in the classroom. The georoute will provide a real-life context for understanding landscape formation, geological processes, and the geological history of a region. Developing observation skills, the georoute allows students to connect what they learn in the classroom to their local environment, fostering a sense of belonging and appreciation for the geological heritage of the region. Visiting geological sites of interest, as previously described, can ignite students' interest and curiosity, motivating them to conduct independent research on specific geological topics, promoting continuous learning beyond the school environment. The development of geotourism activities could inspire students to consider careers in fields related to geosciences, providing them with a deeper and practical understanding of these disciplines. Therefore, geotourism through a georoute offers a dynamic and experiential platform to enrich the geoscientific education of students, preventing them from having a significant gap in their understanding of essential topics to comprehend nature and its relationship with daily life. Finally, the lack of knowledge about the conservation and effective defense of the natural and cultural heritage of the Cañón del Chicamocha territory is highlighted, as well as the need to use the Earth's

natural resources appropriately. It is essential to take actions focused on contributing to the mitigation of Earth exploitation and the insufficient understanding of geological processes, including geo-threats such as landslides, volcanism, earthquakes, tsunamis, etc. Incorporating this knowledge into territory planning, its natural resources, and benefits is crucial, promoting sustainability and long-term conservation. In this way, the need to make geosciences visible and understandable becomes evident to effectively address current and future challenges in Colombia. The education system in the Mesa de Los Santos region faces a clear deficiency in geosciences teaching, affecting the understanding of the next generation regarding the value and importance of protecting geological heritage. Recognizing the importance of geological heritage in this region is crucial not only for understanding it but also for broader aspects of society, linking it to other values of the natural and cultural heritage of the Cañón del Chicamocha territory. Therefore, efforts need to be invested to address these gaps and design and implement geoeducation strategies to create a more informed and geologically conscious citizenship in the territory. Brilha (2016) highlights the possibility of integrating elements of geodiversity and geoheritage into geology-focused educational programs. Emphasis is placed on the importance of creating and implementing regional geological conservation strategies and the necessity of evaluating components of geological heritage based on their geological diversity and educational and interpretative potential. Geoeducation is fundamental in educational institutions in both rural and urban areas for various reasons, as they represent not just learning environments but authentic nurseries where the seeds of leadership and decision-making that will shape the future of our nation sprout. However, there are specific considerations that make geoeducation particularly crucial in rural areas. There, daily life is closely linked to the surrounding natural and geographical environment. Geoeducation enables students to better understand their surroundings, natural resources, geographical features, and specific challenges they face in their local communities. Additionally, it helps them grasp the importance of sustainability, proper resource management, and how to make informed decisions to preserve the environment and ensure food security. Geographic knowledge can assist students in participating in local planning and development, contributing to improving the quality of life in their communities. Rural areas are often more exposed to threats and natural disasters. Geoeducation not only contributes to theoretical understanding of these events but also has practical applications in their preparation, response, and mitigation. The Mesa de los Santos region is subject to various threats and natural disasters. The most significant threat is the numerous earthquakes that occur daily, considering that this region hosts the world's second most important seismic nest. A strong earthquake of 6.6 degrees on the Richter scale was recorded there on March 10, 2015. Due to the mountainous topography of the region, there are risks of mass movements, especially during periods of heavy rainfall. Deforestation and improper agricultural practices can increase this risk. Heavy rains can lead to floods, especially in low-lying areas and along rivers, and vulnerability to floods may be influenced by the geomorphology and hydrographic network of the region. During dry periods, there is a risk of wildfires, which can be triggered by human activities or adverse weather conditions. Changes in climate patterns, such as droughts or extreme precipitation events, can affect water availability and agriculture in the region. In recent years, the municipality of Los Santos has been affected by the consequences of the El Niño phenomenon, experiencing a critical water shortage, leading to a public emergency, mainly in the remote hamlets of the municipality. In rural areas of the Mesa de Los Santos region, daily life is intrinsically linked to natural environments rich in biodiversity. Geoeducation allows students to understand local geography and explore the diversity of fauna and flora species present in their surroundings. This direct connection fosters greater appreciation and care for the region's unique biodiversity. Geoeducation can also play a significant role in promoting cultural identity in rural areas, helping students understand the history, traditions, and the relationship between geography and local culture. Geoeducation is a valuable tool for conveying knowledge to students about the history and traditions of the Guane culture that inhabited this region in pre-Columbian times. This may include aspects such as how members of this ancestral culture interacted with their geographical environment, the agricultural practices they employed, the architecture of their settlements, and how these factors were intertwined with their cultural identity. In rural areas, access to educational and economic opportunities can be limited; therefore, geoeducation emerges as a strategic tool to empower students, providing them with knowledge and skills that are relevant not only for their participation in society but also for fostering sustainable practices, contributing to long-term economic and social development. The georoute Refugio La Roca—Los Santos constitutes an invaluable tool, especially when guided by expert geoguides, with the fundamental purpose of educating those who explore this specific part of the Cañón del Chicamocha territory about its transcendent importance and significant impact on the surrounding ecosystem. In this context, geological routes not only serve an educational function but also play an essential role in highlighting the relevance and repercussions that these geographical areas have on the health and sustainability of the natural environment. By capitalizing on the experience and specialized knowledge of geoguides, the transmission of detailed and pertinent information about the geological elements present, their environmental consequences, and their

contribution to the valuable natural and cultural heritage of the Cañón del Chicamocha region is facilitated. This direct connection to the geological environment through the georoute promotes a deeper and more appreciative understanding of the interrelation between local geology and the overall health of the ecosystem, emphasizing the importance of its preservation for future generations. In line with the planning and agenda of UNESCO (2015), Global Geoparks have actively committed to promoting education and sustainable development as central objectives. In this sense, it is essential to provide educational support to students in institutions in rural areas of the Mesa de Los Santos region, which is part of the territory of the Chicamocha Canyon that aspires to become a UNESCO Global Geopark, based on its valuable natural and cultural heritage, which, through the protection of this heritage and education, contributes to the development of responsible tourism, strengthening the local economy and promoting sustainable development (Herrera-Franco et al. 2020). This support aims to enhance the understanding of students about sustainability and its associated positive prospects, with the ultimate goal of creating more optimal living conditions for future generations. By strengthening awareness and knowledge about sustainability in this rural context, the intention is to empower students to actively contribute to the well-being of their communities and promote practices that drive harmonious and environmentally respectful development.

Practical Actions for Geoconservation in Rural Areas of the Mesa de Los Santos Region

In the Mesa de Los Santos region, which is part of the Cañón del Chicamocha territory and aspires to become a UNESCO Global Geopark, the implementation of practical actions for geoconservation in rural areas is presented as a crucial strategy. Focusing our attention on a specifically designed georoute to explore geological points of interest, despite the current lack of interpretative signage and other resources, opportunities arise to implement effective conservation measures. The focus is on community development, aiming not only to preserve geological heritage linked to other cultural values but also to strengthen the bond between local communities and their natural environment. Throughout this process, active community participation, promotion of environmental awareness, and identification of sustainable strategies to foster long-term protection of geological heritage are encouraged. Below are detailed actions that could be undertaken to contribute to the comprehensive initiative of geoconservation and cultural appreciation in rural areas of the Mesa de Los Santos region. Community awareness and distribution of educational material are key strategies to emphasize the importance of preserving geological heritage. Through talks and workshops in local communities, the goal is to highlight the uniqueness and fragility of geological points of interest. Community involvement will be strengthened through community meetings addressing sustainable practices and the relevance of preserving the georoute, inviting communities to actively participate in identifying and protecting these sites. The organization of guided walks will not only promote the creation of local guides capable of leading educational walks despite the lack of official signage but will also allow for the development of crucial awareness activities for the protection of geological sites. The promotion of artistic and cultural projects in communities will showcase the beauty and relevance of the georoute, establishing a cultural connection with the territory. Collaboration with educational institutions will be essential to gradually integrate geological concepts into the curriculum and organize field trips through the georoute. Support and collaboration from local organizations and NGOs interested in conservation and environmental education will play a fundamental role. The implementation of mobile applications emerges as a valuable tool to enhance the user experience, provide educational information, promote safety, and facilitate effective georoute management. These measures, even without advanced infrastructure, lay the foundation for geoconservation and contribute to raising awareness and local support for future georoute development projects.

Conclusions

Addressing geotourism and geoeducation in the rural areas of Mesa de los Santos, Colombia, requires a multifaceted approach. Firstly, the identification and valorization of geological heritage are crucial for creating a comprehensive inventory of geological and geotouristic resources. This includes recognizing and showcasing unique geological sites, rock formations, and features of interest. Developing geotouristic trails and routes that harmonize geological and cultural aspects is equally important. Integrating interpretative signage along these routes enhances visitor education about the region's geology and local history. To further enhance awareness, it is imperative to design and implement environmental education and geoethics programs in collaboration with local schools. These initiatives not only underscore the significance of geology and the environment but also promote sustainable tourism practices. Community involvement is fundamental, emphasizing active participation from local residents in the planning and execution of geotourism and geoeducation initiatives. This engagement extends to the conservation of geological heritage and the creation of authentic experiences for visitors. Improving tourist infrastructure, including viewpoints and educational facilities, is pivotal for ensuring the comfort and safety of visitors. Simultaneously, the development of marketing

strategies that showcase the geological uniqueness of the region, coupled with collaboration with government entities and tourism organizations, is vital for positioning Mesa de los Santos as a prominent geotourism destination. Scientific research on local geology, involving academics and scientists, is imperative for advancing geological knowledge in the region. Establishing monitoring programs is equally crucial to assess the impact of tourism on the geological environment and make necessary adjustments. In light of these considerations, the georoute Refugio La Roca—Los Santos, Santander (Colombia), emerges as an indispensable tool. This georoute facilitates a deeper understanding of the interplay between geosciences and the rural population in Mesa de Los Santos, particularly regarding geological phenomena shaping the landscape. Additionally, the georoute contributes significantly to geotourism and geoeducation activities, focusing on heritage conservation, environmental preservation, and enhancing the well-being of the rural population. It represents a distinctive and appealing tourist product that aligns with the expectations of geotourists. Looking ahead, a sustained commitment to these strategies will undoubtedly foster sustainable development and nurture a heightened appreciation for the geological environment in Mesa de los Santos.

Acknowledgements This research received financial support from Universidad Industrial de Santander to facilitate the development of numerous fieldwork projects in the Mesa de Los Santos region. We appreciate the anonymous reviewers for their valuable comments and suggestions on this manuscript. The critical review provided by these experts has been fundamental in enhancing the content and presentation of this document. We are deeply thankful for the financial support and academic collaboration we have received, as both have been essential in conducting this research effectively and contributing to the advancement of knowledge in the Mesa de Los Santos region.

Author Contribution All authors have contributed significantly to the development and completion of this manuscript, and they have read and approved the final version of the manuscript.

Funding Open Access funding provided by Colombia Consortium. This research received financial support from Universidad Industrial de Santander. We acknowledge its contribution to the successful completion of this study.

Declarations

Competing Interest The authors declare no competing interests.

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