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ORIGINAL ARTICLE

Design of Geotouristic and Cultural Routes Integrated into the Ophiolitic Context of the Moa-Baracoa Region

Diseño de rutas geoturísticas y culturales integradas en el contexto ofiolítico de la región Moa-Baracoa

Yaniset Fuentes-Londres[1*], Leonardo González-Villavicencio[2], Yurisley Valdés-Mariño[1], Arlenys Carbonell-Pupo[1], Dioelis Guerra-Santiesteban[1]

[1]University of Moa, Holguín, Cuba.

[2]Mining Company of the Caribbean, Pinar del Río, Cuba.

[*]Corresponding author: yflondres@ismm.edu.cu

Abstract

The municipality of Moa, in eastern Cuba, host the most important ophiolite complex in the Caribbean, combining exceptional geodiversity with a unique mining and cultural tradition. However, this heritage has not yet been comprehensively assessed in relation to territorial development. This study not only characterizes the geological heritage but also proposes an integration model by designing geotourism routes to articulate natural and cultural values. The quantitative valuation methodology adapted from Gutiérrez-Domech (2007), based on scientific, educational, tourism and conservation criteria, revealed ten geosites of international relevance in the Yamanigüey-Potosí-Santa María sector combining scientific, historical and ecological value. The synthesis of this evaluation enabled the design of two thematic cultural routes. The proposed integration stands as a well-founded strategy to diversify the local economy, promoting environmental education and moving towards a sustainable management model, aligned with Sustainable Development Goals (8 and 11) in Cuba. This proposal positions Moa as an emerging destination for scientific tourism.

Keywords: geodiversity, geological heritage, geotourism, cultural routes, sustainable local development, Moa

Resumen

El municipio de Moa, en el oriente de Cuba, alberga el complejo ofiolítico más importante del Caribe, uniendo una excepcional geodiversidad a una tradición minera y cultural singular. Sin embargo, este patrimonio carece de una valoración integral que lo vincule al desarrollo territorial. Este estudio no solo

caracteriza el patrimonio geológico, sino que propone un modelo de integración mediante el diseño de rutas geoturísticas que articulan los valores naturales y culturales. La metodología de valoración cuantitativa adaptada de Gutiérrez-Domech (2007), basada en criterios científicos, educativos, turísticos y de conservación, reveló en el sector Yamanigüey-Potosí-Santa María, diez geositios de relevancia internacional que combinan valor científico, histórico y ecológico; la síntesis de esta evaluación permitió diseñar dos rutas culturales temáticas. La integración propuesta se erige como una estrategia fundamentada para diversificar la economía local, promover la educación ambiental y avanzar hacia un modelo de gestión sostenible, alineado con los Objetivos (8 y 11) del Desarrollo Sostenible en Cuba. Esta propuesta posiciona a Moa como un destino emergente de turismo científico.

Palabras clave: geodiversidad, patrimonio geológico, geoturismo, rutas culturales, desarrollo local sostenible, Moa

1. INTRODUCTION

Geological heritage, particularly in ophiolitic contexts, constitutes a strategic resource for the deep understanding of the territory and for promoting sustainable local development models. In regions such as Moa, where notable geodiversity, a deep-rooted mining tradition, and unique cultural expressions converge, the valorization of geological resources acquires a key role in economic diversification and in the construction of territorial identity.

The design of geotouristic routes presents itself as an opportunity to integrate science, culture, and nature, creating educational experiences that contribute not only to heritage conservation but also to the well-being of local communities (Guma, 2025; Morosi, 2025). These geotouristic trails, conceived as thematic itineraries, allow the interpretation of the natural and sociocultural environment, fostering local participation and the sustainable use of geological resources (González-Villavicencio, 2022; López, 2024; Solís et al., 2024).

Geotouristic routes in Moa not only facilitate the direct observation of geological and landscape processes but also promote the recognition and appreciation of cultural manifestations that constitute the collective memory and identity of the territory. Through an educational and enriching experience, these routes favor the interpretation of the environment, stimulating knowledge about local uses and values, and highlighting the main natural and cultural attractions of the area (Font, 1992; Escalona-Miranda, et al., 2023; Umajinga and Gálvez, 2024; Delgado-Martínez, 2024; Fiallos-Saquinga, 2024).

Geotourism, understood as a modality of sustainable tourism that values geodiversity and geological heritage, becomes an effective instrument to strengthen environmental education and revitalize local economies (Tourtellot, 2009; Fernández et al., 2015; Toribio et al., 2021; Batista-Nuñez et al., 2025). This tourism modality fosters learning experiences through the exploration of rock formations, fossils, and landscapes of high scientific and aesthetic value, also integrating historical and cultural values into the interpretation of the territory (Font 1992; Caseres-Cimet et al., 2021; Cifuentes-Correa et al., 2023; Escalona-Miranda et al., 2023; Vidal and Tassara, 2023; Delgado-Martínez, 2024; Fiallos-Saquinga, 2024).

In this sense, geoscientific knowledge not only transcends the academic sphere but also becomes a tool for local development. Geological and mining heritage is consolidated as a strategic resource, articulating science, culture, and nature. The identification and valorization of geosites not only expand the touristic offer but also strengthen territorial identity, promote environmental education, and generate sustainable economic opportunities for local communities, positioning the region as a destination for responsible and competitive tourism (Dunán-Avila et al., 2021; Páez et al., 2021; López, 2024; Lorenzo-Comesaña and Valdes-Mariño, 2024; Guibert-Mejias et al., 2025; Ortiz-Pérez, et al., 2025).

In such a context, geotourism is presented as a recreational and educational modality that materializes the articulation between heritage and local development. Geological formations, mining, and landscape geomorphology become the main attractions for activities such as excursions, mountaineering, river observation, beach exploration, and other related activities, favoring geoscientific education and stimulating the local economy. This consolidates the region as a benchmark for responsible and sustainable tourism (Tourtellot, 2009; Domínguez-González and Rodríguez-Infante, 2007; da Silva-Henriques and de Medeiros-Alves, 2023).

From a physiological and psychological perspective, the appreciation of geological formations and landscapes largely determines the visitor's first impression. However, this perception is enriched by emotional components, where previous experiences, emotions, and expectations influence the way the environment is interpreted. Added to this are cultural dimensions, imbued with values, symbols, and collective imaginaries, which confer differentiated meanings to the landscape (Escalona-Miranda et al., 2023; Delgado-Martínez, 2024).

Therefore, this research proposes the characterization of the geosites in the sector, with the purpose of establishing connections between cultural routes

and geotourism, which allows promoting an integrated model of sustainable development.

2. MATERIALES Y MÉTODOS

The Global Positioning System (GPS) was used. The Mendeley bibliographic manager was used to compile information, the geographic information system (ArcGis) to prepare the maps, and Microsoft Excel to elaborate tables and graphs.

2.1. Evaluation of geosites

The geosites were evaluated using the methodology proposed by Gutiérrez-Domech (2007), adapting it to the objectives of the present study. This choice was based on the fact that this method is integrative, unlike others focused solely on scientific value (Torres et al., 2019), and it incorporates, in a weighted manner, educational, touristic, and vulnerability criteria, which aligns with the purpose of designing sustainable geotouristic routes.

2.2. Fieldworks

The geological itineraries were carried out through an in-depth study of each outcrop, with emphasis on geological processes and phenomena. A total of four route marches were conducted and ten documentation points were determined.

3. RESULTS

3.1. Characterization of the geosites

Point 1: El Meandro Pool (X: 255029.7073, Y: 662017.04266)

The geosite exhibits notable ecological and geological diversity, integrating pine forests, gallery forests, charrascales (xerophytic scrublands on serpentinite), and secondary vegetation thriving on soils derived from metamorphosed ultramafic rocks. In this environment, the Yamanigüey River flows between serpentinite outcrops belonging to the eastern ophiolitic complex. The natural slope exposed on the riverbank shows fractured and partially weathered serpentinites, along with reddish lateritic horizons formed by intense chemical alteration, in a setting where fluvial erosion and subsequent plant stabilization reflect the active interaction between geology, geomorphology, and tropical ecology. This site, of high landscape and educational value, constitutes a key point for the development of geotouristic routes (Figure 1a).

Point 2: La Curva Landslide (X: 213599.34942, Y: 716288.89)

It is a slope approximately 80 m high and 200 m long, where a significant mass movement process has exposed the gabbroic crust of the eastern ophiolitic complex. In the area, outcrops of gabbros and altered ultramafic rocks are distinguished, along with colluvial and alluvial deposits forming the riverbank. The chromatic diversity of the slope—with reddish, whitish, and dark tones—reflects different degrees of alteration and weathering, which grants notable landscape and scientific value to the site (Figure 1b). Due to its geological uniqueness, accessibility, and educational potential, the La Curva Landslide is recognized as a strategic resource for sustainable geotourism, based on geoscientific integration applied to landscape aesthetics and the strengthening of territorial identity linked to the geomining heritage of the Moa-Baracoa region.

Point 3: Yamanigüey Dikes (X: 212946.61029, Y: 715746.88946)

The outcrop is located on the banks of a fluvial channel of the Yamanigüey River. At the site, intrusive bodies in the form of gabbro-pegmatite dikes are observed, with thicknesses of up to 30 cm and approximate lengths of 7 m, distinguished by their high resistance to erosion compared to the host rocks. From a petrographic and structural point of view, these dikes correspond to a late stage of magmatic crystallization, associated with differentiation processes of gabbroic magma and circulation of metasomatic fluids. From a scientific and didactic perspective, this outcrop constitutes a geosite of high petrographic and geochemical value, as it evidences the interaction between magmatism, tectonics, and metasomatic processes. Its inclusion in geotouristic and educational routes provides an opportunity for the interpretation of the geological and mining heritage of the area (Figure 1c).

Point 4: Rock detachment on the Yamanigüey River (X: 213893.87, Y: 715271.35).

The outcrop, adjacent to the river channel, exhibits large blocks with fractured surfaces. The arrangement of the blocks and the surrounding relief reflect transport and collapse dynamics typical of channels with moderate to steep slopes. The presence of reddish and brown tones suggests alteration by iron oxides. This geosite obtained high scores in scientific representativeness, didactic value, and aesthetic appeal, standing out as a representative example of ophiolitic landscape modeling and fluvial processes in ultramafic contexts. Its integration into geotouristic routes would allow showing visitors and students the effects of erosion, sedimentation, and chemical alteration on rocks of high scientific interest (Figure 2a).

Figure 1. a) El Meandro Pool, b) La Curva Landslide, c) Gabbro-pegmatite dikes.

Point 5: Potosí II Dikes (X: 212442.35, Y: 715753.33).

The geosite is characterized by steep, structurally controlled surfaces, fractures with vegetation in cracks, and evidence of incipient chemical and biological weathering. Its size and exposure make it visually striking, with high aesthetic and educational value. However, slope stability and the presence of loose rocks classify it as a vulnerable geosite, requiring signage, safe routes, and access restrictions to protect visitors and the geological heritage. This site allows direct observation of textures and structures of igneous rocks, enabling geological interpretation and environmental education in geotouristic contexts (Figure 2b).

Point 6: Carbonate mineralizations (X: 212797.09, Y: 715838.60)

This point is characterized by the presence of ultramafic rocks, upon which superficial speleothem-type crusts develop, with bluish and greenish tones, associated with copper, nickel, and cobalt carbonates. Historically linked to chromium exploitation, the geosite possesses high cultural and educational value, allowing the interpretation of secondary mineralization geochemical processes and the rescue of local mining memory. Its integration into geotouristic routes can serve as a thematic geomining interpretation station,

combining science, culture, and heritage, and fostering learning experiences oriented towards sustainability (Figure 2c).

Figure 2. a) Rock detachment on the Yamanigüey River. b) Potosí II Dikes c) Carbonate mineralizations

Point 7: Yamanigüey Bay (X: 214773.60527, Y: 719837.61335)

Yamanigüey Bay presents a pocket-like morphology, surrounded by several keys, including Cayo del Medio (Figure 3a). It stands out for its notable biological diversity, with the presence of Thalassia testudinum (seagrass) and Avicennia germinans (mangrove) (Figure 3b), which confers high ecological and scientific value. Coastal dynamics, sedimentation processes, and the interaction between marine and terrestrial ecosystems make this site a strategic resource for educational geotourism, promoting environmental interpretation, biodiversity conservation, and landscape valorization as part of sustainable routes in the Moa-Baracoa region (Figures 3c and 3d).

Point 8: Jiguaní River Mouth (X: 212687.64642, Y: 720968.69234)

The estuary formed at the mouth of the Jiguaní River constitutes an erosive-accumulative pocket (Figure 3e). Igneous rock outcrops at its base, while the surface is covered by fine-grained conglomerates and minor sediments; a lithological unconformity is observed (Figure 3f). This site allows the

interpretation of geomorphological and sedimentary processes in fluvial interfaces, enabling the definition of a geotouristic route that integrates environmental education, scientific research, and recreational experience, contributing to the connection between natural and cultural heritage.

Point 9: Santa María Conglomerates (X: 210588.91217, Y: 721492.17753)

Along the Moa-Baracoa highway, an outcrop of sandstones and conglomerates with a 15° dip towards the NW is found (Figure 3g). Large-sized sediments, including gabbros and serpentinites, evidence a lithological unconformity with the surrounding metamorphic rocks. This geosite allows the study of sedimentary and tectonic processes in the region, and its integration into routes facilitates the interpretation of geological history, promotes geoscientific education, and sustainable tourism as a driver of local development.

Point 10: Yamanigüey Viewpoint (X: 213073.3849, Y: 717439.65217)

It is located on a slope 200 m long and 50 m high (Figure 3h), covered by a lateritic soil layer approximately one meter thick, a product of intense tropical weathering. Beneath this layer, a strongly altered serpentinite massif outcrops, evidence of a prolonged history of geochemical and mineralogical transformation. This site combines aesthetic, educational, and scientific value; it also constitutes a strategic point for geotourism, where visitors can appreciate weathering processes and ophiolitic landscapes, integrating geological interpretation with culture, local identity, and contributing to the sustainable development of the territory.

Figure 3. a) Yamanigüey Bay. b) Cayo del Medio, c) and d) Fauna and flora of the keys. e) Jiguaní River Mouth. f) Jiguaní River. g) Santa María Conglomerates. h) Yamanigüey Viewpoint (González-Villavicencio, 2022).

The scientific relevance of the geosites in the sector lies in the fact that they allow clear observation of the nature of the ophiolites, as well as identifying their structural, lithological, and tectonic particularities. This geological richness constitutes the basis for the design and development of geotouristic trails, integrating scientific interpretation, heritage, and natural landscapes. Thus, sustainable geotourism is promoted, contributing to the strengthening of local identity, environmental education, and the generation of socioeconomic benefits, enabling the definition of the Moa region as a

benchmark for cultural routes and geotourism for sustainable local development.

3.2. Classification of the geosites

From the results of the information processing, an analytical table of the numerical behavior of the parameters of the methodology used was created (Table 1).

Table 1. Classification of the proposed geosites

Point	Parameters										Score	Classification
	1	2	3	4	5	6	7	8	9	10		
1	10	7	7	8	4	8	3	12	6	6	71	C
2	10	7	7	8	4	8	3	8	4	5	64	C
3	15	10	10	12	12	8	3	2	4	5	81	B
4	10	7	7	8	4	8	4	8	6	5	67	C
5	10	7	7	12	4	8	4	8	4	5	69	C
6	15	10	10	12	12	8	3	12	6	5	93	A
7	15	10	10	12	12	12	3	8	2	5	89	A
8	15	10	10	12	12	12	3	8	2	5	89	A
9	15	10	7	12	4	8	4	8	4	6	78	B
10	10	7	10	12	4	8	3	2	4	6	67	C

Parameters: 1) Representativeness and scientific value. 2) Historical value. 3) Aesthetic value for teaching and tourism. 4) Didactic importance. 5) Rarity. 6) Uniqueness. 7) Physical condition of the geosite. 8) Vulnerability. 9) Size. 10) Accessibility.

4. DISCUSSION

In the Yamanigüey-Potosí-Santa María sector, notable geodiversity is evidenced, identified through geological mapping and geosite characterization. The analysis hierarchizes the sites based on their geological, scientific, historical, and touristic value, highlighting the potential for the development of cultural routes and sustainable geotourism, which contribute to the strengthening of local identity and the socioeconomic development of Moa.

In terms of representativeness and scientific value, 50% of the geosites present a high level and the other 50% a medium level, evidencing a general balance in the scientific importance of the area. The most outstanding outcrops include Potosí Dikes, Carbonate mineralizations, Yamanigüey Bay,

Jiguaní River Mouth, Yamanigüey Viewpoint, and Santa María Conglomerates. Historical value reflects a similar pattern, with 50% of high quality and 50% medium, reaffirming their relevance as witnesses of the regional geological past.

Regarding aesthetic value for teaching and tourism, only 42% reach high levels, while 58% present low values; however, many sites retain attractive landscape-environmental structures for conventional and educational tourism activities.

Didactic importance is a distinctive factor, with 67% of the sites evaluated at a high level and 33% at a medium level. Concerning rarity, 58% are classified as common, while Potosí Dikes, Carbonate mineralizations, Yamanigüey Bay, and Jiguaní River Mouth are notable for their uniqueness. Regarding uniqueness, 83% are repeatable and only 17% are non-repeatable.

Didactic importance is a distinctive factor, with 67% of the sites evaluated at a high level and 33% at a medium level. Concerning rarity, 58% are classified as common, while Potosí Dikes, Carbonate mineralizations, Yamanigüey Bay, and Jiguaní River Mouth are notable for their uniqueness. Regarding uniqueness, 83% are repeatable and only 17% are non-repeatable.

The physical condition shows that 59% of the geosites are in appropriate conditions, 33% in somewhat inappropriate, and 8% in inappropriate conditions, while the vulnerability index indicates that 58% are exposed to risks of deterioration due to natural and anthropic factors, underscoring the need for conservation measures and sustainable management. Size distribution is balanced: 27% large, 46% medium, and 27% small. Regarding accessibility, 25% are very accessible, 67% accessible, and 8% poorly accessible, with the Santa María Conglomerates and the Jiguaní River Mouth sites standing out.

Although the analysis of the geosites in the sector evidences significant differences between the most accessible sites and those that are more remote or less protected, the integration of these spaces into well-designed tourist routes, such as the Yamanigüey-Potosí Mine Trails and the Yamanigüey Bay-Jiguaní-Santa María Trails, can balance these disparities. In fact, these itineraries constitute concrete examples of how to effectively link nature, culture, and community, allowing enjoyment for both visitors and residents.

This approach not only maximizes the use of geological and cultural resources but also promotes a harmonious relationship between environmental conservation and tourism development. To guarantee the sustainability of activities such as hiking, geological interpretation, and tourism, responsible

planning and management of the routes are essential. This strategy must consider the regulation of visitor flows and the adequate temporal distribution of visits, to avoid ecosystem degradation and ensure the protection of the most vulnerable geosites.En este contexto, las rutas emergen como un ejemplo destacado de cómo articular la geología, la cultura y el paisaje en un itinerario turístico que va más allá de la observación pasiva, convirtiéndose en una experiencia educativa activa (Figura 4).

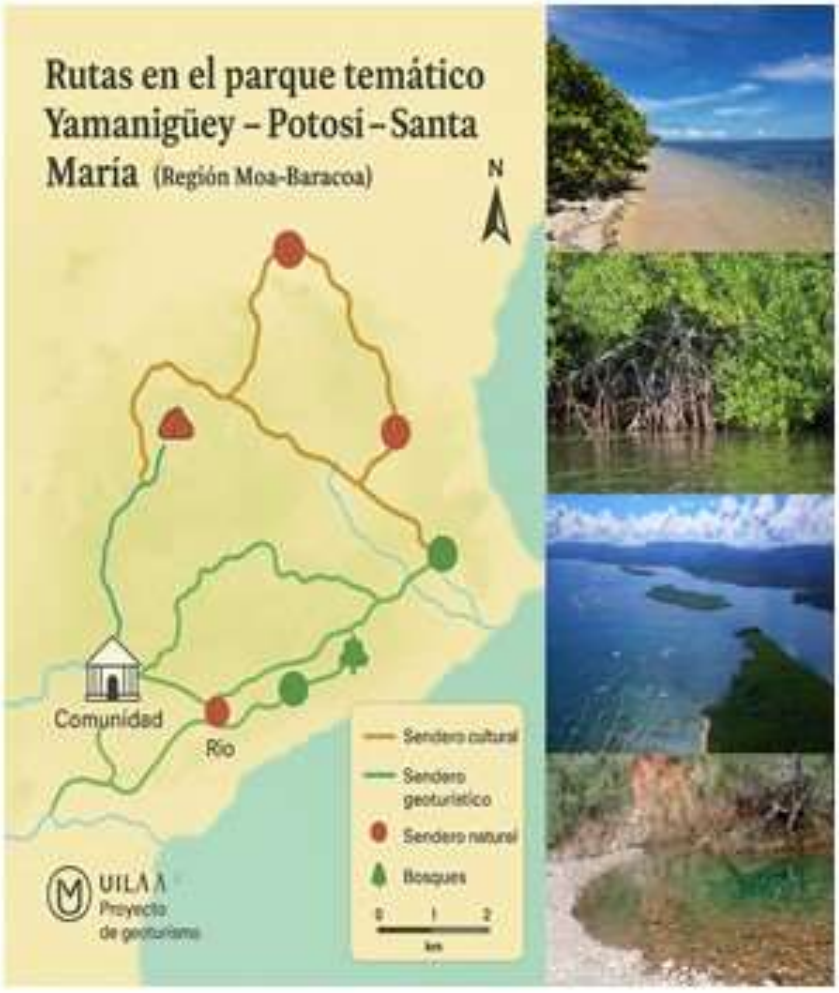

Figure 4. Route Scheme in the Yamanigüey area.

The identification of ten key geosites has allowed the construction of a coherent narrative linking the geological and mining history of the region, strengthening collective memory. Through the participation of students, guides, and residents in interpretive activities, the understanding of geological processes underscores the effectiveness of the pedagogical approach of geotourism; this also has a significant symbolic and cultural impact, as it allows visitors and the local community to connect with the landscape from an emotional and spiritual perspective.

In socioeconomic terms, geotourism is configured as an economic catalyst to diversify the income sources of the region, traditionally dependent on mining. The implementation of the Routes could generate employment in areas such as specialized guiding, rural lodging, and ecological transport, linking the local economy with the conservation of geological heritage. This integration of economic, educational, and heritage values reinforces social sustainability and fosters the development of new opportunities for communities.

The model of geotourism and local development in an ophiolitic context: design of integrated cultural routes in Moa, not only seeks to promote environmental conservation and scientific knowledge but also the active participation of the community in territorial management.

The combination of these factors positions the Geotouristic and Cultural Route as a sustainable management model, capable of articulating science, culture, and local development, within the framework of participatory territorial planning that involves all social actors in the process of transformation and enhancement of heritage. This approach establishes the foundations for geotourism that not only benefits the local economy but also contributes to the strengthening of cultural identity and the protection of natural resources for future generations.

5. CONCLUSIONES

- The Yamanigüey-Potosí-Santa María sector exhibits the geological and ecological richness of the territory, where ten key geosites are distinguished by their scientific, historical, and landscape value.
- The design of geotouristic routes in the Moa-Baracoa region allows the direct observation of geological processes, such as mineralizations, structuring, and geomorphological phenomena, while facilitating contact with fluvial and coastal ecosystems.
- The integration of geological and cultural elements, geotourism in Moa-Baracoa reinforces territorial identity and promotes active participation of local actors, consolidating the geosites as symbols of historical memory and scientific knowledge.
- The integrated approach of geotourism and cultural routes is configured as a sustainable management model, capable of articulating the conservation of geological heritage with socioeconomic revitalization. This model not only favors conservation and environmental education but also positions Moa as an emerging destination for scientific geotourism, aligned with the Sustainable

Development Goals (SDGs), particularly those related to inclusive economic growth and sustainable urban development.

- The design of integrated cultural routes in the Moa-Baracoa region offers a unique opportunity for local development, leveraging the ophiolitic context of the region as an engine for sustainability, based on the conservation of geological heritage and community participation, has the potential to generate long-term economic benefits and strengthen local identity, contributing to the responsible and balanced development of the region.

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Additional information

Conflict of interest

The authors declare that there are no conflicts of interest.

Author contributions

All authors contributed equally.

ORCID

YFL, https://orcid.org/0000-0002-9668-8107

LGV, https://orcid.org/0000-0002-2488-0730

YVM, https://orcid.org/0000-0002-4631-3972

ACP, https://orcid.org/0000-0002-3716-9075

DGS, https://orcid.org/0000-0001-8168-0658

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