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ORIGINAL ARTICLE

Geotourism in Regions with Influence from the Oil Industry: a Study Case of the Middle Magdalena Valley Basin (Colombia)

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Abstract
This paper discusses the petroleum geology-related sites along the Middle Magdalena Valley Basin (Colombia) and their potentials as geotourism resources. This initiative is based on the experience of the authors over several years of fieldwork in this region. There are different geological and anthropic features in this region, which are closely related to petroleum geology. The geotourism represents a strategic alternative for the promotion of sustainable tourism. The present work refers to geotourism in regions with influence of the oil industry, which would constitute a pioneering example in Latin America from the development of a scenic georoute for those who visit the operations of the oil industry through tourism programs. The region of interest has beautiful landscapes and is very useful for performing different geoeducation and geotourism activities for geoconservation purposes. All these sites and features can attract people to visit this region, not only geologists and geology students who want to study the petroleum geology of this region, but also the local communities and tourists who are interested in visiting it.

Keywords Oil industry · Geotourism; Geoeducation · Geoconservation · Georoute

Introduction

Tourism has experienced continuous growth and deep diversification, until it became one of the fastest growing economic sectors in the world (UNWTO 2016). Currently, tourism activity has a strong impact on the balance of payments balance, on the contribution to gross domestic product (GDP), and on job creation (Franco-Aliaga and García-Guillen 1999). Tourism has become the activity that mobilizes the most resources on an international scale and is on the way to continue to lead because it grows faster than other areas of the economy (Telfer 2000). It contributes to the generation of direct and indirect jobs, products, offers, and tourist packages, increasingly adapted to meet the standards of satisfaction required by visitors (Matos and Pérez 2019), being an activity of great economic and social significance worldwide (Pérez 2011). Colombia is a country that has great natural biodiversity and a variety of landscapes, which place it among the fourteen most mega-diverse countries in the world (Andrade 2011). The protection, management, and use of geodiversity and geological heritage in the framework of sustainable development are important. In Colombia, a collective hysteria has been created associated with the exploitation of non-renewable natural resources, including hydrocarbons, which have a history of more than 100 years in Colombia, associating the activity directly with environmental pollution. However, this jeopardizes the knowledge that local communities possess about this industry and its advances, considering that currently there are technologies and techniques that allow operations to be carried out without putting the integrity of ecosystems at risk. This work seeks to establish a space for geoscientific knowledge transfer in the areas of influence of the activities of the oil industry as a focus for exploration and development of these resources. The city of Barrancabermeja is located in

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the Department of Santander (Colombia) on the banks of the Magdalena River (Fig. 1); the Colombian oil industry was born there, thanks to the discovery of oil from the drilling of the first producing well in Campo La Cira Infantas in 1918. Barrancabermeja went from being a small hamlet dedicated to fishing and a port of passage for travelers and merchants at the beginning of the twentieth century to the modern city of today, which is home to the country's largest oil refinery and one of the most important in Latin America. The regions with influence of the oil industry can be considered as an excellent natural laboratory for the study of oil geology in Colombia, with interesting sites with great potential to become geotourism resources for the city of Barrancabermeja. Thomas A. Hose coined the term "Geotourism" in the 1990s. The first attempts to define geotourism (e.g., Hose 1995, 1997, 2000) were related to aspects of interpretative provision for geoconservation purposes at in situ geosites and geomorphosites, as well as museums, library and archive collections, together with artistic outputs. The original definition (Hose 1995) and the approach surrounding it were accepted and promoted by UNESCO in its initial geopark documentation (UNESCO 2000) and should underpin all modern geopark developments. He also gave one of the earliest definitions of geotourism and improved it during the past decades. Hose and Vasiljevic (2012) published the latest version of the definition. This term has been used by the National Geographic Society (NGS) and is a relatively new concept in the tourism industry (Turner 2006), which is being adopted worldwide. According to Dowling and Newsome (2010), geotourism is a sustainable tourism with a primary focus on experiencing the geological features of our planet in a way that fosters environmental and cultural understanding, appreciation, and conservation and is beneficial at the local level. The global oil industry has been experiencing significant changes towards new forms of hydrocarbon exploration and production in different geological contexts and environmentally sensitive and socially complex areas (Saavedra and Jiménez 2014). Local communities could embrace alternatives that allow them to transform regions with influence from the oil industry into scenic routes for geotourism.

To date, there is not publications in the academic literature on the development of geotourism in regions with influence of the oil industry in Colombia. Therefore, this work aims to contribute to closing this gap, to assess the potential for geotourism development in a region with influence of the oil industry as the Middle Magdalena Valley Basin (MMVB) by exploring geosites that form part of its natural and cultural heritage, and to discuss the role of geotourism in sustainable development of this region. The geosites for this study were selected because they have a high grade of valuation and are the components of the route proposed by the authors. Moreover, these geosites include valuable resources of the natural and cultural heritage linked to the petroleum industry as an engine for job creation and income opportunities in all economic sectors and the implementation of profitable and sustainable activities. Therefore, tourism can be configured as a complementary activity in this region, generating significant sustainable socio-economic development in this region.

Research Methods

This contribution is schematized based on the field geology and visiting of geosites in different parts of a region with influence of the oil industry as the MMVB. The touristic attractions (mostly in regards of geological, cultural, and historic aspects) in geosites of valuable importance for the natural and cultural heritage along with their destruction and pollution possible risks are considered in this research. Accordingly, various kinds of library documentation studies, field studies, direct observations, and survey and evaluation of this region from its geological, cultural, historical, and economical condition are taken into account in suggestion of suitable sites. Published related documents help to propose some advantages of establishing geotourism in this region in order to contribute to its sustainable development.

Problems that have Affected the Development of Tourism and Opportunities for the Region

According to experts and economists in the tourism industry, tourism would exceed the income of the main oil-producing countries in the world, becoming the fundamental pillar of their economy (e.g., Jafari 2005; Seguí-Llinás 2005). In the case of Saudi Arabia, despite being a country rich in oil revenues, it has the largest sovereign wealth fund in the world, and oil production represents approximately 50% of the country's GDP. It has been revitalizing its economy to the oil crisis (e.g., Erb 2008), in order to create an alternative economy to take over industrial sectors and reduce dependence on oil (e.g., Domínguez de Olazábal 2017). There is a trend not only in the big cities of our country but also in small towns, where it is possible to observe tourists of different nationalities with the desire to know a country that is making an enormous effort to show a different image before the world than years ago it had been directly affecting tourist activity and the development of our country. This is due to problems like the image of conflict in the country at the international level (e.g., Gómez 2002; Menchero-Sánchez 2018), poor infrastructure in road networks, signaling, electric lighting, transport network, basic and complementary services, informality of tourism, public policy decisions

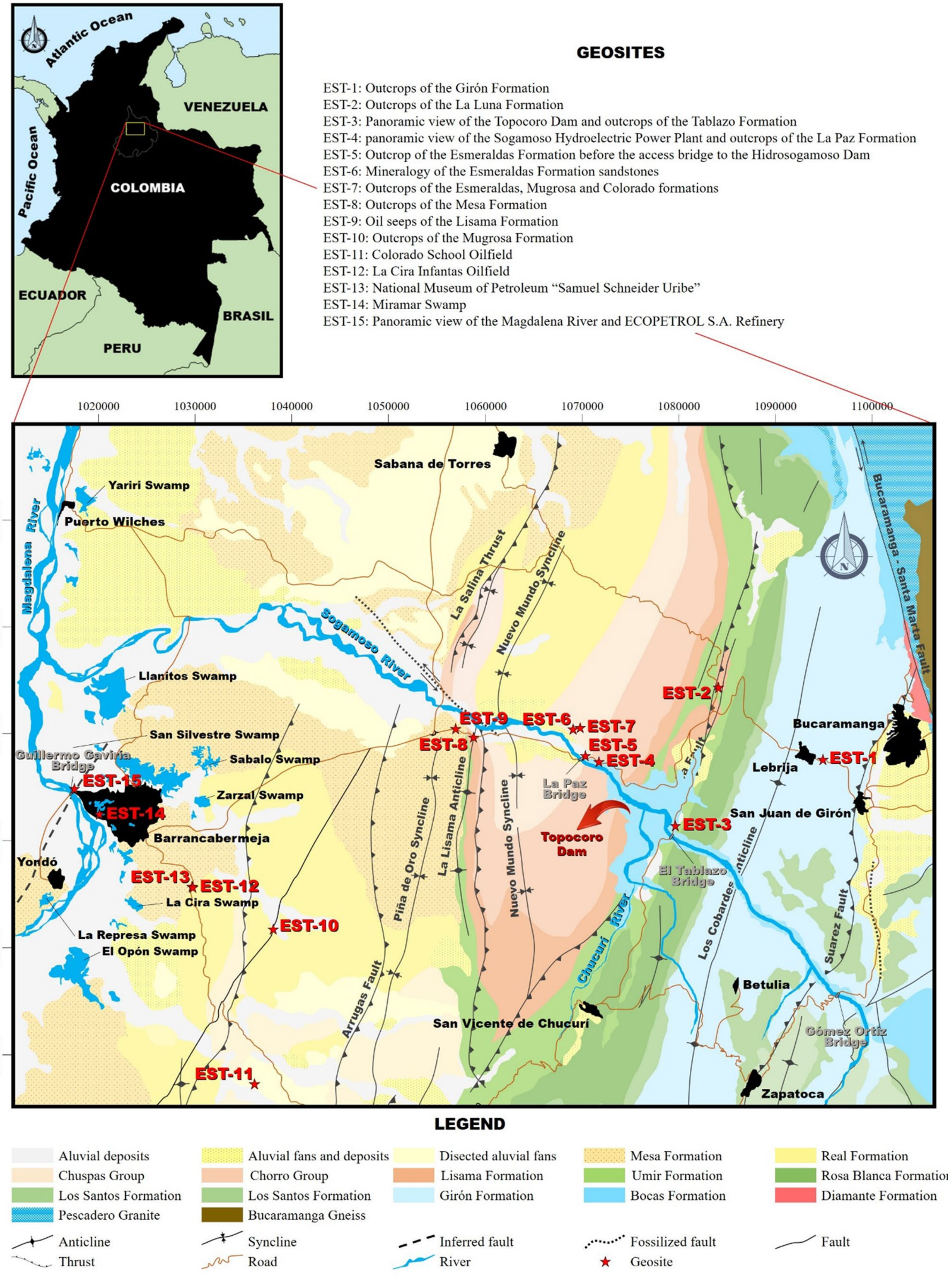

Fig. 1 Geological map, showing the geosites along the georoute

that closed the economy through high tariffs and exchange restrictions, quality in the offer and low competitiveness of the tourist product, ignorance of the tourist emitting markets, bilingualism, connectivity between regions, environmental sustainability, and selective tourism and low constancy. The tourist demand has two aspects: the interior of the country itself and the one fed by international visitors (Franco-Aliaga and García-Guillen 1999). On the other hand, the devaluation of the Colombian peso in recent years not only makes our country a cheaper destination for foreigners, but also makes it more expensive for nationals to travel abroad. In our opinion, it is not a question of geotourism becoming the new oil of Colombia, but of seeing this sector as an alternative solution to the economic and social problems of our country, with numerous benefits. Santander has evolved positively in relation to the development of tourism and could become the first option for national and foreign tourists seeking a wide and varied tourist offer in Colombia to enjoy its natural and cultural heritage, outlining itself as a country to develop a true offer quality tourism that generates more socio-economic and environmental benefits.

Benefits of Geotourism

Tourism is one of the activities that has grown the most in recent years, proving to be very important for the socio-economic and environmental well-being of a country. In Colombia, tourism has gone from having a secondary position to being a growing activity, especially in recent years (Menchero-Sánchez 2018). The MMVB has been focusing for some years on peace building from organizational processes that involve dialogue and the action of multiple social actors. Since 1995, the Colombian government created the Magdalena Medio Peace and Development Program in order to insert itself into the life of the territory and create favorable dynamics for development and peace based on the training and participation of local communities, which allowed the planning and execution of numerous economic, educational, productive, communicative, coexistence, and peace initiatives. However, this region presents paradoxical realities as, despite being rich in water sources, it does not have aqueducts or final disposal of waste; it has abundant wealth, but high rates of poverty; it has forests and fertile soils, but it does not have food production systems; it extracts geo-resources, but its population has high rates of unsatisfied basic needs. This scenario would suppose the progress and development of the region. However, poverty and economic and social inequalities have increased there. Despite being a territory with a disadvantaged socio-economic situation, the MMVB has in its territory a valuable natural and cultural heritage that project it towards a geoconservation strategy based on the development of geotourism and geoeducation. However, it is necessary that the municipal administration, the Santander Government, the Republic of Colombia, and the environmental authorities generate more effective solutions that allow the articulation and commitment of the different governmental, economic, and social sectors, territorial entities, and local communities, and profiled this region to develop a real tourism offer, of quality, which generates more socio-economic and environmental benefits.

The tourism sector in Colombia could benefit in numerous ways considering the environment of international uncertainty that has been negatively affecting other sectors of the national economy. Geotourism could become the socio-economic engine of the MMVB region, being a generator of employment, investment and business opportunities as suggested by Sati (2018). This region has enormous potential for promoting geotourism initiatives through the geological heritage inserted in the urban area, with different outcrops of interest for the oil and gas industry. Obviously, the petroleum crisis with the drop in prices became an opportunity for this region in which some companies migrated to other sectors. To promote tourism, different strategies can be implemented, such as the production of products based on the geological elements that combine traditional products with new concepts (e.g., Farsani et al. 2011), including geofoods, outcrop cakes, fossil chocolate and bread, fruit geosalads, jewelry with fossils, rock-based crafts, meetings (events, conventions, fairs, and exhibitions), maintenance of oil and gas facilities, or construction of civil works. Rodrigues et al. (2017) consider that georestaurants, georesorts, and geocompanies that promote geotourism can offer tourism services, although geoproducts also include visits to production units, tastings, and workshops as well as presentations, fairs, festivals, specialized markets, and trade shows for professionals. It is also important to highlight the need to train local communities engaged in agricultural production, as soil conditions depend on the geological characteristics of the rocks that emerge in the region. This understanding of the richness of the soil and subsoil should focus on promoting the conservation and protection of the environment in all its aspects, given the importance it represents for the long-term sustainability of local communities. However, it is very important the participation of local communities in innovative strategies to promote the local economy and public knowledge about geology. Geotourism can improve the quality of life of local communities and stimulate the local economic growth. It is also important to consider that tourism must be sustainable with the environment (e.g., Barrera and Bahamondes 2012), protecting the country's natural and cultural heritage with the tourist offer. This must be accompanied by the improvement of tourist services and accessibility to the different tourist attractions in the region, preparing the necessary infrastructure, as well as service providers, such as travel and tourism agencies, tourist transport companies, hotels, restaurants, bars, and similar businesses, with training programs that target different market niches. This initiative aims to transfer the geological knowledge of the environment and the balance between extractive activity and the environment through geotourism.

Petroleum Prospects Facing the Reality of Tourism

Tourism has become one of the main actors in international trade and represents at the same time one of the main sources of income for many developing countries like Colombia. Sustainable tourism can generate great socio-economic benefits in different sectors (Fig. 2). Colombia has hydrocarbon deposits of international importance. Hydrocarbons represent as not only an exceptional energy resource, but also a resource of the geological heritage (Molchanova and Ruban 2019). The georoute Bucaramanga-Barrancabermeja (Colombia) represents a natural setting of great importance for research in geosciences, and the development of geoeducation and geotourism activities for geoconservation purposes, which can bring great socio-economic benefits to the region. There are numerous geological features in and around this city that are closely related to the oil industry, such as outcrops of geological formations considered to be hydrocarbon source or reservoir rocks, oil-impregnated rocks, oil seeps, geoforms, and faulty geological structures or folds that affect the sedimentary sequence to explain the structural or stratigraphic entanglement and the migration of hydrocarbons. They are essential for the development of geotourism with the participation of professionals in geosciences, teachers and students of geology, or anyone who wishes to learn about the importance of geosciences and, in particular, of the geology of oil in the region based on geoeducation so that it transcends decision-makers and local communities. To involve the regions influenced by the oil industry, taking advantage of the fact that their surroundings have beautiful landscapes, tourists could carry out various activities such as excursions, mountaineering, hiking, horseback riding, bird watching, canopy, torrentism, canoeing, and mountain biking. Geotourism can be approached as a complement to massive conventional tourism (Villalobos 2001), offering new options from neighboring areas to major centers of interest, diversifying its offer and the distribution of economic and social benefits. However, for geotourism to generate benefits, it is necessary to convert that local heritage into a self-sustaining product based on a tourist infrastructure based on oil activity. A georoute made up of geosites will create a sense of belonging in local communities towards the oil resource and infrastructure. On the other hand, it will show harmony between oil activity and ecosystems, which in turn will facilitate the monitoring and surveillance of said infrastructure, and will generate new sources of self-sustainable employment. It is essential to implement a signaling system, with informative and interpretive panels,

Fig. 2 Benefits of sustainable tourism

that allows tourists to participate in geoeducation activities focused on transferring knowledge in relation to oil projects, which local communities do not receive in the best way mainly due to the ignorance and disinformation. The challenges of geotourism are (1) creating attractions starting from geosites to illustrate the tourist who has little knowledge of geology and (2) transmitting basic knowledge about our planet and the geological phenomena that occur on it. On the other hand, it is necessary to present alternative solutions for the efficient management of resources, conservation and development of a true tourist offer, the presentation of a geoscientific interpretation system, environmental education and dissemination of geological heritage, active exchange with geoparks, continuous training, and community engagement (e.g., Wang et al. 2015). This will be essential for the preservation of the natural and cultural heritage, as well as the development of the tourism industry in our country. Therefore, geotourism and geoeducation activities related to the hydrocarbon sector can have mutual benefits. However, it is important that the municipal administration and the departmental and national government promote the development of infrastructure and participation in geotourism programs and geoeducation coordinated through a visitor interpretation center.

Petroleum Geology Georoute

The georoute promotes sites of geological interest for the oil and gas industry in Colombia in a scientifically correct and accessible way for visitors of any kind, including unskilled geologists and academics, which is essential to promote the development of geotourism. The specific objectives of the petroleum geology georoute are (1) to carry out the study and observation of the most outstanding geological features of the MMVB; (2) to highlight the richness of the geological environment from the geological route, bringing the visitor closer to some of the basic elements of the geological heritage; (3) to describe the geosites at an elementary level for those who are learning geosciences and complex for geology professionals; (4) to facilitate the observation of geological phenomena theoretically studied in the classroom through the practical application of their knowledge in a natural laboratory; (5) to create a didactic instrument, aimed at all those interested in geosciences that allows to publicize the valuable geological heritage that is part of the natural resource of Colombia; and (6) to provide a basis for the development of georoutes in other regions that serve not only to disseminate its geology but also to encourage attitudes of knowledge, respect, and conservation of the geological heritage.

The georoute (Fig. 1) has geosites to know the different types of rocks, to understand how each type of rock influences the formation of the landscape that we see today. The development of various investigations in this region has contributed to the knowledge not only of its geology but also of its historical evolution. To carry out the georoute, it is necessary to take the National Route 66 that connects the cities of Bucaramanga and Barrancabermeja (Santander). On this road, outcrops of the Girón Formation occur close to the municipality of Lebrija (EST-1). To go to EST-2 (outcrops of the La Luna Formation), it is necessary to take a deviation from the National Route 66 on the right side to the municipality of Sabana de Torres. Then, on the National Route 66, take a deviation on the left side to the municipality of San Vicente de Chucurí to observe an excellent view of the Topocoro Dam and outcrops of the Tablazo Formation (EST-3). Along the National Route 66, it is possible to observe the geosites briefly described below. EST-4 is a view of the Sogamoso Hydroelectric Power Plant, where is possible to observe outcrops of the La Paz Formation. In EST-5, outcrops of the Esmeraldas Formation occur before the access bridge to the Hidrosogamoso Dam. EST-6 reveals outcrops of the Esmeraldas Formation. Sedimentary rocks of the Esmeraldas, Mugrosa, and Colorado formations crop out in EST-7. In EST-8, outcrops of the Mesa Formation occur in La Fortuna. Oil seeps that migrate up through the sedimentary rocks of the Lisama Formation occur in EST-9 within the Lisama Field. From La Lisama, it is necessary to take the National Route 45 on the way to Puerto Nare (Boyaca) to get the EST-10 (outcrops of the Mugrosa Formation) and EST-11 (Colorado School Oilfield). On the Barrancabermeja–Troncal del Magdalena route, it is possible to get the geosites EST-12 (La Cira Infantas Oilfield), EST-13 (National Museum of Petroleum "Samuel Schneider Uribe"), and EST-14 (Miramar Swamp). The georoute will end at EST-15, where the Magdalena River and ECOPETROL S.A. refinery are observed. Table 1 summarizes the main natural and cultural heritage that forms part of the MMVB and surrounding areas.

Next, the main aspects related to the geology of petroleum in the MMVB, particularly the main parameters associated with its petroleum system, are described, which has been widely characterized, as important oilfields are part of it. The MMVB's hydrocarbon comes mainly from limestones, black shales, and thin layers of cherts, which are part of the Cretaceous Rosa Blanca, Paja, Tablazo, Simití, and La Luna formations; the main source rocks being the limestones of the La Luna Formation, which shows a percentage of organic matter of 1–6% and a kerogen of type II. The siltstones of the Mugrosa Formation and the sandstones of the La Paz, Esmeraldas, Colorado, Umir, and Lisama formations of Tertiary age are reservoir rocks. Hydrocarbon generated from the source rocks somewhere of the eastern part of the MMVB and migrated throughout the entire basin towards the western flank of the Magdalena Valley during the early Tertiary (Dickey 1992). However, according to Ramón et al.

Table 1 Main natural and cultural heritage of the MMVB and surrounding areas

Geosite		Typological category	Heritage category	Heritage subcategory	Value criteria	Location
EST-1	Outcrops of the Girón Formation	Point	Sedimentology, stratigraphy	Sedimentary rocks	Scientific, educative, touristic	Lebrija
EST-2	Outcrops of the La Luna Formation	Point	Sedimentology, stratigraphy, structural geology, paleontology	Sedimentary rocks, fossils, structural slope, river	Aesthetic, ecological, scientific, educative, touristic	Lebrija
EST-3	Landscape panoramic view of the Topocoro Dam	View point	Geomorphology, geotechnics	Geoforms, dam, slope stabilization	Aesthetic, ecological, scientific, educative, touristic	Giron
	Outcrops of the Tablazo Formation	Point	Sedimentology, stratigraphy, structural geology, paleontology	Sedimentary rocks, fossils, structural slope	Scientific, educative, touristic	Giron
EST-4	Panoramic view of the Sogamoso Hydroelectric Power Plant	View point	Geomorphology, geotechnics	Geoforms, dam, tunnels	Aesthetic, ecological, scientific, educative, touristic	Giron
	Outcrops of the La Paz Formation	Point	Sedimentology, stratigraphy	Sedimentary rocks	Scientific, educative, touristic	Giron
EST-5	Outcrop of the Esmeraldas Formation	Point	Sedimentology, stratigraphy	Sedimentary rocks	Scientific, educative, touristic	Giron
EST-6	Mineralogy of the sedimentary rocks of the Esmeraldas Formation	Point	Sedimentology, mineralogy, petrophysics	Sedimentary rocks, minerals	Scientific, educative	Giron
EST-7	Outcrops of the Esmeraldas, Mugrosa and Colorado formations	Point	Sedimentology, mineralogy, petrophysics, paleontology	Sedimentary rocks, fossils	Scientific, educative	Betulia
EST-8	Outcrops of the Mesa Formation	Point	Sedimentology, stratigraphy, geomorphology, hydrology	Sedimentary rocks, faults, erosion	Aesthetic, ecological, scientific, educative, touristic	Barrancabermeja
EST-9	Oil seeps of the Lisama Formation	Point	Sedimentology, stratigraphy, structural geology, petroleum geology, petrophysics	Sedimentary rocks, oil oozes, trap, hydrocarbon migration	Aesthetic, ecological, scientific, educative, touristic	Barrancabermeja
EST-10	Outcrops of the Mugrosa Formation	Point	Sedimentology, stratigraphy, mineralogy, petrophysics	Sedimentary rocks, reservoir rock, minerals	Scientific, educative, touristic	Barrancabermeja
EST-11	Colorado School Oilfield	Area	Geomorphology, petroleum engineering	Landscape, river, work operations, environmental passives	Aesthetic, ecological, scientific, educative, touristic	San Vicente de Chucurí
EST-12	La Cira Infantas Oilfield	Area	Petroleum engineering	Work operations, environmental passives	Aesthetic, ecological, scientific, educative, historical, touristic	Barrancabermeja
EST-13	National Museum of Petroleum “Samuel Schneider Uribe”	Point	Museography	Photographs, illustrations, models, machines, archives	Cultural, historical, scientific, educative	Barrancabermeja
EST-14	Miramar Swamp	View point	Architectonic, biodiversity	River, swamp, monuments, recycling	Aesthetic, ecological, scientific, educative, historical, touristic	Barrancabermeja

Table 1 (continued)

Geosite		Typological category	Heritage category	Heritage subcategory	Value criteria	Location
EST-15	Panoramic view of the Magdalena River	View point	Geomorphology, civil engineering	River, bridge	Aesthetic, ecological, scientific, educative, touristic	Barrancabermeja
	Panoramic view of the ECOPETROL S.A. Refinery	View point	Petroleum engineering	Work operations, environmental passives	Aesthetic, ecological, scientific, educative, historical, touristic	Barrancabermeja
Other ESTs	Paseo Yuma	Area	Architectonic, biodiversity	Monuments, recycling	Cultural, historical, scientific, educative	Barrancabermeja
	Plaza of the Cacique Pipatón and Princess Yarima	Area	Architectonic	Monuments	Cultural, historical, scientific, educative	Barrancabermeja
	Paseo de la Cultura	Area	Architectonic	Monuments	Cultural, historical, scientific, educative	Barrancabermeja
	Monument to the Railroad	Point	Art	Monuments	Cultural, historical, scientific, educative	Barrancabermeja
	Camilo Torres Park	Area	Architectonic	Sport and recreation facilities	Aesthetic, touristic	Barrancabermeja
	Nuestra Señora del Carmen Church	Point	Architectonic	Historical, religious	Cultural, historical, religious, touristic	Barrancabermeja
	Roller Skating Rink	Area	Architectonic	Sport and recreation facilities	Aesthetic, touristic	Barrancabermeja
	"Daniel Villa Zapata" Stadium	Area	Architectonic	Sport and recreation facilities	Aesthetic, touristic	Barrancabermeja
	"Luis Fernando Castellanos" Coliseum	Area	Architectonic	Sport and recreation facilities	Aesthetic, touristic	Barrancabermeja
	Festivals	Area	Cultural heritage	Art, folk, gastronomy	Cultural, touristic	Barrancabermeja

(1997), the hydrocarbon compositions suggest a complex migration history. The migration of hydrocarbons, until it was trapped, occurred before the failure of the structures (Moros and Serrano 2016). For the MMVB, the intra-formational clay levels of the Paja, Simití, Umir, Lisama, La Paz, Esmeraldas, Mugrosa, and Colorado formations act as seal rocks. In the MMVB, the traps correspond mainly to anticline structures associated with inverse and normal faults (La Cira and Infantas fault system) reactivated by Andean tectonics. During the Eocene, an angular unconformity separated the underlying active source rocks from the reservoir rocks.

EST-1: Outcrops of the Girón Formation

The oil route begins with the base of the stratigraphic sequence of the Middle Magdalena Valley Basin (MMVB), some outcrops of the Girón Formation of Triassic-Jurassic age, that occur in extensive strips between the municipalities of Giron and Lebrija, on the slopes of Mesa de Lebrija, particularly on the San Juan de Girón road–Palonegro International Airport, where it is in failed contact with the Triassic-Jurassic Jordan Formation and discordantly underlies sediments from the Quaternary Bucaramanga Formation. In the petroleum industry lexicon, the rocks of the Girón formation would form the economic base of the sedimentary basin. Hettner (1892) to designate a sequence of reddish-brown sandstones, conglomerates, and mudstones that emerge west of Bucaramanga and take the name of the Municipality of San Juan de Girón introduced the term “Girón Series”. Lanhenheim (1959) designated the Lebrija River Canyon outcrops as the type section and defined the boundaries there as underlying and overlying contacts with the Bocas and Los Santos formations, respectively. This sedimentary unit consists of intercalations of medium to coarse brown orange sandstones and purplish mudstones in tabular and coined layers (Fig. 3a–b), with flat surfaces, flat parallel and cross stratifications, and flat contacts between the layers and

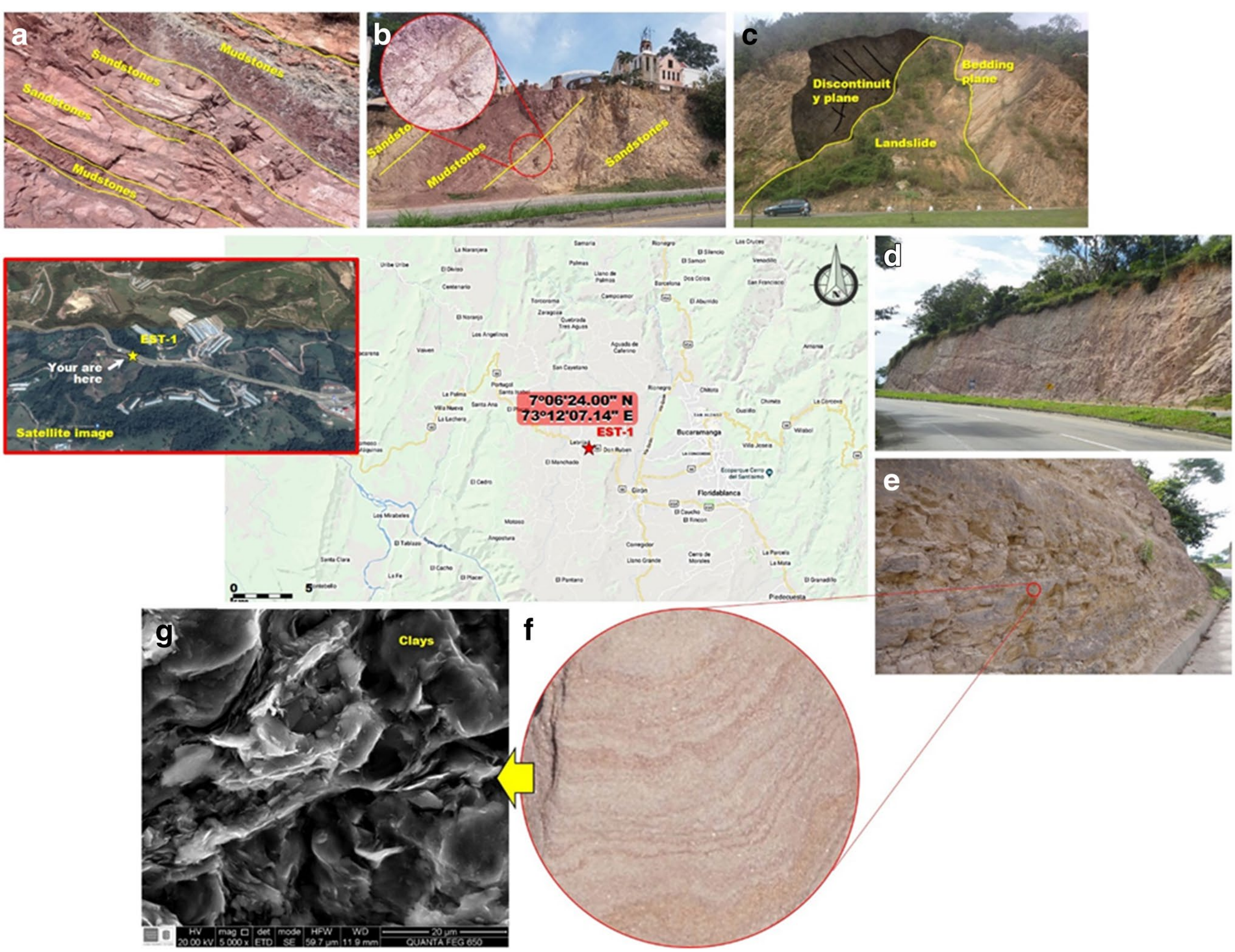

Fig. 3 Rocks of sedimentary origin, arranged in tabular layers made up of sandstones and mudstones belonging to the Girón Formation

discontinuous and erosive lithological contacts with the Los Santos Formation and Quaternary deposits. It is possible to observe outcrops of the Girón Formation affected by landslides like the one illustrated in Fig. 3c, which is the result of the intersection of the stratification plane with a discontinuity plane closely associated with the Suarez fault system (Afanador 2018). Figure 3d–e illustrate an extensive outcrop of approximately 200 m in length interspersed with interspersed grayish-brown conglomeratic sandstones and reddish-colored mudstones with a tabular geometry and cross-stratification. Figure 3f–g illustrate the macroscopic scale stratification and the morphology of clays in secondary electrons (SE), respectively, in a typical sample of sandstone from the Girón Formation.

EST-2: Outcrops of the La Luna Formation

In recent years, the oil industry has been focusing its attention on unconventional resources, with hydrocarbons in rocks with porosity at the nanometer scale and low permeability, evaluating their potential in many sedimentary basins worldwide. On the National Route 66 that connects the cities of Bucaramanga and Barrancabermeja, near the intersection towards the Municipality of San Vicente de Chucurí, in the sector known as La Azufrada, it is possible to take a deviation towards the sector de la Uribe to access the La Sorda stream (Fig. 4). Here, La Luna Formation of Turonian-Santonian age, which is the main rock that generates the hydrocarbons discovered in the MMVB and is the base of

Fig. 4 Outcrops of sedimentary rocks of the Luna Formation in the Azufrada sector. (**a**)–(**c**) Fossiliferous concretions in calcareous shales with parallel plane layering. (**d**) Phosphoric rock. (**e**) Calcareous shales with fossiliferous concretions. (**f**) Ammonite in concretion

the oil system of the region, has been the subject of interest in different studies (e.g., Morales et al. 1958; Montgomery 1992; Torres 2013; Gómez 2014; Casadiego 2014) and represents the main source rock in the MMVB oil systems. It is considered as an unconventional gas reservoir, with a mature window of hydrocarbon formation, classified according to the oxygen index as propane gas with a T_{max} close to 440 °C, an average production index (PI) between 0.02 and 0.10, primary porosity of 1–5%, and secondary porosity 1–15% (Casadiego and Ríos 2016). According to Torres (2013), the La Luna Formation consists of clay and black calcareous limestone, with a high content of foraminifera and limestone concretions, which deposited in a shallow marine environment, from medium to outer platform, in a transgressive sea. The La Luna Formation presents abundant planktonic foraminifera, ammonites, and fish remains. Recently, the oil industry has been focusing its attention on unconventional resources, with Colombia being the third country in South America with the greatest potential for "gas shales" after Argentina and Brazil. This sector probably has outcrops of the upper part of La Luna Formation. It is possible to find concretions composed of gray to black, calcareous, thin layers of black shale, calcareous shale with thin limestone interbeds, and some thin beds of chert.

EST-3: Panoramic View of the Topocoro Dam and Outcrops of the Tablazo Formation

On the road that leads to San Vicente de Chucurí at the height of the bridge over the Sogamoso River, there is an excellent panoramic view of the Topocoro Reservoir (Fig. 5a–c). It reveals the potential in the offer of geotouristic services that can be developed mainly taking advantage of the beautiful landscapes around it for the enjoyment of the visitor, which strengthen the value of its natural and cultural heritage of the route, essential for the development of a true tourist industry in our country. Figure 5d–g illustrate outcrops of the Tablazo Formation, where intercalations of fine-grained sandstones and gray shales of parallel flat bedding with thin gypsum lenses occur with strong dip. Observe on the stratification surface the development of intense bioturbation as revealed by the occurrence of traces assigned to Thalassinoides sp., which form by a complex network of horizontal and more rarely vertical cylindrical galleries with

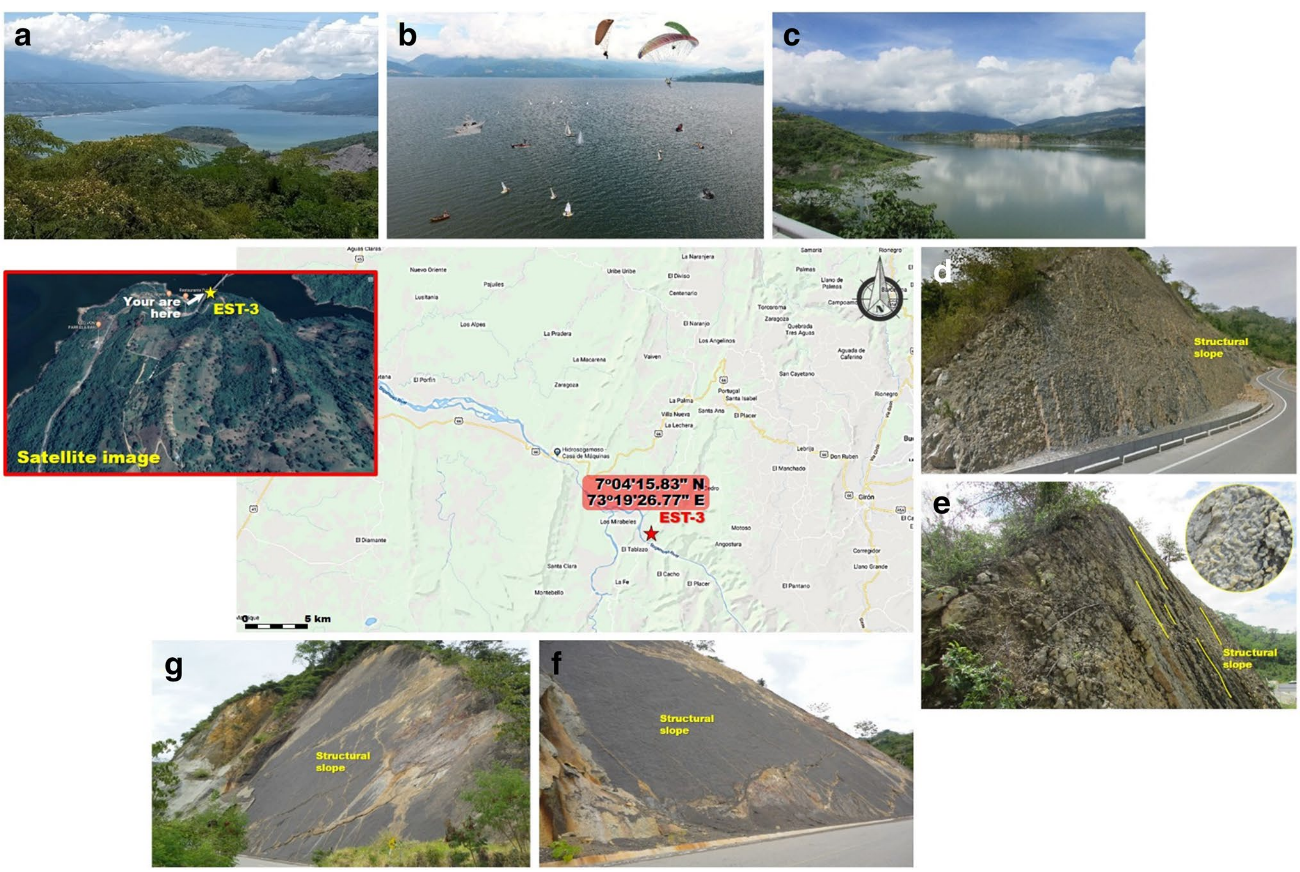

Fig. 5 (**a**)–(**b**) Aerial views with drone of the Topocoro Reservoir. (**c**) Panoramic from the bridge over the Sogamoso River on the road to San Vicente de Chucurí. (**d**)–(**g**) Outcrops of the Tablazo Formation, showing Thalassinoides sp. on layering surface

smooth walls and frequent thickened T and Y bifurcations, which represents important evidence of the presence of icnofacies in this geological unit. According to Bustillo et al. (2017), the ichnogenus Thalassinoides shows smooth-walled galleries, whose genesis depends on biological and diagenetic processes. The type section of the Tablazo Formation, designated by Wheeler (1935), is located in the Tablazo, where the Bucaramanga to San Vicente de Chucurí highway crosses the Sogamoso River. This sedimentary sequence consists of thickly stratified limestone, extremely fossiliferous at the top, and loam or clay limestone at the bottom (Morales et al. 1958). The Tablazo Formation reflects deficiencies in the hydrocarbon storage capacity (Lozano and Zamora 2014). This sedimentary unit shows concordant and gradation contacts with the underlying Paja Formation and concordant with the overlying Simití Formation. The sedimentation environment is a marine platform (Lozano and Zamora 2014). The age assigned for this sedimentary unit is Aptiano Superior–Albiano Inferior, based on the comparison with the supra and underlying formations, since ammonites are not reported in the type locality (Sarmiento et al. 2015).

This geosite is very important to develop outdoor adventure, sports, and health activities, which can represent segments of tourism of special interest, which are functionally related in terms of travel motivations and social values in search of improving the quality of life of people. According to Dickson et al. (2008), outdoor experiences have evolved from necessity to recreation, offering alternatives of interaction of tourists with nature and among those who are part of these. According to the Territorial Ordinance Plan of the Topocoro Dam proposed for the development of tourist activities in this sector, it was proposed to organize and zoning the use with the following activities: ecotourism (observation of birds and other fauna and flora associated with the landscape, mountain biking or trekking); aquatourism (riding in a motor boat, aquatic biking and motorcycling); nautical tourism (kayaking, canoeing, windsurfing, jet skiing).

EST-4: Panoramic View of the Sogamoso Hydroelectric Power Plant and Outcrops of the La Paz Formation

The construction of the Sogamoso Hydroelectric Power Plant led to the discovery of a series of fossils that have allowed us to expand our knowledge regarding the fauna and flora that existed in this part of Colombia during the Upper Cretaceous. It forms part of an initiative led by the Colombian Geological Service and the Smithsonian Institute in the collaboration with ISAGEN, focused on rescuing as many fossils exposed thanks to the works performed during the engineering project. The discovery of a fossil shrimp from 110 Ma ago was reported here on the El Tablazo Bridge, via San Vicente de Chucurí. However, the fossils found include a great variety of marine fauna represented by fish, sharks, plesiosaurs, echinoderms, and crustaceans, as well as abundant leaves and seeds and ichnites of dinosaurs (titannosaurs) and a jaw that defines a new species of pterosaur. Therefore, this region constitutes a paleontological deposit of great importance that will help describe the ecosystems that were part of this part of the South American continent during the Cretaceous (CGS-ISAGEN-STRI 2020). On National Route 45, it is possible to observe the Sogamoso Hydroelectric Power Plant (Fig. 6a), which also provides a tourist attraction for the region. On the other hand, sedimentary rocks of the La Paz Formation emerge here (Fig. 6b–d), which is characterized by the presence of conglomeratic sandstones. The type section cropping up in the Sogamoso River canyon consists of conglomeratic sandstones and conglomerates with intercalations of thick clay levels of tabular geometry with diffuse laminations. The basal Toro shale member presents of mottled, vary-colored mudstones, and subordinate intercalations of conglomeratic sandstones with cross-stratification (e.g., Caballero et al. 2010). The age of the La Paz Formation is Middle to Late Eocene based on its fauna content (e.g., Pardo and Roche 2009).

EST-5: Outcrops of the Esmeraldas Formation Before the Access Bridge to the Hidrosogamoso Dam

The Esmeraldas Formation outcrops on the E flank of the New World Synclinal consist of fine-grained sandstones, light gray to greenish-gray in color, with fine-to-layered stratification, and shades of dark gray shale and mottled colors of red, purple, and brown (Gómez et al. 2008). Figure 7a–c illustrate outcrops of the Esmeraldas Formation before the access bridge to the Hidrosogamoso Dam. According to Sarmiento et al. (2015), the Esmeraldas Formation is of late Eocene age based on palynological associations. The sedimentation environment is typical of river systems of floodplains and meandering rivers that vary north to low lake plains probably affected by marine influence as revealed by the presence of the fossiliferous level (gastropods, bivalves, and plant macro-fragments) “Los Corros” (Caballero et al. 2010). The lower contact with the La Paz Formation is conformational and transitional, but not in conformity with the overlying Mugrosa Formation (Morales et al. 1958).

EST-6: Mineralogy of the Esmeraldas Formation Sandstones

The Esmeraldas Formation sandstones show good continuity but of little thickness, with a predominance of fines, corresponding to floodplain facies and floodplain sands (Madero et al. 2010). Recently, Ordoñez et al. (2019) reviewed the type locality of one of the best-known fossil horizons in

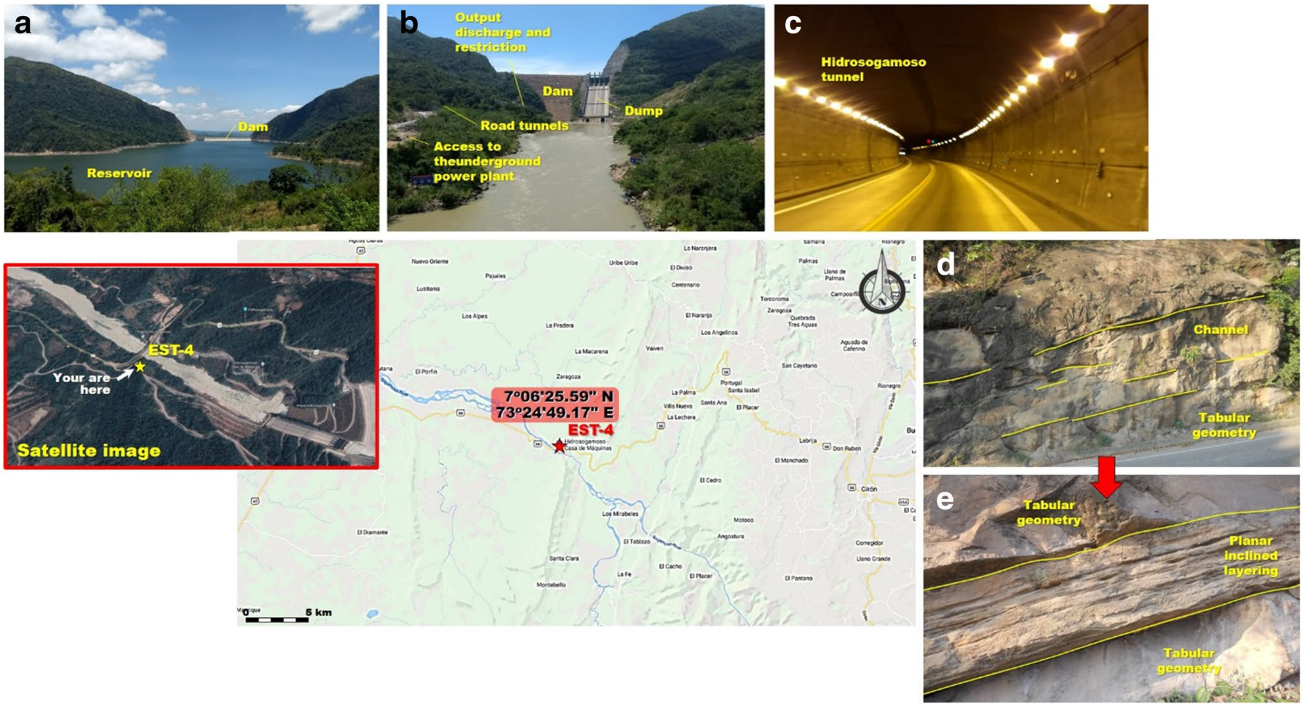

Fig. 6 (**a**)–(**b**) Panoramic view of the Sogamoso Hydroelectric Power Plant. (**c**) Hidrosogamoso tunnel along the Bucaramanga-Barrancabermeja highway. (**d**)–(**e**) Outcrops of conglomerate sandstones of the La Paz Formation on the left side of the highway.

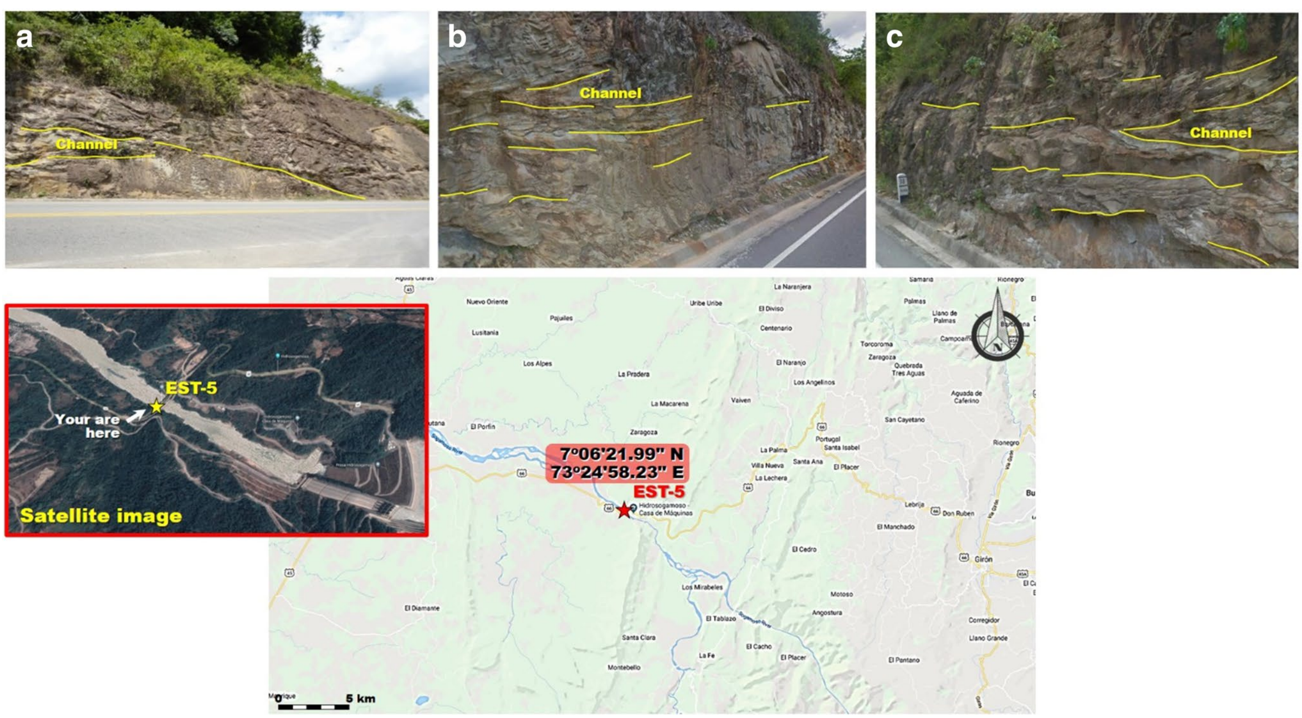

Fig. 7 Outcrop of the Esmeraldas Formation

the upper part of the Esmeraldas Formation (Los Corros). Beyond corresponding to a discrete interval, of well-defined thickness, it actually comprises a heterogeneous lithostratigraphic segment, in which both the abundance, preservation, and species richness of the mollusks found (bivalves and gastropods) suggest a greater complexity in the deposit environment.

The Esmeraldas Formation is characterized here by the presence of moderately selected coarse-grained sublitharenites (Fig. 8), composed mainly of mono- and polycrystalline quartz grains (69.7%), albite (9.6%), microcline (8.8%), and rock fragments igneous and sedimentary. The interstitial material is mainly muscovite (4.6%), montmorillonite (4.3%), and kaolinite (3.0%). It is common to observe silica as overgrowths on quartz grains.

EST-7: Outcrops of the Esmeraldas, Mugrosa, and Colorado Formations

In the surroundings of this sector, it is possible to observe the Esmeraldas, Mugrosa, and Colorado formations of great importance, as they are reservoir rocks of hydrocarbons in the MMVB. The underlying and overlying contacts of the Upper Eocene–Lower Oligocene Mugrosa Formation (Gómez et al. 2005) with the Esmeraldas and Colorado formations are discordant and concordant, respectively. The Mugrosa Formation consists of intercalations of fine-grained sandstones, quartz, brown, coined laterally which would express the increase in the base level of the channels and their consequent abandonment, and gray to black mudstones related to floodplain environments (Casadiego et al. 2010). The sedimentary rocks of the Mugrosa Formation were deposited under anastomosed and meandering fluvial conditions (e.g., Ramón and Cross 1997). The Mugrosa Formation consists of poorly selected medium sand sublitharenites (Fig. 9). It represents one of the most important hydrocarbon reservoirs in Colombia (Clavijo and Royero 2001) due to their anastomosed channels that deposited gas and oil sands with very good lateral continuity from 5- to 30-m thick. Outcrops of this sedimentary unit occur in the La Uribe-Uribe sector, where clay deposits of the flood plains isolated some channels similar to what Qiu et al. (2019) report. The Esmeraldas Formation shows good selection in grain size, good porosity, and permeability, which makes it a good reservoir rock (Mier-Umaña et al. 2016). According to Casadiego et al. (2010), in this sector, it is possible to observe imbricated clasts from the Colorado Formation and ichnofosiles from the Mugrosa Formation. Previous studies (e.g., Mier-Umaña et al. 2016; UPME 2018) reveal that the sandstones of the Mugrosa and Colorado formations show

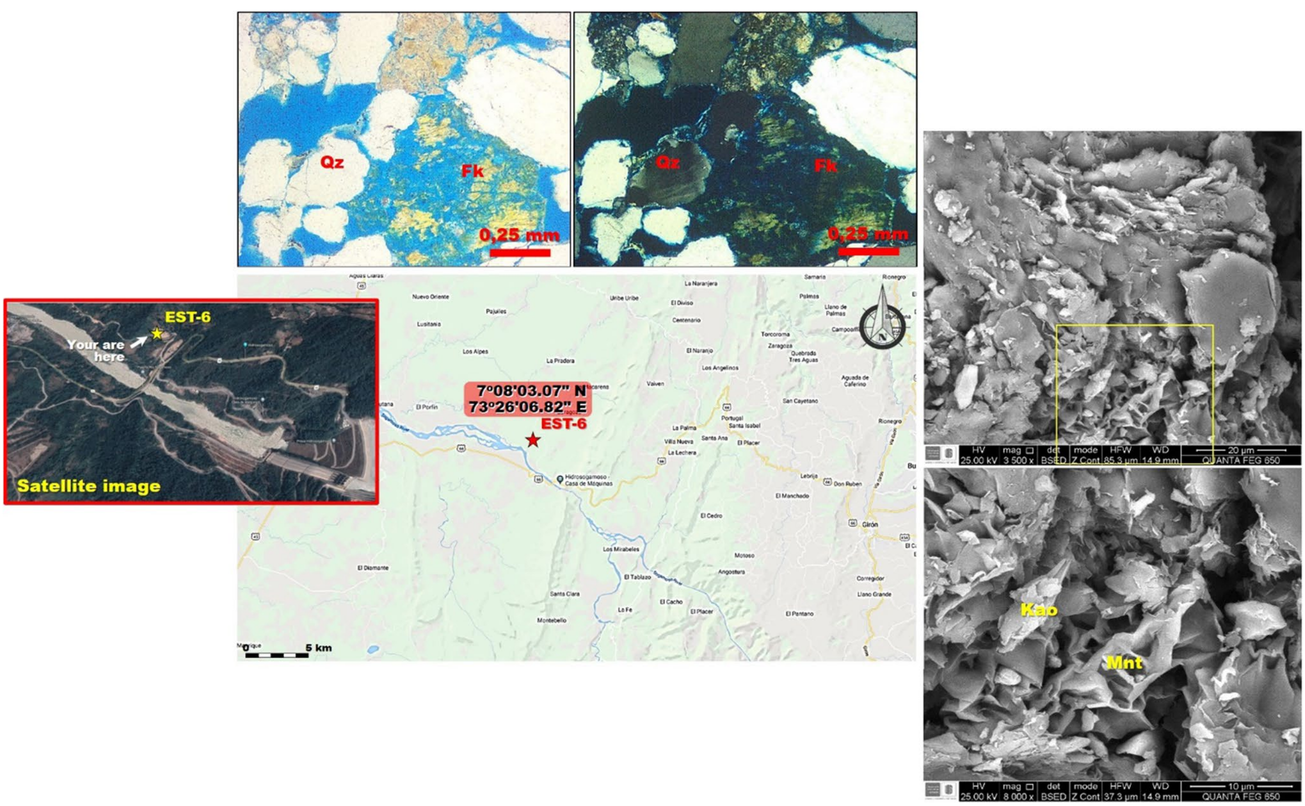

Fig. 8 Moderately coarse-grained sublitharenite from the Esmeraldas Formation

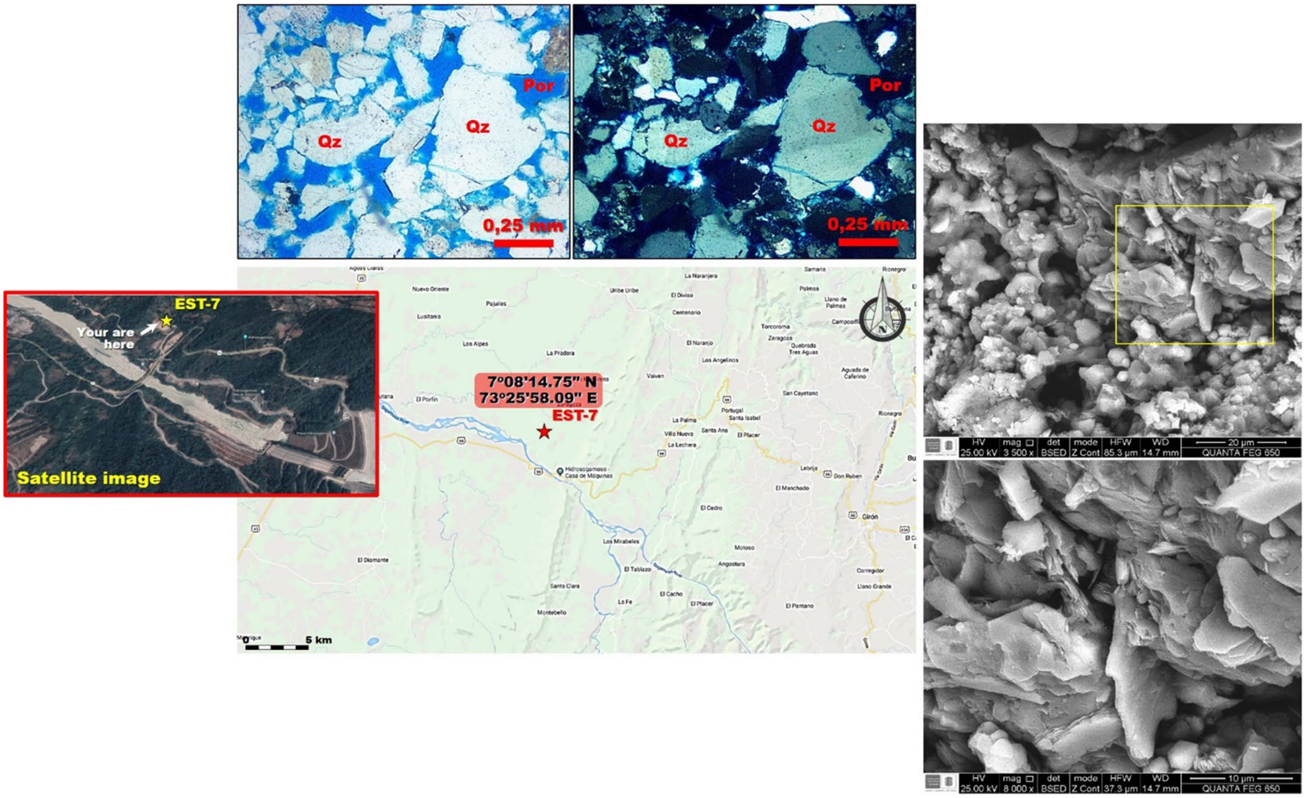

Fig. 9 Sublitharenites of medium sand from the Mugrosa Formation

good porosity (9–26%) and permeability (100–500 mD) values, which are optimal for hydrocarbon storage and, therefore, make them good reservoir rocks, within a thermally medium maturity basin with thickness variations.

EST-8: Outcrops of the Mesa Formation

At the La Fortuna hamlet, it is possible to observe different cut slopes along the new road under construction where vary-colored clays of the Mesa Formation emerge (Fig. 10a–f), which in some cases show tectonic and erosion phenomena active. Weiske (1926) defined this sedimentary unit, and its type locality is located to the west of the city of Honda. The Mesa Formation is a series of horizontal strata that rest discordantly on older formations. It consists of a series of conglomerates and loosely consolidated sandstones and andesitic tuffs. According to Morales et al. (1958), this represents volcano sedimentary accumulations of tuff sandstones, andesitic tuffs, agglomerates and intercalations of clays, silts, conglomerates, and pyroclastic deposits. According to Caballero et al. (2010), the sedimentation conditions of the Mesa Formation reveal the occurrence of flood plains. Its age is probably Pliocene–Pleistocene (e.g., Caballero et al. 2010; Sarmiento et al. 2015), although there is not enough paleontological evidence to support it. Here, it is also possible to observe oil wells in operation (Fig. 10f).

In this geosite, the presence of erosion in furrows (with development of erosive gullies) is highlighted, which is the result of the rains that erode the slopes, leaving long longitudinal furrows, once the slope is built and before the vegetation is established. However, there are different factors that influence the magnitude of erosion, such as the rainfall regime, the slope, the lithological characteristics, and the vegetation. In order to prevent the advance of the erosive process, it is important to protect the slope with a vegetation cover. On the other hand, this geosite is of importance as it should motivate both the evaluation of soil erosion into land use planning exercises and the development of educational strategies focused on the management and conservation of soils. Soil erosion by rainfall and runoff is a land surface process strongly controlled by climate and is one of the most threatening environmental problems in the world (Ke and Zhang 2021).

EST-9: Oil Seeps of the Lisama Formation

On the National Route 66, passing the Sogamoso River toll, 12 km ahead is the La Lisama Oilfield, where a special geological phenomenon occurs on the highway,

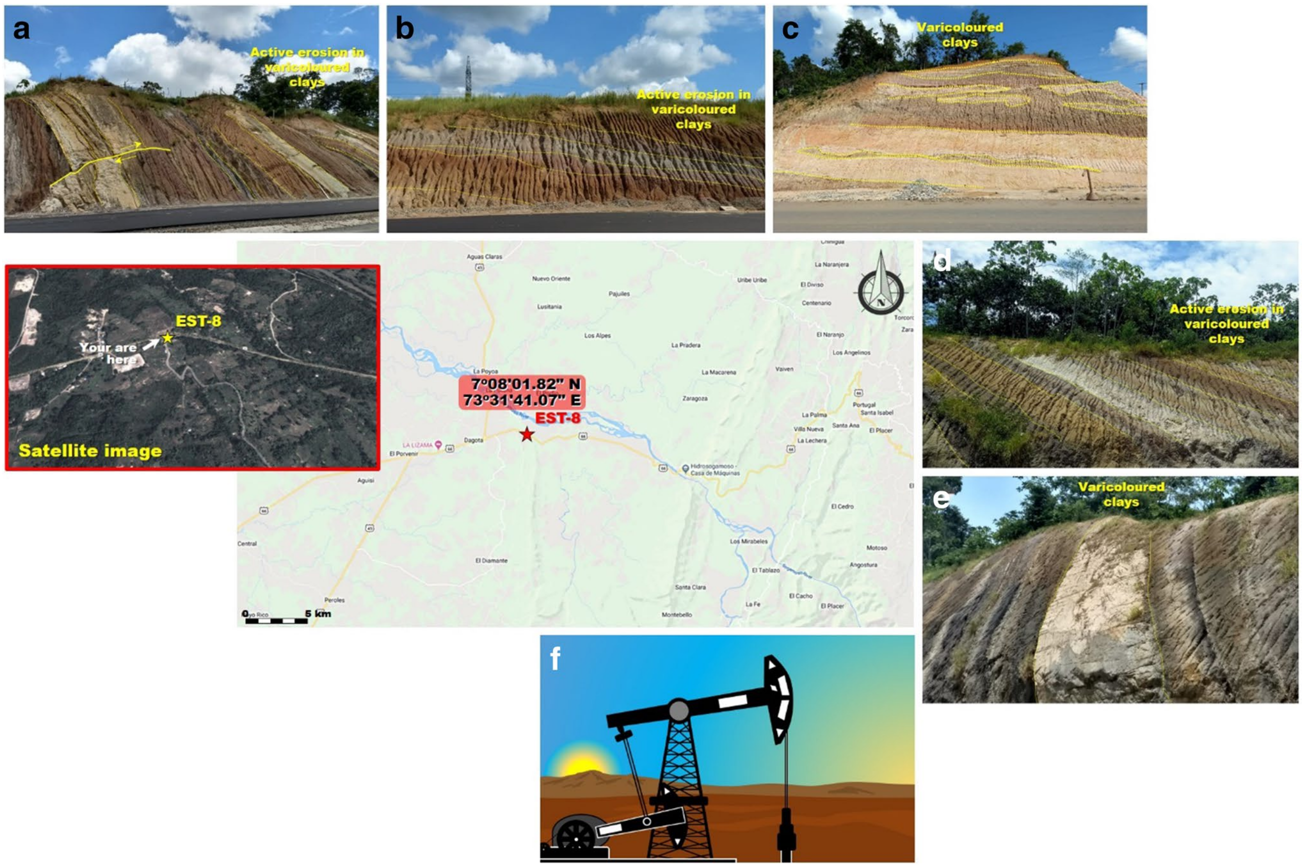

Fig. 10 (**a**)–(**f**) Outcrops of the base of the Mesa Formation. (**d**) Oil wells in operation

corresponding to the occurrence of oozing of crude oil, which sprout in outcrops of rocks of the Lisama Formation naturally (Fig. 11a–b). What is a hydrocarbon ooze? A hydrocarbon ooze represents a place where hydrocarbon (liquid or gaseous) naturally flows through fractures or pores in the rock. However, there are hydrocarbon seeps due to anthropogenic intervention. On the other hand, oil spills, one of the biggest environmental problems worldwide, are accidental or intentional releases of crude oil and petroleum products into the natural environment because of human activities (Pinto et al. 2019). The ignorance by the local communities of the natural causes that could cause the oil spill has generated intense controversy against ECOPETROL S.A. However, despite acknowledging no responsibility for these natural spills, it carries out control in affected areas. Geoeducation emerges here as a strategy that could contribute not only to transfer knowledge regarding the natural and anthropogenic causes of oil spills and to raise awareness of the dangers of oil spills and why they are dangerous to wildlife, as well such as difficulties in cleaning up areas and creatures affected by oil spills. Another important aspect here is to illustrate the meaning of reservoir rocks, which have the capacity to store hydrocarbons that can migrate through their pores or fractures (Fig. 11c). Its main petrophysical properties are porosity and permeability. These rocks may have (1) few pores and very low permeability, (2) unconnected pores and low permeability, or (3) connected pores and high permeability (Fig. 11d). The sandstones of the Lisama Formation show a porosity of 1–20% and a permeability of 5–500 mD (UPME 2018).

This geosite represents an excelent example of how oil at depth migrated to the surface, which attests to the existence of an active oil system. The oil probably migrated from the source rocks to the surface through fractures or other migration pathways (e.g., Abrams 2005; Galarrage et al. 2010) and invaded the host sandstone. Similar oil seeps have been reported in several parts of the world (e.g., Abrams 2005; Escobar et al. 2011; Galarrage et al. 2010; Burton et al. 2019; Al-Khafaji et al. 2020; Al-Khafaji 2021). It can provide valuable information on the presence of a petroleum system, nature of the source rocks, thermal maturity level of the organic matter, and migration pathway of the hydrocarbons as suggested by several authors (e.g., Abrams 2005; Burton et al. 2019).

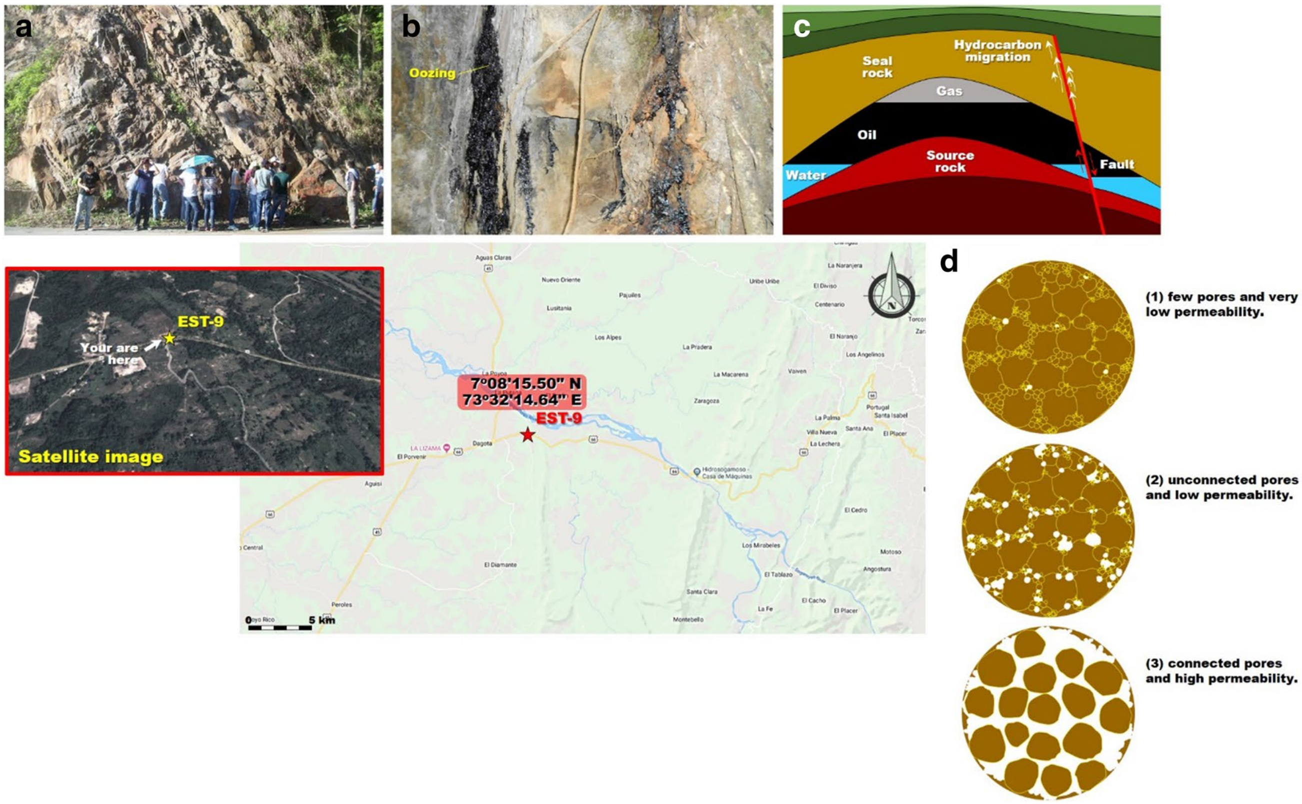

Fig. 11 (**a**)–(**b**) Outcrop of the Lisama Formation, illustrating the occurrence of oozing of crude oil. (**c**) Deposit and migration of hydrocarbons. (**d**) Reservoir rocks

EST-10: Outcrops of the Mugrosa Formation

On the National Route 45, between Campo 23 and the deviation towards the Yarima township, outcrops of the Mugrosa Formation of Tertiary age occur, which is considered to have the main reservoir rocks of the MMVB. These sedimentary units deposited in continental environments consist of intercalations of fine and thick material in wedge-shaped strata, with internal stratification typical of these deposit environments. In the La Fortuna sector, near Yarima, an outcrop of

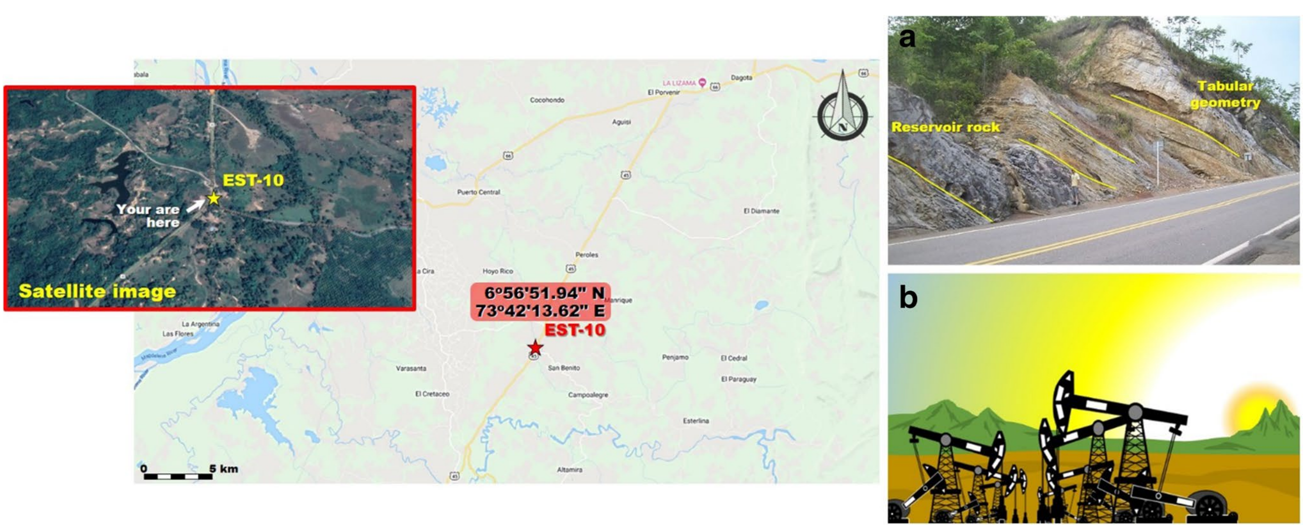

Fig. 12 (**a**) Shows a typical outcrop of the Mugrosa Formation showing the reservoir rock. (**b**) Illustrates a sketch of an oil field

the Mugrosa Formation of approximately 80 m in length and more than 5 m in height is observed, which is characterized by presenting towards the base layers of sandstones with cross-layering in trough impregnated with crude oil and towards the top intercalations of layers of mudstones interspersed with thin layers of sandstones (Fig. 12). In this outcrop, it is possible to observe the typical features deposition of old channeled systems as well weathering processes. Some beds show cavities of 5–20 cm produced by dissolution of possible calcareous concretions.

This geosite is of important geological interest, since it contains valuable information on the conditions of sedimentation of the Mugrosa Formation under transitional braided-meandering with lateral litofacies changes that complicates the hydrocarbon traps (Casadiego et al. 2010). The Mugrosa Formation is a predominantly muddy unit (Caballero 2010), consisting of gray to grayish-green fine- to medium-grained sandstones, with interbedded bluish-gray mudstones and some conglomeratic beds in the lower part. The outcrops of the Mugrosa Formation show the channel geometries and real thickness, which is very useful to perform correlations cross this geological unit in all directions to know the connection of transversal and longitudinal channels in paleocurrents direction. Near this site, it is possible to observe numerous oil wells in operation that explode heavy crude.

This geosite is also an excellent example to highlight that the essential element of a reservoir rock is its porosity to allow the storage of hydrocarbons, although this condition is not sufficient, since the pores must also be interconnected to allow the flow of hydrocarbons through of the rock; that is, the rock must be permeable. In this way, the petrographic and diagenetic analysis of the sandstones of interest of the Mugrosa Formation is of great importance since it allows determining the quality of the rocks as hydrocarbon reservoirs, as well as the impact of diagenesis on the reservoir rock quality. The Mugrosa Formation is characterized by the presence of feldspathic litharenites (Fig. 13, above) and subarkose (Fig. 13, below). Feldspathic litharenites are fine-grained and are essentially composed of monocrystalline and polycrystalline quartz grains (72.3%), microcline (6.8%), Orthoclase (3.1%), traces of albite-type plagioclase, fragments of micaceous and graphite schists, and in less amount of felsic igneous rocks. The interstitial material is mainly montmorillonite (6.3%), muscovite (5.8%), and kaolinite

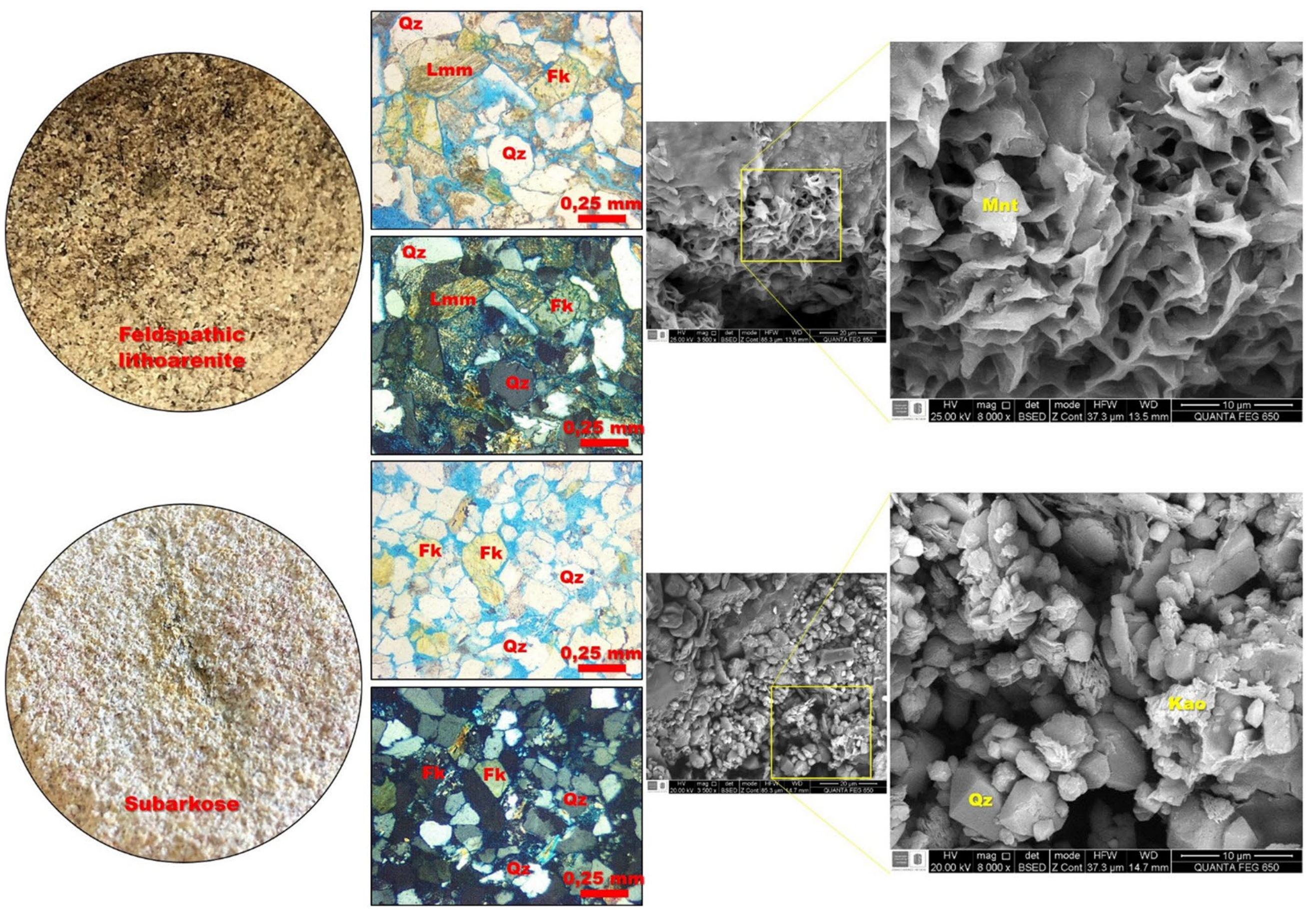

Fig. 13 Textural and compositional features of sedimentary rocks of the Mugrosa Formation; feldspathic litharenite (top) and subarkose (bottom)

(5.4%). Subarkoses are fine-grained and are composed of monocrystalline and polycrystalline quartz (96.0%), microcline (2.2%), and microcrystalline chert grains in low quantities, as well as traces of tourmaline and zircon. The interstitial material is mainly kaolinite (1.4%). The quality of a reservoir rock mainly depends on the textural characteristics and the diagenetic events that have taken place in the rock (Rahman and McCann 2012). Several types of diagenetic alteration have affected the studied sandstones. The main diagenetic processes that have affected the quality of the rock were compaction, cement precipitation, clay minerals, and the dissolution of detrital grains in the rock. These processes have greatly affected the petrophysical properties of porosity and permeability in the rock, being mechanical compaction and cementation the processes that have played the most important role in reducing the quality of reservoir rock. Clay minerals such as montmorillonite and kaolinite are bordering pores and grains of the rock, occluding primary and secondary porosity, generating a low correlation between porosity and permeability data. This information is of great importance in order to carry out its integration with geological, well log, reservoir engineering, sedimentological, and petrophysical information, in order to establish the best rock quality through data integration.

EST-11: Colorado School Oilfield

The Colorado School Oilfield (Fig. 14) is the result of the Inter-administrative Agreement for Business Cooperation for Scientific and Technological purposes between the Industrial University of Santander and ECOPETROL S.A. The alliance between these institutions became the first national experience in the field of academia-industry interaction in the hydrocarbon sector and whose mission is to strengthen the comprehensive training of students by incorporating a practical component in their academic programs and developing research projects and technological appropriation. On the other hand, it is very important to promote training in areas related to the hydrocarbon sector and improve the living conditions of local communities. The wells of this oilfield have allowed the study of the stratigraphic sequence of the top of the late Eocene–early Oligocene Mugrosa Formation, which consists of a base to ceiling of fine-to-medium greenish-gray sandstones, with intercalations of gray to bluish mudstones and some layers of conglomeratic sandstones, mottled shales with some sandstone intercalations, and mottled and fossiliferous mudstones (Royero and Clavijo 2001). According to Fonseca and García (2009), the sedimentation of the Mugrosa Formation took place in a meandering river type environment, characterized by a marked lateral migration of the channel, with medium sinuosity, with alternating bars.

EST-12: La Cira Infantas Oilfield

On the National Route 66 that leads from Bucaramanga city to Barrancabermeja city, in the sector known as Campo 23, take the "Y" that deviates towards the Barrancabermeja city, this road crosses the La Cira Infantas Oilfield, which is located in the central section of the MMVB.

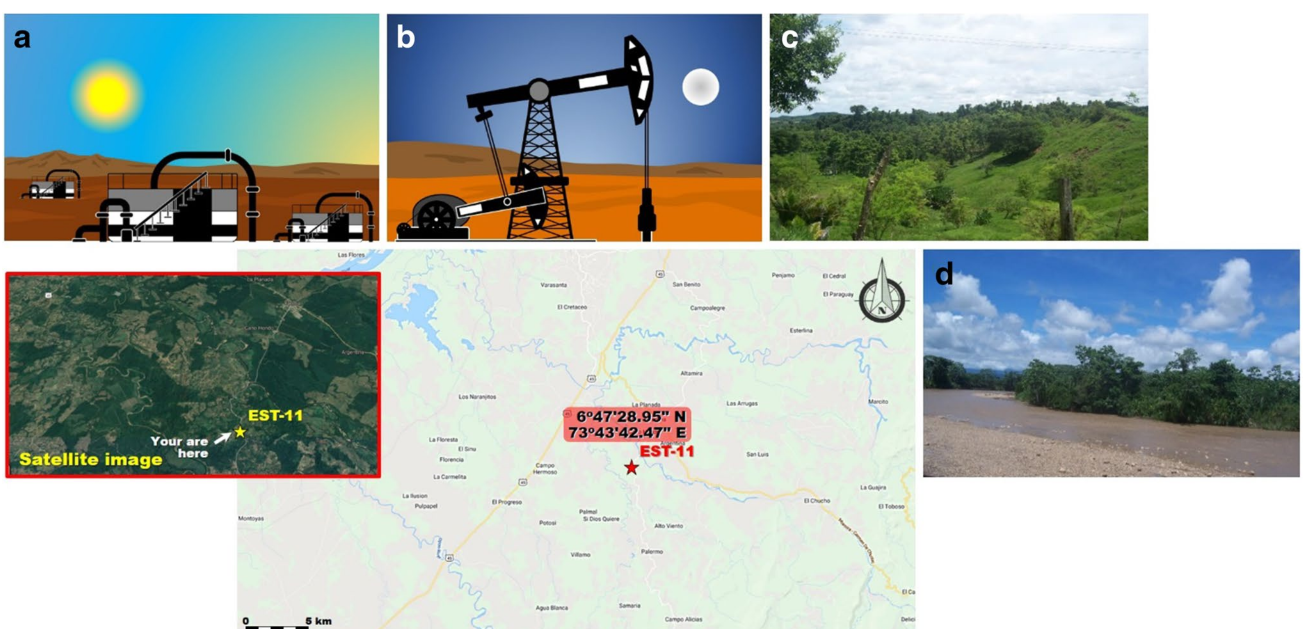

Fig. 14 (**a**) and (**b**) A sketch of an oild field. (**c**) and (**d**) Surroundings of the Colorado School Oilfield

This geosite is very important, because in the La Cira Infantas Oilfield, the history of the oil industry in Colombia was born, because in 1905 is when the Colombian Government decided to sign the first concession contracts with natural persons, among which was Roberto De Mares, with whom it was signed concession for land located in the Department of Santander. In this way, the “De Mares Concession” was born, which later passed into the hands of the North American Tropical Oil Company, which was owned by the Standard Oil Company. Therefore, it is the oldest oilfield in Colombia, and its production history began in 1918 with drilling the Infantas 1 and Infantas 2 wells. In 1939, it reached the highest production in its history with 64.971 barrels of oil per day. On August 25, 1951, the “Concession De Mares” ends, giving way to the birth of the state company ECOPETROL S.A. It receives the name because the hydrocarbons are extracted from two adjacent geological structures, the La Cira and Infantas anticlines (e.g., Gutiérrez 2001; Mora et al. 2017), which are located in the Cachira paleo high, a structurally controlled topographic high that was active between the late Cretaceous and late Eocene (Olaya 1997).

La Cira Infantas Oilfield is a mature field with high potential in the lowest part of the structure, undergoing water flood using horizontal wells to increase the reservoir pressure and oil recovery factor (Mora et al. 2017). The Colorado (zone A), Mugrosa (zones B and C), and Esmeraldas (zone D) formations constitute its reservoir rocks. However, the sandstones of the zone C of the Mugrosa Formation are the main target of the development program in this oilfield. This oilfield represents a challenge, where the problem of low effectiveness in chemical stimulation operations is due to the poor quality of the injection water and accumulation of sediments, incrustations, and migration of fines on the face of the formation of the perforated intervals. Some of the relevant aspects of this geosite are the history of the La Cira Infantas Oilfield and the challenge posed by the oil industry in relation to the methods of stimulation of mature reservoirs.

EST-13: National Museum of Petroleum “Samuel Schneider Uribe”

The National Museum of Petroleum “Samuel Schneider Uribe” was founded in 1984 and has a fully modernized and interactive infrastructure, thanks to the celebration of the centenary of the La Cira Infantas Oilfield, to improve the experience of its visitors, thus how to offer a cultural and historical connection with the petroleum industry in Colombia.

This geosite plays a major role in revealing to the visitors the existence and characteristics of interesting aspects on the petroleum industry. It also associates the local communities, its active members, and the groups and institutions emanating from it to all aspects and stages of natural and cultural heritage management. The National Museum of Petroleum can be visited by students of all ages and for many people visiting the region, and its collections are a great national interest and contribute to transfer the knowledge of the different phases of the oil cycle. These collections form part of research work carried out in the MMVB as a source of evidence in tackling major challenges of the petroleum industry and engaging visitors in petroleum geology valuable pieces, including parts and instruments that were used in the first years in the El Centro and Casabe oilfields, as well as photographs and illustrations of the hydrocarbon exploration, production and refining process to acquire a basic understanding of the oil industry, models and maps, and historical documents. The museum shows the different phases of oil activity in our country, among which the development of upstream oil operations offshore (Fig. 15a) and onshore (Fig. 15b) and downstream refinement (Fig. 15c) is highlighted. Midstream-transport (Fig. 15d), sale, and distribution (Fig. 15e) are also some of the main aspects of the oil industry that are illustrated in this museum. On the other hand, during its tour, it is possible to learn about the history of the Colombian state company (ECOPETROL S.A.), the presidents it has had, the managers of the refinery in Barrancabermeja, and the monuments that this company built in different areas of the municipality, as well as other details of great relevance to the oil industry in the country, such as the history of the first refinery that existed, built in 1906 by General Virgilio Barco in Tibú (Norte de Santander). The diverse and unique nature of this museum contributes to scientific advancement and understanding of Earth processes for researchers, students, and the public, highlighting the scientific breakthroughs in the history of the petroleum industry and the geological heritage in the MMVB. Together they represent an unparalleled scientific and cultural resource that attracts visitors from around the world. Public access to collections often provides the opportunity for performing an interaction with some evidences of the past, helping to develop a more concrete understanding of the processes they represent. Collections can provide people to better understand the natural and cultural heritage in the region, teach on several aspects on geological processes particularly related to the petroleum geology of the MMVB with a complex geological history discussed over last years, and contribute to the conservation and communication of the geodiversity and geological heritage.

EST-14: Miramar Swamp

The Miramar Swamp is an artificial water mirror of approximately 89 hectares within which the Petroleum Christ stands out (Fig. 16a), a structure made of wrought iron that expels

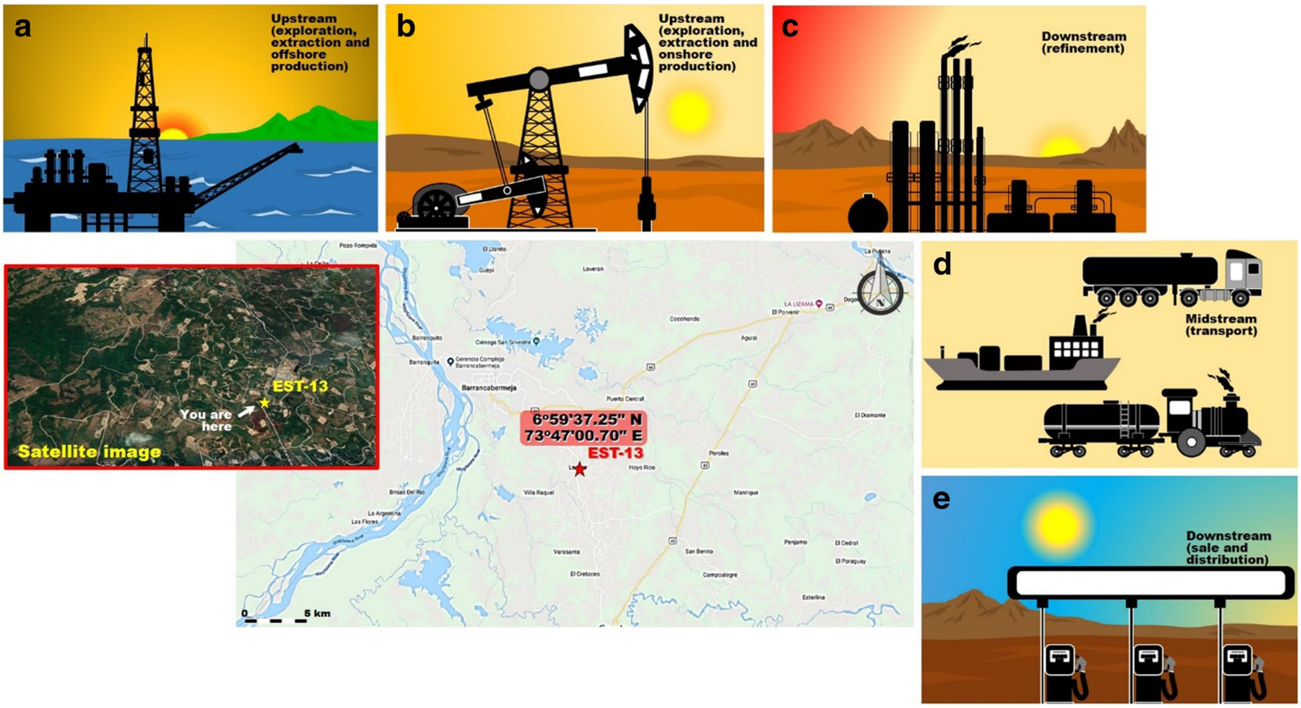

Fig. 15 Oil operations illustrated in the National Museum of Petroleum

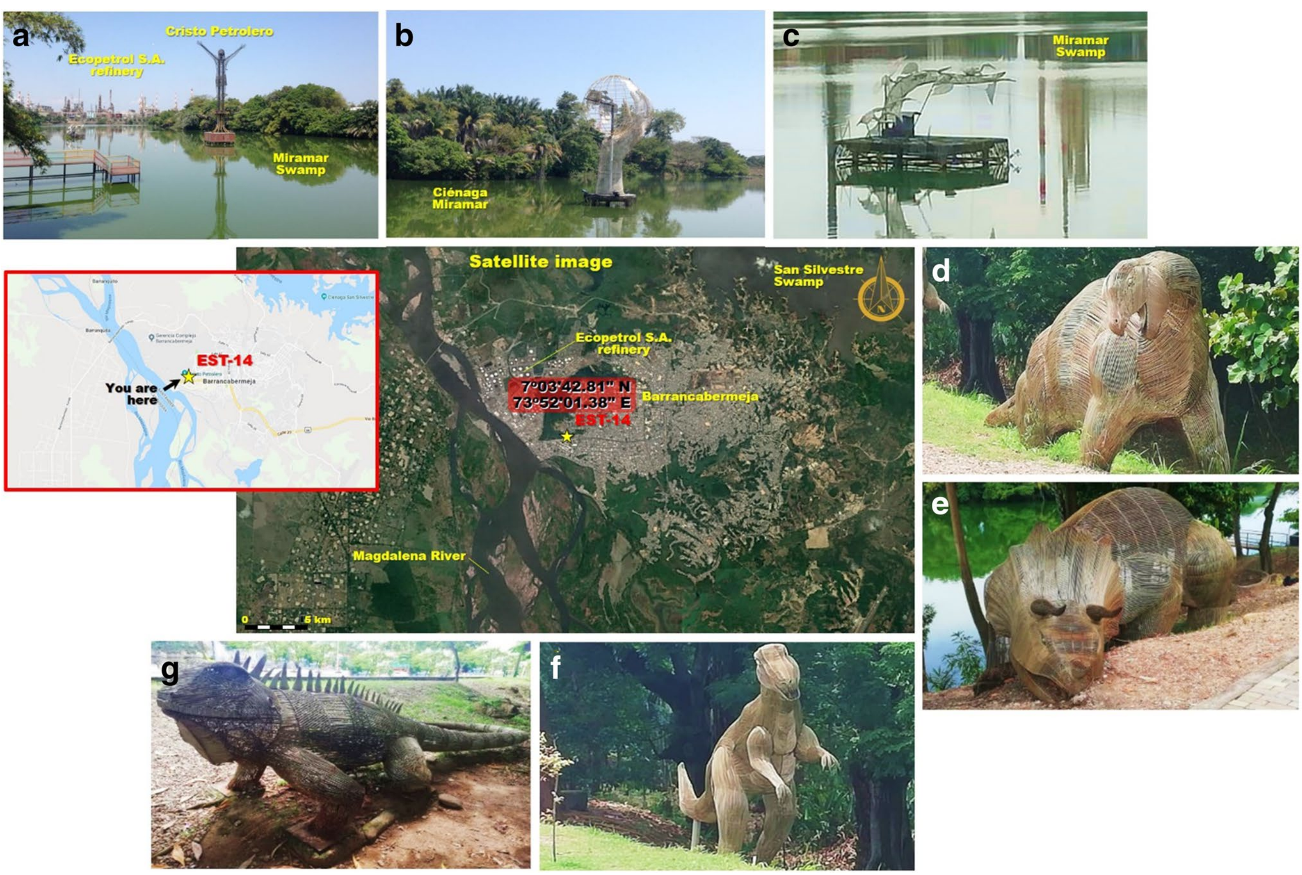

Fig. 16 Panoramic views of the Miramar Swamp and surroundings

about 850 gallons of water per minute through the fingers of its hands, the Labor Hand that sustains the world (Fig. 16b) and the Las Garzas Monument (Fig. 16c), which are opposite the Malecon of Cristo Petrolero where the tourist information center of the city of Barrancabermeja works. The Cristo Petrolero is one of the emblematic tourist sites that represented Barrancabermeja more than 25 years ago; the sculpture was designed by Fernando Fernandez, a worker at ECOPETROL S.A., and donated by the state company to beautify Barrancabermeja; it is located in the heart of the Miramar Swamp with a height of 26 m and a weight of 20 tons and was inaugurated on December 7, 1995. Along this boardwalk, it is also possible to observe life-sized dinosaurs (Fig. 16d–f) and iguanas (Fig. 16g) built with iron residues from the oil industry. Recently, the municipal administration undertook actions aimed at recovering such public space where people can take a fantastic trip to the world of dinosaurs.

EST-15: Panoramic View of the Magdalena River and ECOPETROL S.A. Refinery

At the Yuma River Terminal Pier (Fig. 17a), it is possible to take a boat and to take a walk along the Magdalena River, enjoying the scenery of the banks of the Magdalena River (Fig. 17b) and the oil port, as well as the facilities of the ECOPETROL S.A. refinery in which the gigantic tanks for the storage of crude oil stand out, enormous warehouses and pipes of all sizes. This refinery is the most important in our country and produces 95% of the fuel that supplies national demand, currently considered one of the most efficient and competitive in Latin America. From the Guillermo Gaviria Correa Bridge (Fig. 17c) that connects the cities of Barrancabermeja and Yondó, it is possible to enjoy an excellent panoramic view of the greatness and the imposing landscape of the Magdalena River, the ECOPETROL S.A. refinery, the dock where the trailers dock, and the Yuma Fluvial Terminal Pier (Fig. 17d), as well as other nearby places, where it is possible to observe how the boats pass and spectacular sunsets. Recently, the Senate of the Republic approved that Barrancabermeja be declared a special, port, industrial, tourist, and biodiversity district of Colombia, which would have a local development fund with 10% of the mandatory free destination income, reactivating navigation to through the Magdalena River, modernizing the facilities of the ECOPETROL S.A. refinery, and executing projects with a social fabric to alleviate poverty. This will be essential to convert the Barrancabermeja oil port into a true port authority, contributing to the development of initiatives other than the oil industry.

History and Culture of Barrancabermeja

Barrancabermeja has many places of interest to visit, which allow tourists to enjoy beautiful natural landscapes, among which the San Silvestre Swamp stands out, with great biodiversity, which attract different types of tourism, highlighting its historical, cultural, and religious traditions, health tourism, and business and events. Since several years ago, ECOPETROL S.A. defined biodiversity

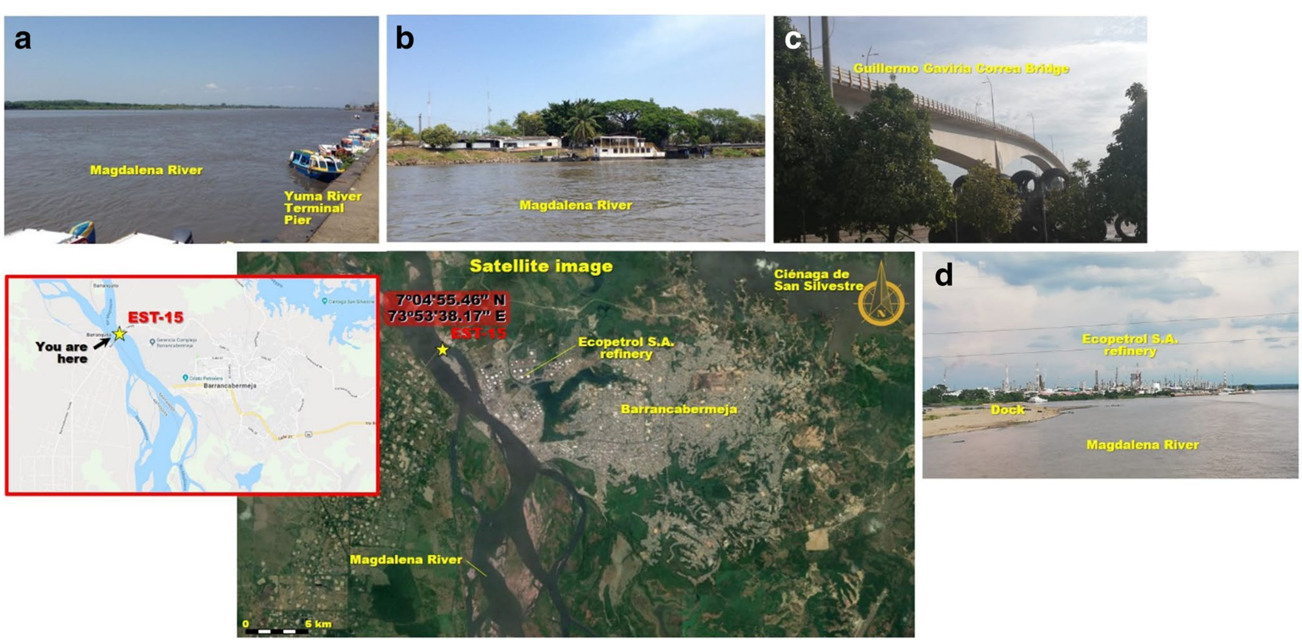

Fig. 17 Panoramic views of the Río Magdalena and ECOPETROL S.A. refinery

as one of its strategic environmental pillars, and since then, it has been carrying out some activities focused on internalizing this issue in the organization and positioning the state company as a responsible entity against biodiversity. The initiative led by the Wildlife Conservation Society Colombia (WCS) and ECOPETROL S.A. stands out, whose objective has been to implement conservation programs for fauna and flora species in the Magdalena Medio regions (blue-billed paujil, striped catfish, Caribbean manatee, cart and spider monkey, or marimonda del Magdalena). The Paseo Yuma is part of the Avenida de los Fundadores, whose separators are the monuments of the Colombian sculptor Héctor Lombana, who made the history of the fauna and flora of Barrancabermeja a reality (Fig. 18a–f) and ends in the plaza of the Cacique Pipatón and Princess Yarima (Fig. 18g). The Paseo de la Cultura is located on Avenida 60 of the city, with three temples with names alluding to great compositions of wind or papayera music, the statue of "La Pollera Colorá" (Fig. 18h), and the "Llama Olímpica" built during the World Skating Championship that took place in Barrancabermeja in 1996. The monument to the railroad (Fig. 18i), which is located on Avenida Circunvalar, is a tribute to the railroad not only in Barrancabermeja but throughout our country, and it is part of what ancient generations told about how fun it was to take a train ride through Colombia. The railroad was a very popular form of transportation between the 1960s and 1980s; however, today, it is but a sad reminder of what this form of transportation once was. Unfortunately, this monument requires maintenance as the inhabitants have been using it for garbage disposal. Another icon is the monument to the fisherman that is located on the Barrancabermeja dock. Unfortunately, the lack of elements that are part of its structure, graffiti, and rubbish are some

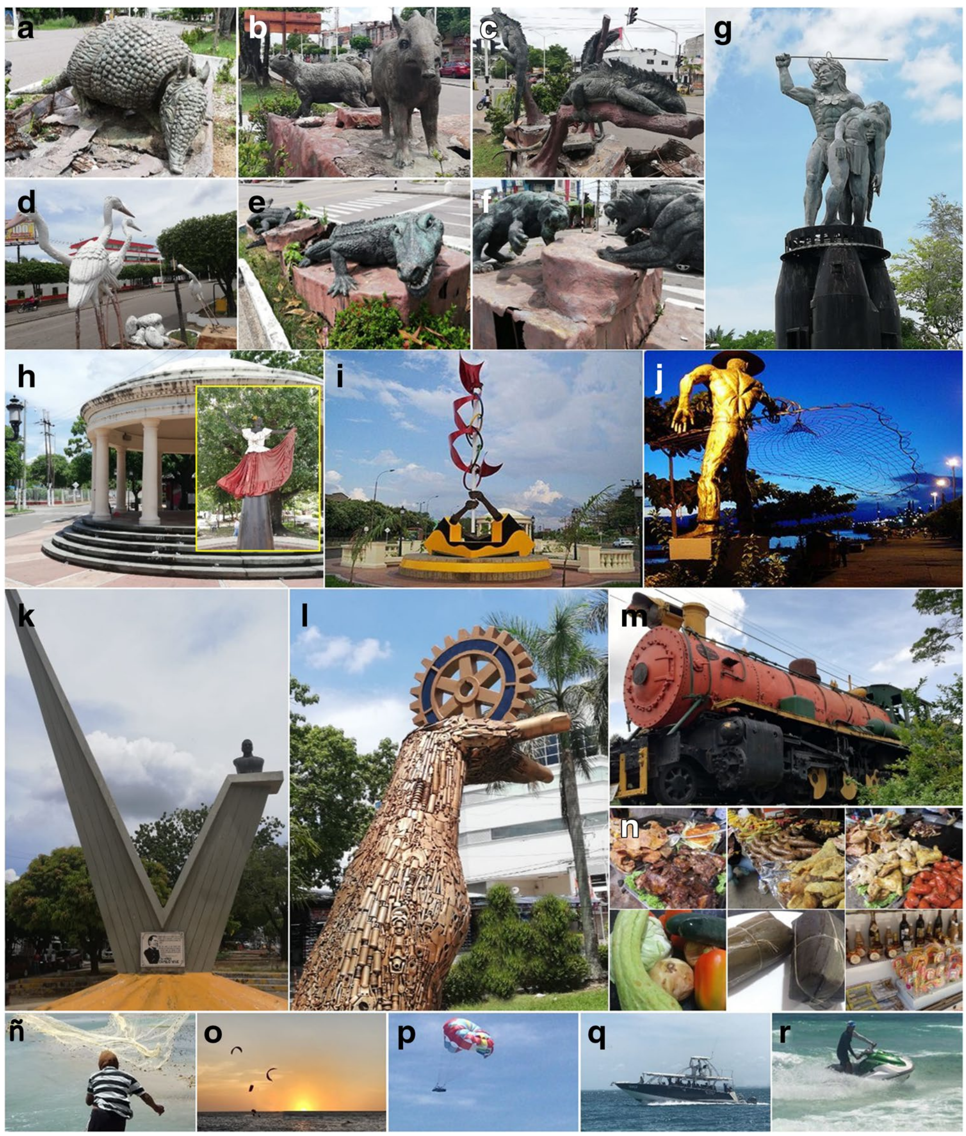

Fig. 18 History and culture of Barrancabermeja

of the problems reflected in the lack of maintenance and care of the monuments to the detriment of the history of the oil port. The Camilo Torres Park (Fig. 18j), called by people as “the headless”, was created in tribute to the ELN guerrilla priest. The Rotary Club of Barrancabermeja whose mission is to provide service to others, promote integrity, and foster understanding, goodwill, and peace among nations through the fellowship activities of our business, professional, and civic leaders exhibits abroad a scrap metal monument (Fig. 18k). Therefore, it is essential to promote sustainable tourism in such a way that awareness-raising work is carried out in local communities with the support of the municipal administration as the most effective strategy in the long-term conservation of these historical moments. The Nuestra Señora del Carmen Church is located in the Barrio Palmira and has an oil-drilling tower as a bell tower, being the only one of its kind. The roller skating rink has been a sports venue in 1996 and 2000 for the speed skating world championships and in 2008 for the IX Skating America Cup. The “Daniel Villa Zapata” stadium is the city’s highest sports arena for soccer practice. The “Luis Fernando Castellanos” coliseum is an important sports venue in the city, which hosted the Women’s Futsal World Cup in 2013. Among the most important festivities in the oil capital of Colombia, the following stand out: sweet festival, festival of fish, gastronomic festival of colonies, national oil festival, festival of folk bands, accordion festival of the Rio Grande de la Magdalena, fandango, festival of the bun, and agricultural and agroindustrial fair. One of the most important attractions of the Barrancabermeja municipality is the San Silvestre Swamp, which represents the most important water mirror in Magdalena Medio, located in the municipality of Barrancabermeja, which supplies through the company Aguas de Barrancabermeja S.A.E.S.P. This swamp is part of the jaguar corridor, is the home of the Antillean manatee, and has been a very attractive site for the development of different tourist activities. However, the advance of the agricultural and livestock frontier, as well as the indiscriminate dumping of leachate from two sanitary landfills built in its vicinity polluted its waters.

The Magdalena River and its banks have been the inspiration of myths and legends, remaining in the memory of its inhabitants and whose legacy is transmitted from generation to generation. Some of these myths and legends include the Madremonte (a large, elegant woman dressed in fresh leaves, moss, who defends nature); the Mother of water (woman who lives underwater and scares children and fishermen by drowning them); the Mohan (mischievous man who scares fishermen by snatching fish from them); the Alligator Man (man who fished in the river and spied on women); La Llorona (a woman who is heard screaming and wailing on moonlight nights looking for her son); La Candileja (large incandescent fireball that can be seen in the distance, although in general the stories refer to souls in pain); and La Patasola (a very beautiful woman who attracts peasants to later eat them, leaving their bones bare).

Conclusions

The MMVB is one of the most prolific hydrocarbon deposits in Colombia, with important discoveries. The geosites identified in this region have high educational and scientific value. The complex history of transformation of organic matter in this basin reveals significant differences in the burial patterns and thermal histories of its source rocks, with the Lower Cretaceous rocks being the most mature and probably the most prolific in hydrocarbon generation. The La Luna Formation represents the main rock that generates the hydrocarbons discovered in this region, constitutes the base of the oil system of the region, and is a very important unconventional gas reservoir. On the other hand, the geosites provide a means of studying the relationship between Cretaceous units and pre-Cretaceous rocks, the transgressive–regressive cycle, Cretaceous to Neogene stratigraphy, tectonic development, and deformation history of the basin.

The beautiful landscape with extensive swamps and wetlands along the Magdalena River, forested areas, and native fauna and flora, as well as geodiversity, are combined with the petroleum industry in Barrancabermeja, which makes this region a site of great attraction for large numbers of people with different backgrounds for the geotourism development. However, its geoheritage sites are severely damaged or threatened by human activities. Therefore, owing to the high educational and scientific interest of the geosites in this region, it is necessary to undertake their geoconservation and that government, civil, and private entities adopt policies for the sustainable development and promotion of the tourism sector in the region in order to capture the attention of national and foreign tourists. The lack of knowledge and meaning of the natural and cultural heritage is reflected in the lack of sensitivity towards these heritage values as manifested in the aesthetics and functionality of the emblematic sites of the city, which are in an advanced state of deterioration, making them lose its attraction for those who visit the oil port, still far from being a tourist destination of national and world importance. Finally, it is important that the petroleum industry of our country design and implement strategies that allow the participation of local communities and access to national and foreign tourists to the oil infrastructure with trained guides who provide the necessary information regarding the operations of the sector.

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