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ORIGINAL ARTICLE

Advances in Geoconservation in Cuba: Assessment of the Guaniguanico Range and Guanahacabibes Plain (Pinar del Río)

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Abstract The application of geoconservation concepts in Cuba is very recent, despite the wide body of knowledge accumulated through the study of Cuban geology. Recently, the establishment and consolidation of a National System of Protected Areas that stresses interaction with scientific institutions has greatly helped initiate geoconservation in Cuba. In this study, we review the geoconservation criteria used in the management of protected areas, their precedents and administrative framework. We used the methodology proposed by Bruschi (2007) for the characterisation, assessment and management of geodiversity resources, and modified its criteria for use in selecting geosites. We have applied the methodology to assess the Guaniguanico Range and the Guanahacabibes Plain where 162 geosites were defined. Of the 162 geosites assessed, 107 were at Viñales National Park, so it could be a potential area to become the first Caribbean Geopark.

Keywords Geoconservation · Protected areas · Geosites · Geodiversity · Cuba

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Introduction

The history of geological sciences in Cuba, as in most Central American and Caribbean countries, is closely related with the development of the mining industry. For a better understanding, this introduction is divided into several stages, from the Aboriginal phase to the Socialist era. For every stage, the major scientific advances—associated with mining deposit studies—are emphasised, mapping documents and mining methods that have allowed economic and social development.

According to Iturralde (2006) in Cuba, "the true birth of geological surveys did not occur until the nineteenth century, after the visit to Cuba of the German scientist Alexander von Humboldt" considered the "Father of Cuban Geology". This is not the case with the Cuban Geological Heritage Conservation, whose practices are closely related to the emergence and strengthening of the National System of Protected Areas (SNAP) and less widely publicised than the historical and cultural aspects.

Law 81 on the environment, adopted on 11 July 1997, establishes the main responsibilities of the state representatives in environmental issues and the rights and obligations of Cuban society in general. However, Rojas and Isaac (2008) consider that this law is too broad regarding natural heritage in the way it treats the heritage protection of geosites and ignores the paleontological patrimony—sometimes included in the archaeological or anthropological heritage.

At an international level, the conservation of geological heritage and geodiversity is relatively new and still in its infancy (Carcavilla et al. 2007). In Cuba, it is a growing concern for Cuban geoscientists, expressed since the first edition of the Cuban Convention on Earth Sciences held in Havana in 2005

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(Rojas and Isaac 2008). Since then, the use of terms such as geological heritage, geodiversity, geoconservation and geotourism has begun to spread. These terms were hitherto unknown, as well as ignored and rejected by the vast majority of the population and scientific community.

Institutions like the Institute of Geology and Palaeontology, the National Museum of Natural History, the Cuban Society of Geology, the SNAP and, at a local level, the Viñales National Park, are the main protagonists in the process. The Viñales National Park is a pioneer in experimenting and applying geoconservation methods and in hosting meetings, workshops and projects closely related with this subject.

Throughout the country, the richness of flora and fauna endemism, as well as its abundance, rarity and diversity is associated with geologically unique substrates, materials or processes. Despite this association, it is clear that in protected areas, the protection of geological heritage is still considered in a casual or indirect way (Corvea et al. 2010). In addition, it should be noted that the long-term preservation of geosites is more effective when these sites are managed in the framework of legally protected areas (Dingwall 2000).

Progress in geoconservation in Cuba is closely related with the evolution and management of the protected areas system, based on three fundamental criteria explained in more detail below, together with the legal background and administrative bases created. In this work, we also present the results of the first geodiversity evaluation experience in the west of the country, in two areas of high natural richness: the Guaniguanico Range and the Guanahacabibes Plain.

SNAP, the Main Setting for Geoconservation in Cuba

The Cuban SNAP has the mission for the 2009–2013 period of contributing to the reduction of biodiversity loss, the protection of natural heritage values and sustainable development (García 2010). The SNAP consists of 253 protected areas distributed throughout the country, including terrestrial and marine coastal areas (Fig. 1).

The contribution to the protection of the natural heritage (regulated by the national governing body, the SNAP) is one of the objectives explicitly recommended for the management of protected areas in the country. However, locally, these recommendations have also been followed by a few local administrations, which include their geological heritage as a specific element for conservation.

The potential of Cuban nature is evident and extends over the whole territory, including coastal marine areas. The most important ecosystems in the country are among the protected areas identified in the eight conservation categories, notably 14 national parks (García 2010). They stand out not only for

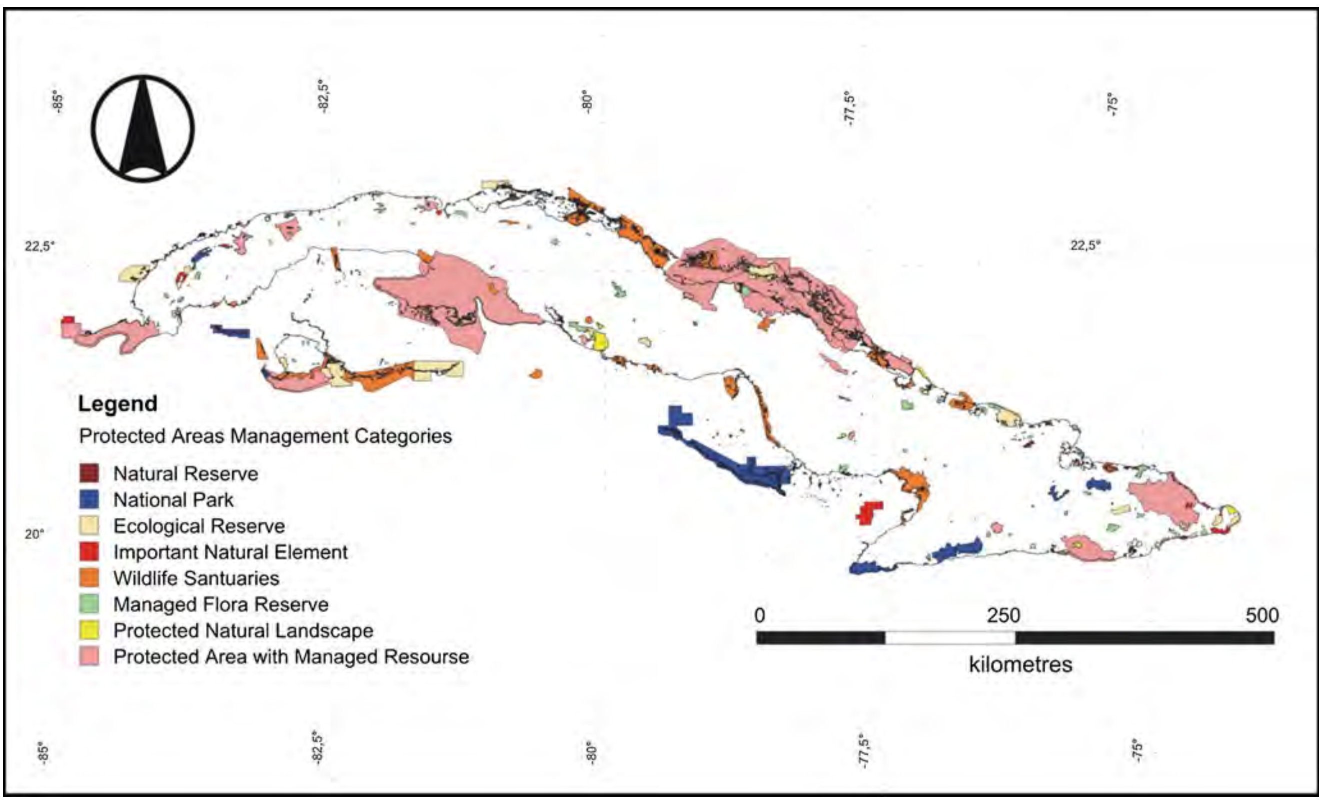

Fig. 1 Protected areas integrating the National System of Protected Areas (SNAP). The *different colours* are related with different management categories of protected areas

their biological values, but also for their geological peculiarities. Their geological wealth has not yet been studied in accordance with its intrinsic values, vulnerability and risk of degradation. Currently, three natural sites in Cuba are included in the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage List; two of them, Desembarco del Granma National Park and Alejandro de Humboldt National Park, for their natural values and the other, Viñales National Park, for its landscape value, which includes cultural aspects (way of life adapted to nature).

Among the natural values of Desembarco del Granma National Park, a system of emerged and submerged marine terraces stands out, identifying up to 20 different sea levels with well-developed karst features and recognised worldwide for their good state of preservation. On the other hand, the Alejandro de Humboldt National Park is considered the best-preserved mountain system of the Antilles, with reliefs showing karst shapes and systems in non-carbonated rocks ("pseudokarst"). The Viñales National Park is characterised by its spectacular karst mountain system, unique in the country.

The above examples, together with six Biosphere Reserves and the other protected areas, provide the ideal setting to implement geoconservation in Cuba under SNAP coordination.

Nationally Acknowledged Criteria for Geoconservation

There is currently no complete inventory of the geoconservation potential of each province. However, SNAP recommends a set of criteria for the inclusion of geoconservation in the management of protected areas.

According to Corvea et al. (2009a), these criteria include the integration of "the geoconservation dimension" within the planning process itself. This involves taking into account the peculiarities of the local geological heritage in each planning stage: diagnostic, normative, programmatic and cartographic.

Protected areas should include intrinsic natural values but also other extrinsic ones, such as spatial (areal) distribution, diversity of georesources, territorial connectivity, the representativity of protected areas, the diversity of management and protection categories, the current state of resource conservation and current knowledge about resources and the geodiversity index.

In Cuba, there are areas with high natural values that could be considered geoparks which meet the requirements set by UNESCO, such as zones with well-defined boundaries and sufficient area for local economic and cultural development, comprising a number of internationally important geosites or items of special scientific geological importance, rarity or beauty (UNESCO 2007). Moreover, most of them have specific management plans.

Previous Geoconservation Initiatives in Cuba

For many years, it has been a widespread practice worldwide to confer official protective status to a particular space, emphasising biodiversity values above all, "even though it is impossible to observe a plant or animal in its natural habitat by removing the substrate or geological environment in which it develops" (Corvea et al. 2006).

The first protected area in Cuba was created in 1930 and is now named Pico Cristal National Park, mainly due to the conservation of pine forests. During the 1970s, the bases for formation of the current SNAP were established following the guidelines for integrated planning and management defined by Kenton Miller (during his presidential period at the International Union for Conservation of Nature), which were still focused on the conservation of biological values (González and Castañeira 2006).

A first Cuban attempt at geoconservation was made in 1954 by Dr. Carlos Rodríguez Casals, concerning the proposal of the tourism project "International Geological Park Guaniguanico". This project was presented by the Ministry of Education and endorsed by the President of the Republic (El País 1954). The aim was "to develop the culture, promote a large proportion of national and international tourism flow and encourage research and expansion of all activities related with mining" (Rodríguez 1954). Although it was never implemented, it marked the first attempt to establish such an initiative in Cuba (Corvea et al. 2011).

Later, importance was given to arranging guided tours to sites of geological interest. A local example was the selection and description of Places of Didactic Interest (PID) in the Viñales National Park, following the methodology of Corvea et al. (2009b). This approach defined PID as "natural resources whose uniqueness, qualities or property provided, with a pedagogical approach, in situ knowledge of scientific and cultural values".

More recently, the potential for development of geoparks in western Cuba was assessed (Corvea et al. 2011). Knowledge of the heritage values and protection status of the Viñales National Park cave system was updated (Farfán-González et al. 2011). Together with other institutions, a project dedicated to the evaluation of Guaniguanico Range and the Guanahacabibes Peninsula and its potential as geopark was developed (López et al. 2007).

We would like to highlight the contributions made in recent years at the Commission for the Conservation of Geological Heritage of the Cuban Convention on Earth Sciences, where widespread diffusion of the geoconservation issue is evidenced through various initiatives around the territory, such as the geological heritage of the Pinar del Río province (Gutiérrez et al. 2009a), the geological heritage of Juventud Island (Gutiérrez et al. 2009b), the update on the conservation of the Geological Heritage in the Republic of Cuba (Serra and Pérez 2009) and a study related with the criteria of similarity between

points of geological interest for the conservation of natural heritage on the shelf island of Cuba (Gutiérrez et al. 2009c).

Administrative Bases Created for Geoconservation Practice

As stated in previous sections, geoconservation in Cuba is a fairly recent issue, even when the experiences in regulations or standards for the conservation of natural heritage indirectly include geological heritage. On the other hand, research projects, even when they follow a defined environmental policy, do not integrate what Gonggrijp (2000) considers an effective strategy and a sound legal framework; a clear and transparent procedure that leads from basic geological data to designation of protected and managed geological sites. Nevertheless, there are some initiatives that can be considered the administrative basis to ensure effective practice of geoconservation in Cuba:

– There is a SNAP, now reinforced with administrative and technical staff, which should be the basis on which geoconservation in Cuba is sustained. The SNAP has specialists in the fields of geology, geoconservation, protected areas management and other issues related with the environment.
– In the country administration, there is a new methodology for developing management and annual operational plans which facilitates the incorporation of geological heritage as conservation targets in protected areas.
– The creation of the National Commission for the Protection of Karst Ecosystems encouraged the integration of geological heritage conservation in the SNAP administrative programmes, given the wide representation of this type of substrate in the country (Fig. 2).
– There is an adequate state of conservation of the natural areas integrated in the SNAP, so those geological values that fall within these protected areas will have good prospects of future specific conservation.

The Guaniguanico Range and the Guanahacabibes Plain (Pinar del Río): First Geoconservation Experience in Protected Areas in Cuba

Study Area Description

The study area is located in western Cuba, covers a large fraction of the Pinar del Río Province and is divided into two geologically distinct zones: the Guaniguanico Range and the Guanahacabibes Peninsula (Fig. 3).

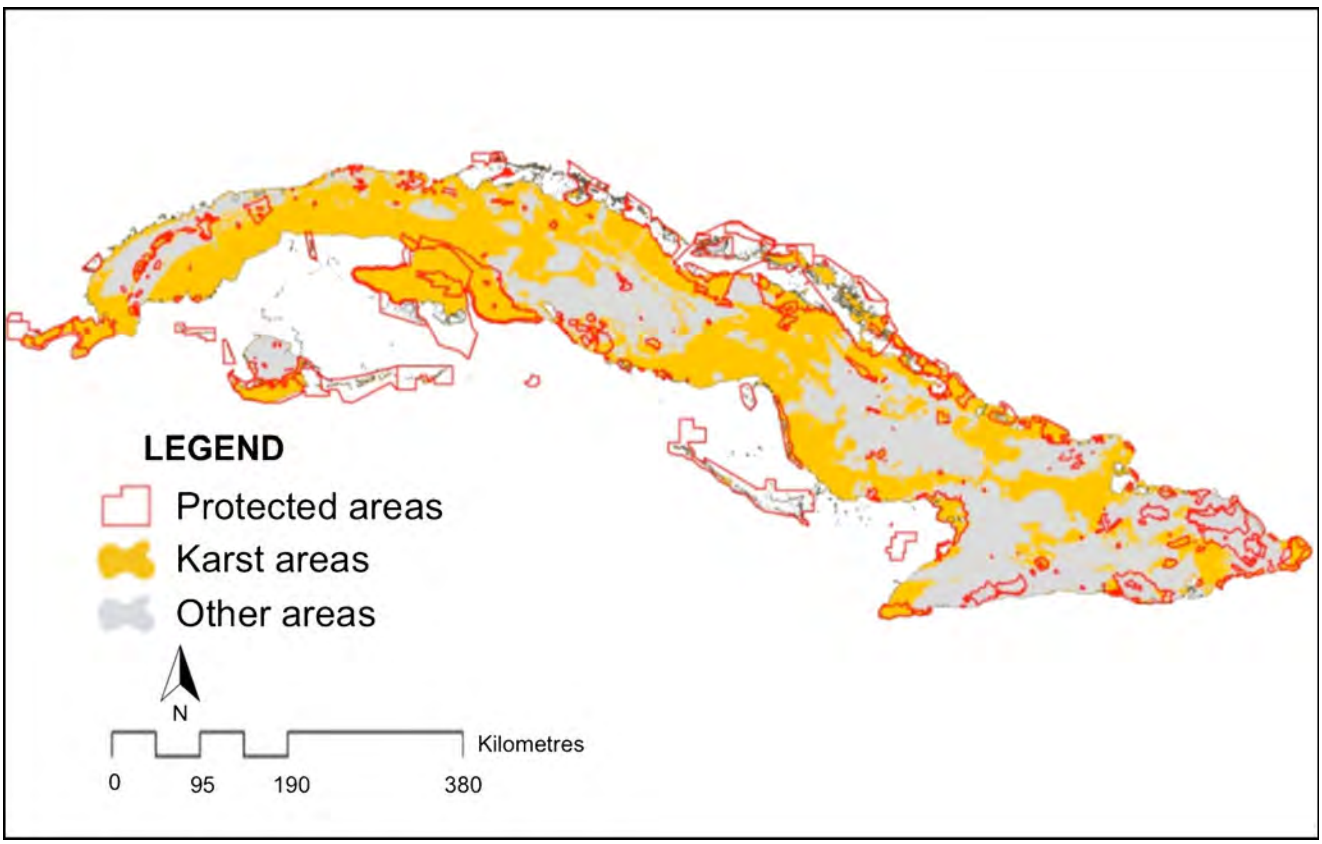

Fig. 2 Overlay of karst formations and protected areas in Cuba

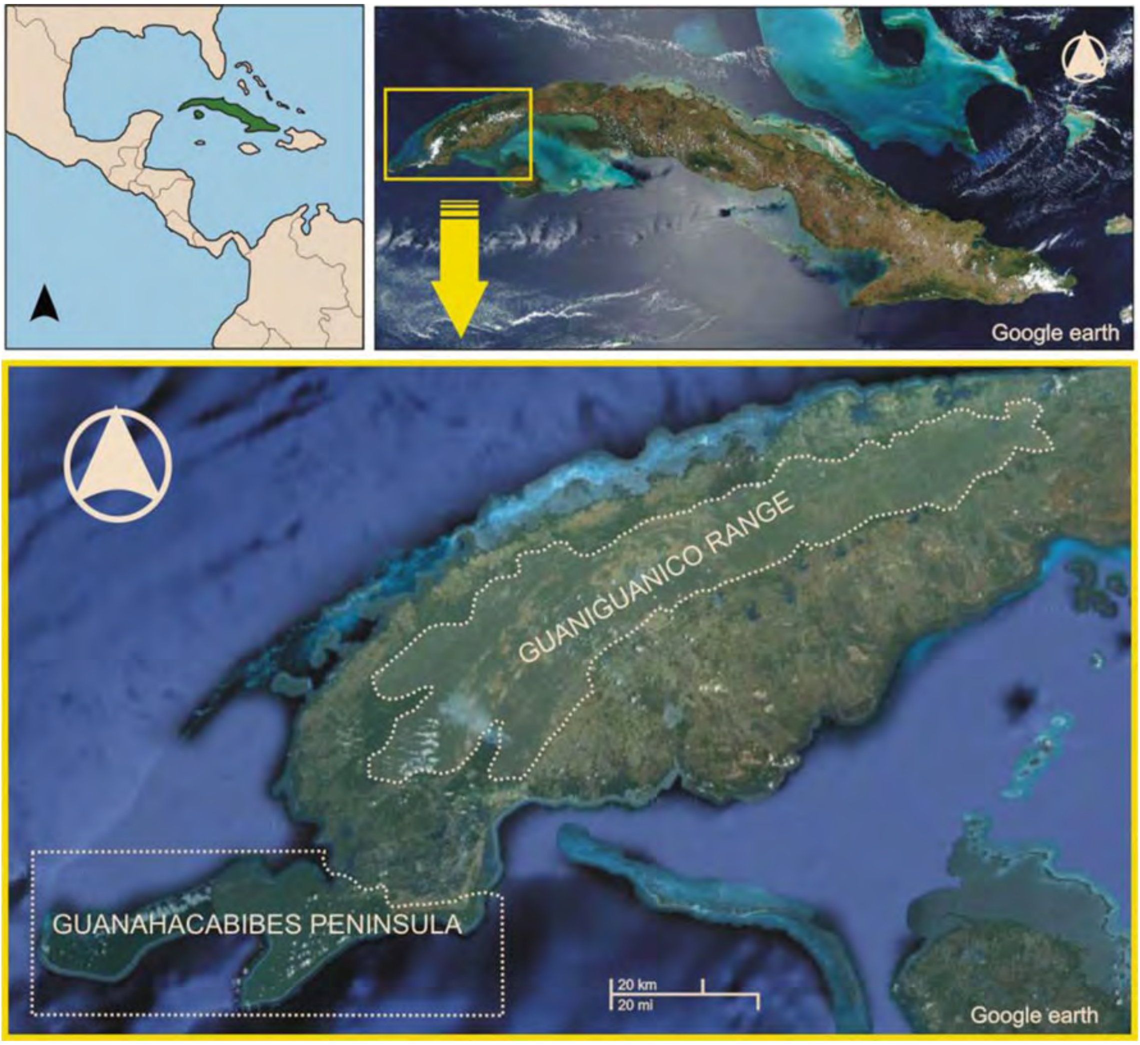

Fig. 3 Geographical setting of the study area: Guaniguanico Range and Guanahacabibes Peninsula Fuente: Google Earth

The Guaniguanico Range extends ENE to WSW along the Pinar del Río province, covering an area of 3,548 km^2 (32.3 % of the province surface) with two mountain chains: *Sierra del Rosario*, which covers 923.4 km^2 in the mid-western portion of the province and the larger *Sierra de los Órganos*, which covers 2,704 km^2 (Fig. 4). This mountain chain is characterised by a combination of mountains, pre-mountain hills, mogotes and valleys. It gives rise to 51 of the 54 rivers of the province and its highest peaks are Pan de Guajaibón (699 m), El Salón (560 m) and Cerro de Cabras (484 m).

Sierra del Rosario This is a key area for the study of Cuban geology (Cofiño and Caceres 2003) because of a wide variety of tectonic, magmatic and stratigraphical elements occur in a small area. The area is characterised by the presence of sediments from Middle and Upper Jurassic to Upper Paleocene–Lower Eocene that are deformed by complex tectonic events, especially in the area of the range (Cobiella et al. 2000). Morphologically, the area presents elevation with variable slope mountainsides and spiky peaks. Moreover, mogotes, caves and other karst formations are present (Fig. 5).

Sierra de los Órganos This includes three separate systems, the northern slates (*Pizarras del Norte*), the southern slates (*Pizarras del Sur*) and the mogote hill belt (*Faja de Mogotes*). Numerous river canyons cut through the mogotes' limestone walls, some of them hanging over 300 m high. Between the mogote hills, karst *poljes* with rich soils are found, as well as large cave systems, of which the National Monument Santo Tomás-Quemado extending for about 46 km is worth mentioning.

The mogote hill belt is bordered by complex folded slate elevations known as *Alturas de Pizarras*, which contain the oldest rocks in the study area (Early–Middle Jurassic to the base of Late Jurassic) dated by their fossil records of ferns, pollen and spores of ferns, conifers, cidaceas (Iturralde 1998) and ammonites of Oxfordian

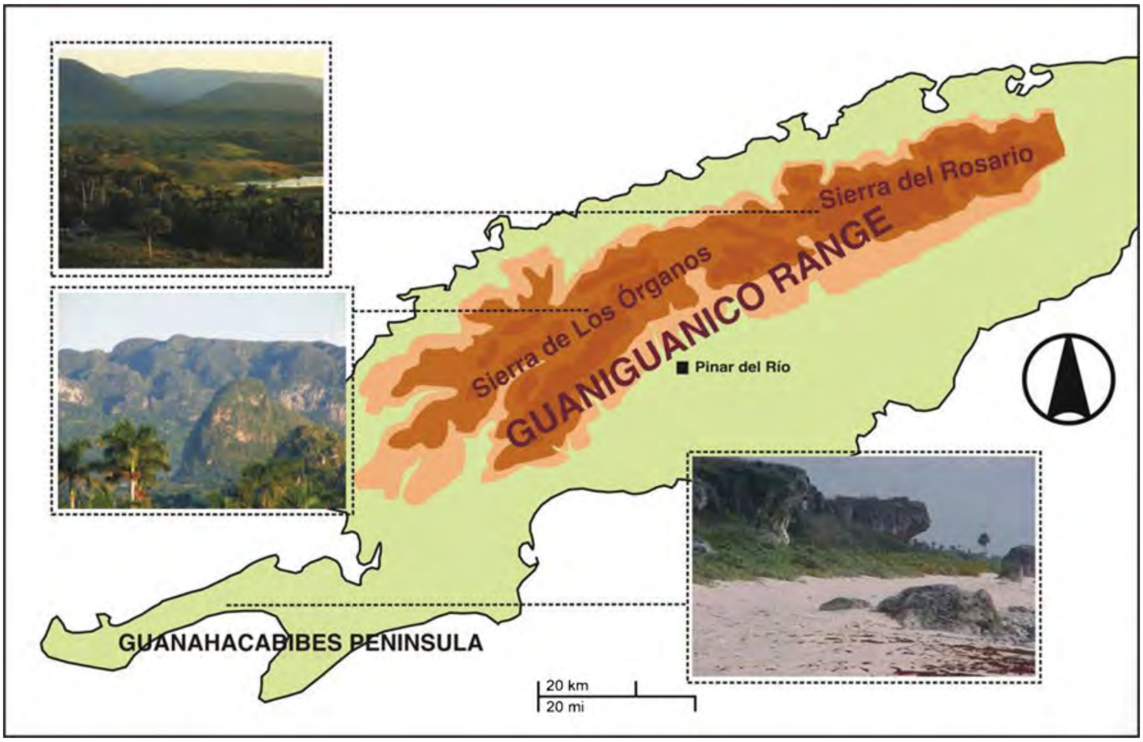

Fig. 4 Geographical location of Sierra del Rosario and Sierra de los Órganos in the Guaniguanico Range

limestones (Iturralde and Norell 1996). Towards the north, the hills are characterised by gentle slopes and rounded tops, while in the south the peaks are usually topped by harder metamorphic strata, which conform jagged peaks and steep slopes and rise higher than other formations usually reaching 400 m above sea level. Due to intense water erosion on friable materials, both slopes of the range are characterised by numerous thalwegs, gullies and valleys. These valleys include numerous poljes with flat bottoms and fertile soils originated in the contact between carbonate and metamorphic rocks. Among them, the picturesque *Valle de Viñales* previously referred to as a national park and a World Heritage site. The Viñales National Park is one of the best examples of tropical karst around the world, where multiple geological processes and phenomena are easy to observe and where many important paleontological and archaeological sites can also be found (Fig. 6).

The Guanahacabibes Peninsula is the westernmost part of the province of Pinar del Río, formed by the connection of San Antonio Cape and Corrientes peninsula by a coastal strip. This region is part of one of the most recent geological

Fig. 5 Elevations of gradually inclined slopes and sharp peaks (Sierra del Rosario)

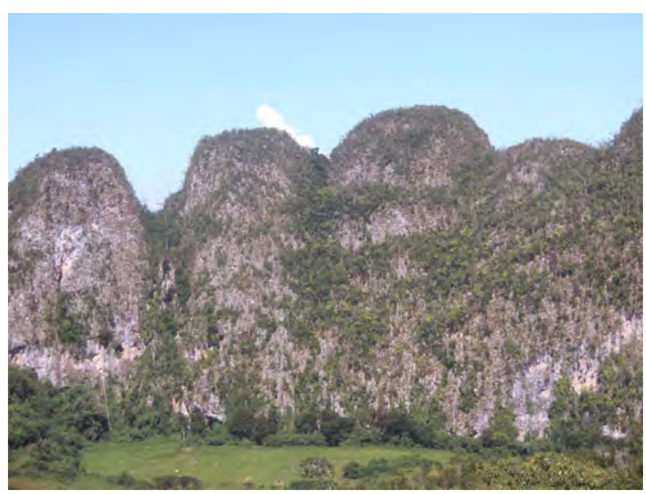

Fig. 6 Karst towers with cupular tops. Las Cuevitas Valley, Viñales National Park

Fig. 7 Coastal reef in the southern shore of the Guanahacabibes Peninsula showing several emerged coastal terraces. Guanahacabibes National Park

and geomorphological units in Cuba. There is a high prevalence of Pliocene and Quaternary carbonated rocks, in which relief modelling processes predominate, particularly karst cracks, voids, dissolution cavities, sinkholes and large deep karren, locally known as *dientes de perro*.

The peninsula is mainly constituted by a limestone substrate that is actively affected by karst geomorphological processes, which are strongly asymmetric as the peninsula is tilting northwards. This defines the presence of very different ecosystems: mangrove swamps in the north, and coastal reefs (Fig. 7) and beach deposits in the south.

Beach formation is the most dynamic among the active geomorphological processes, the local coastal landscape having changed notoriously in recent years. The dynamic modification of sand deposits is highly visible, especially with the formation of sand bars after storms, in which over 15 species of fossil corals can be found. On the other hand, the reefs that form the southern shore show numerous elements associated with sea erosion where terraces, overhangs and cave levels can be found. Towards the interior, sinkholes are a prominent feature, due to the dissolution and collapse of the limestone substrate. Sinkholes are frequently forming lagoons, which generate a particular environment within the main karst topology. In the north, the lowland is mainly flooded, forming swamps which connect to the sea by a system of estuaries and channels.

In the study area, there are plenty of spaces with different protection categories, both in mountainous areas and the coastal zone of the SNAP. The Guaniguanico Range is protected by two natural reserves, a national park, four ecological reserves, four natural highlight elements and two protected areas of managed resources. Two reserves stand

Table 1 Evaluation of the criteria set by the experts and distribution by simple addition

Code	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18	E 19	E 20	Mean	SD	Cov (%)	Total
SV	5	4	5	5	5	4	5	4	5	5	5	5	5	4	5	5	5	5	4	5	4.8	0.44	9.35	95
PE	5	5	4	4	5	4	5	5	5	4	5	5	4	5	5	4	5	5	5	4	4.7	0.49	10.52	93
R/A	5	5	4	5	5	5	4	5	5	4	4	5	5	4	4	5	4	5	4	5	4.6	0.50	10.93	92
CS	4	5	5	5	4	4	5	4	5	3	5	4	5	5	5	4	5	4	5	3	4.5	0.69	15.42	89
FR	5	2	3	5	5	4	4	5	3	4	5	5	5	5	5	4	4	5	4	3	4.3	0.91	21.42	85
LI	5	4	4	5	4	3	4	4	3	5	2	5	4	5	4	5	4	5	4	4	4.2	0.81	19.58	83
CI	4	4	4	5	4	5	3	2	4	3	4	3	5	4	4	2	5	3	4	4	3.8	0.89	23.54	76
RI	3	3	4	4	2	3	4	1	3	2	4	5	3	4	4	5	4	3	3	4	3.4	0.99	29.26	68
EI	4	4	3	2	4	2	3	3	4	5	4	3	2	3	1	3	4	5	4	3	3.3	1.03	31.25	66
NA	2	5	4	2	3	2	3	3	4	5	2	3	4	2	4	3	2	3	3	4	3.2	0.99	31.37	63
OB	2	3	3	4	4	3	2	4	3	5	2	4	3	5	2	1	2	3	4	3	3.1	1.07	34.55	62
EE	2	3	3	4	3	3	2	2	3	4	3	3	2	2	4	4	4	3	2	5	3.1	0.89	29.08	61
EI	4	2	2	2	2	4	3	3	3	2	3	5	3	2	3	3	4	4	3	3	3.0	0.86	28.61	60
VE	3	2	4	4	3	2	3	1	2	3	3	4	3	3	2	5	2	1	2	4	2.8	1.06	37.73	56
PA	3	4	1	4	3	3	1	4	1	5	3	2	4	1	2	2	3	1	1	4	2.6	1.31	50.53	52
SZ	4	3	2	3	1	2	2	3	1	3	2	3	4	2	2	2	4	2	3	2	2.5	0.89	35.54	50
DK	2	2	3	4	3	3	2	1	1	4	3	1	2	3	3	4	3	1	2	1	2.4	1.05	43.60	48
PH	2	4	3	3	2	3	3	2	4	3	2	2	1	3	3	2	1	1	1	2	2.4	0.93	39.71	47
AC	2	1	2	1	3	2	4	3	3	2	1	3	3	2	3	1	1	3	2	5	2.4	1.09	46.36	47
OP	3	4	1	3	2	3	1	1	2	4	3	1	3	3	2	1	1	1	2	3	2.2	1.06	48.01	40

SV scientific value, *PE* processes example, *R/A* rarity/abundance, *CS* conservation status, *FR* fragility, *LI* landscape interest, *CI* cultural interest, *RI* recreational interest, *EI* educational interest, *NA* naturality, *OB* conditions for the observation, *EE* environmental education services, *EI* economic importance, *VE* variety of elements, *PA* natural protected area, *SZ* size, *DK* degree of knowledge, *PH* process–human interaction, *AC* accessibility, *OP* interaction with other processes, *E* interviewed expert (Nr. 20), *SD* standard deviation, *CV* covariance

out from the rest due to their importance and significance: the Sierra del Rosario Biosphere Reserve and the Viñales National Park. Most of the Guanahacabibes peninsula area was declared Biosphere Reserve in 1986. Additionally, in 2001, the homonymous national park was created to protect the coastal and marine ecosystems.

Methods

Based on the methodology developed by Bruschi (2007) for the characterisation, evaluation and management of the geodiversity resources, the first Cuban experience in an area of natural uniqueness is carried out. Execution of the work involved aerial photos at 1:36,500 scale from the 1971 K-10 project, topographic maps at 1:25,000 and 1:50,000 scales, a 1:50,000 geological map from the Cuban Institute of Geology and Palaeontology, a 1:25,000 soil map from the Ministry of Agriculture and the digital terrain model (10 m; GEOCUBA). Satellite images from LANDSAT ETM+sensor (19 Dec 2000) covering the whole area and the software ILWIS v. 3.6. were also used. The compiled information will be integrated into a GIS with the map database.

To evaluate the geological features of the study area, two workshops were held; the first focused on the unification and assessment of criteria used in the identification and selection of geosites. The second was dedicated to the inventory and valuation of the geosites within the study area. These workshops were carried out by a group of 20 experts selected for the purpose.

The first workshop was intended to reach a consensus for geosite evaluation, where the 20 experts interviewed had to quantify the importance of the 20 criteria selected for the identification and assessment of geosites (these criteria are: scientific value, processes example, rarity/abundance, conservation status, fragility, landscape interest, cultural interest, recreational interest, educational interest, naturality, conditions for observation, environmental educational services, economic importance, variety of elements, natural protected area, size, degree of knowledge, process–human interaction, accessibility and interaction with other processes). To quantify these criteria, a semi-quantitative assessment was carried out, using a score of five levels of "quality". After this first contact, attempts were made to find out whether it is possible to evaluate geosites using a lower number of criteria, to facilitate the inventory during the field work. To this end, a statistical treatment was performed by extracting the principal components of the results obtained by the group of experts in the first part of the process. After the selection, the weights were recalculated for each variable that appears in the evaluation's database template.

The second part of the study, after the criteria selection phase, was based on identifying, describing and assessing those areas with enough geological values to be considered geosites. This inventory was conducted by the same group of experts from the first part of the project, but this time they had to evaluate the different geosites of the study area to make up an initial list of these sites within the eight locations chosen for the project, after which the lists were shortened by evaluating concepts such as proximity, similarity and representativeness. After drawing up the final list of geosites, the outcomes of the direct assessment by the experts were compared using a parametric assessment method applying the "quality model" defined by Bruschi and Cendrero (2005):

$$V_G = \sum_{i=1}^{n} c_i \cdot w_i \qquad (1)$$

where, V_G=value of the geosite, c_i=criterion score of the geosite, w_i=criterion weight ($\Sigma\ w_i$=1) and n=number of criteria.

To evaluate the comparison between direct and parametric methods, the Pearson correlation coefficient was calculated, which will reveal whether the results from both methods are similar. If the value is close to 1, it means that the two methods are very similar and may therefore be used indistinctly.

Table 2 Principal components extraction

Component	Eigenvalor	Percent of variance	Percent accumulated
1	3.40944	17.047	17.047
2	2.96943	14.847	31.894
3	2.67328	13.366	45.261
4	2.33938	11.697	56.958
5	1.6436	8.218	65.176
6	1.35179	6.759	71.935
7	1.08032	5.402	77.336
8	0.965504	4.828	82.164
9	0.770231	3.851	86.015
10	0.681559	3.408	89.423
11	0.605523	3.028	92.450
12	0.516577	2.583	95.033
13	0.326458	1.632	96.665
14	0.282465	1.412	98.078
15	0.235987	1.180	99.258
16	0.104404	0.522	99.780
17	0.0321079	0.161	99.940
18	0.0118854	0.059	100.00
19	0.0000557468	0.000	100.00
20	1.96955E-16	0.000	100.00

Table 3 New set of seven criteria derived from statistical analysis and their weights

Criteria	ID	Mean	Sum	Weigh
Scientific value	SV	4.8	95	0.15
Processes example	PE	4.7	93	0.15
Rarity/abundance	R/A	4.6	92	0.15
Conservation status	CS	4.5	89	0.14
Fragility	FR	4.3	85	0.14
Landscape interest	LI	4.2	83	0.13
Cultural interest	CI	3.8	79	0.13

Results

As indicated above, the work plan was divided into two parts. In the first part, the criteria set selected for geosite identification and evaluation were evaluated. The semi-quantitative assessment by experts used a score of 1–5 (very low–very high). As a result of this evaluation, a table was obtained showing all the expert assessments performed for each of the criteria (Table 1). The list was drawn up in order of importance by simple sum, as shown in Table 1.

For the final selection criteria, the experts performed a principal component analysis of the valuations of the set of criteria. According to the outcomes shown in Table 2, the statistical analysis showed how seven of the criteria explain 77 % of the total variance.

Thus, the final list of criteria used to assess the locations selected for the study is shown in Table 3. The weights were recalculated taking into account only the final seven selected parameters.

Below are the results obtained for each selected location of the study area (Fig. 8). In each location, the number of geosites present was obtained, along with a description of the main geological features of each site.

Sierra del Rosario The area is made up of different geological formations, composed of limestone, sandstone and schist. The terrain is rugged with low mountains and hills, with slopes predominantly tectonic, which is the subject of study for geosciences scholars (Fig. 9). We identified a total of 16 geosites, a relatively small result in such an extensive location. The impressive landforms tend to be homogeneous, limiting the diversity of phenomena and processes and thus geodiversity.

Guajaibón-Sierra Azul This area stands as the highest elevation in Western Cuba, with more than 690 m (Fig. 10). It is mainly composed of limestones, flintstones, schists and conglomerates, as well as bauxite horizons, which emphasise its uniqueness. The high contrast of the relief is highlighted, where the vertical dissection values reach more than 550 m, with scenic and aesthetic views. However, it is assigned a limited number of geological sites, according to its values and areal extent—only nine—which may be associated with ignorance due to the inaccessibility.

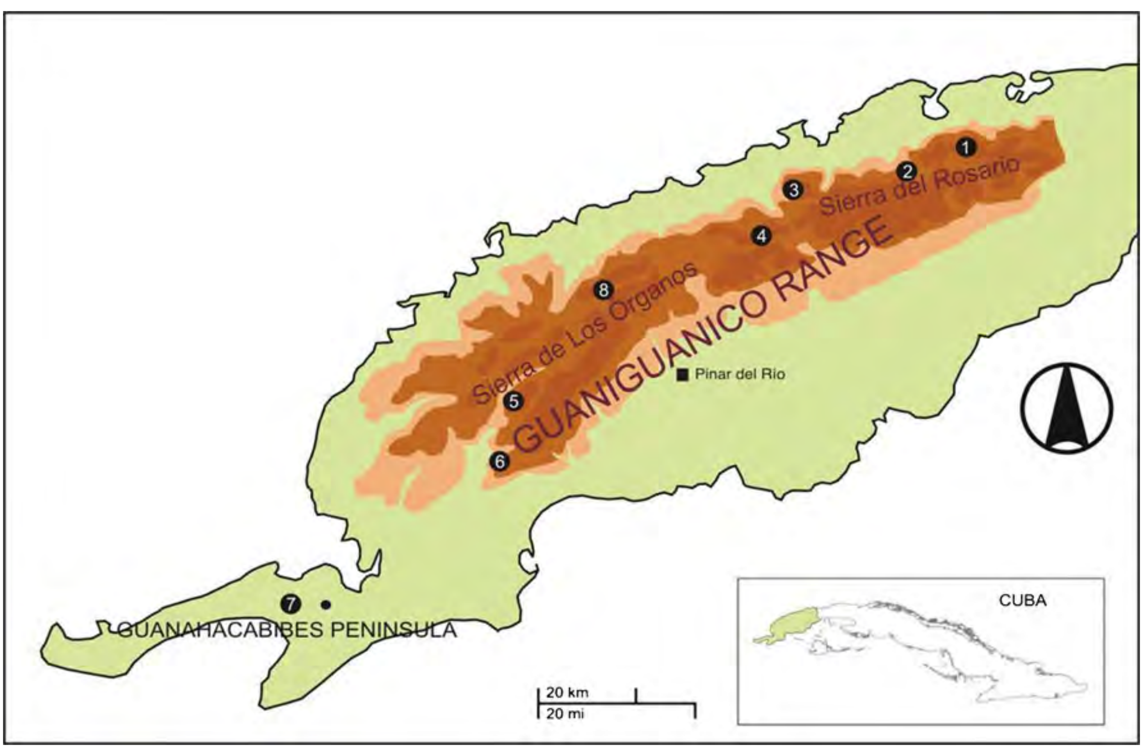

Fig. 8 Location of studied areas; *1* Sierra del Rosario, *2* Guajaibón-Sierra Azul, *3* Cajálbana, *4* San Andrés, *5* San Carlos, *6* Punta de la Sierra, *7* Guanahacabibes, *8* Viñales

Fig. 9 Santa Cruz River's Canyon (Sierra del Rosario). Geosite with evidence of intense tectonic processes

Cajálbana This is a plateau with south-bearing steep slopes, consisting of serpentinised ultrabasic rocks from the hyperbasitic belt of Cuba. The presence of the relief-forming processes, weathering on the rocks and the erosion on a red ferritic soil is interesting, as visible evidence of the migration–accumulation processes of iron (Fig. 11). Only three geological sites are identified in this location, which is a very low number given its surface area.

San Andrés For this location, four geosites were identified with paleontological, hydrogeological and tectonic interest (Fig. 12). A joint collaboration of specialists from the Centre for Research and Environmental Services ECOVIDA, the Institute of Geology and Paleontology and Geology Faculty of the University of Pinar del Río is planned to further scientific studies and the protection mechanisms of one the most fossiliferous areas of Cuba.

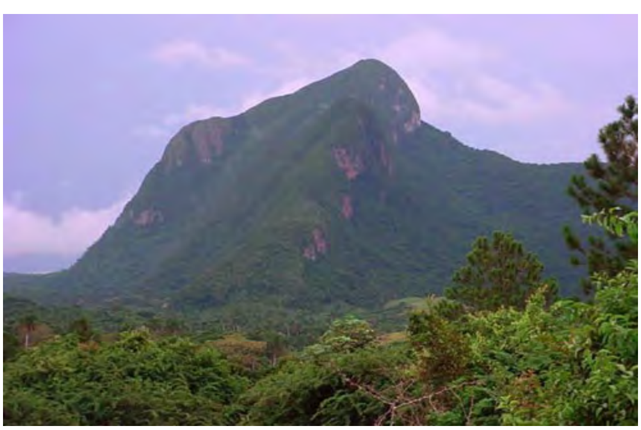

Fig. 10 Pan de Guajaibón, the highest elevation point of the Guaniguanico Range

Fig. 11 Typical erosion processes on the slopes of Cajálbana plateau

San Carlos The area exhibits a combination of forms contrasting karst mountain valleys and the slate elevations of San Cayetano—of extraordinary visual landscape value—with a system of caves of great value to science and adventure tourism (Fig. 13), despite having only three geological sites identified as heritage sites.

Punta de la Sierra In this area, only two geological sites of heritage interest are identified, so this location can be defined with very low value as an exponent of geodiversity (Fig. 14).

Guanahacabibes This karstic plain is an example of more recent geological and geomorphological development, with extensive presence of Pliocene and Quaternary carbonate rocks, which have been shaped by topographic formation processes, especially karstic type (Fig. 15). Carbonated materials from a reef environment are the core elements of the Peninsular land surface and the rocks of higher areal distribution. The alluvial continental terrigenous rise to the east of the location and the coral reef biodetritic limestones from

Fig. 12 Los Portales Cave, karstic galleries with hydrogeological interest and special historical significance. In this cave, the Che command during the Missile Crisis was settled

Fig. 13 System Majagua-Canteras, it extends along San Carlos mountain chain with six levels of galleries and it has a length of more than 35 km. Picture by Juan Carlos Ocaña

Fig. 15 Rounded pool: karst pond, *casimba* o *cenote*, excavated in the first level of emerge marine terrace in Guanahacabibes Peninsula

Superior–Middle Pleistocene Age overlies the core occupying the first marine terrace.

Limited lithological variability and infrequent slope changes, with relative heights between 0 and 6 m, make this location an exclusive place for contemplative and scientific tourism. This limited variability is a disadvantage when assessing the geodiversity compared to the rest of the territory of the province, due to its low coefficient of roughness. It also presented a number of geological sites (48), which were reduced to 18 by the repetition phenomena, with wide prevalence of formation of beaches and karst caves that harbour archaeological sites.

Viñales This area accumulates the majority of geological sites for geodiversity of all the localities studied—a total of 189. Coincidentally, many of these are located in the current perimeter of the National Park and its immediate surroundings; these places were reduced to 107 through successive filters by the team of experts (Fig. 16).

We verified the status of each geosite and compiled a database containing the main characters. Rock samples were obtained from each locality for inclusion in the Mario Sanchez Roig Geological Museum, Institute of Geology and Palaeontology of La Habana.

In the course of the work, it was necessary to consider geomorphological and biostratigraphic interest locations as well as other sites of paleontological importance for Quaternary wildlife, with unknown speleothems in other locations, such as the GEDA and Cumpleaños caves.

Finally, the results have been emphasised in the town of Viñales, since it contains the highest number of geosites and the most diverse. Table 4 shows the values of the 107 geosites identified in Viñales, obtained by applying the formula of

Fig. 14 This village takes its name from the karstic elevations which form the western boundary of the Sierra de los Órganos. Those elevations contact with the isthmic area that separate the mountain chain and the Guanahacabibes block

Fig. 16 Fossil site in the GEDA Cave, with great interest for its good conservation condition. Viñales National Park

Table 4 Geosites values obtained by applying the formula of Bruschi and Cendrero (2005) for the Viñales location

Criteria Geosite	CI (0.15)	EP (0.15)	R/A (0.15)	SP (0.14)	FR (0.14)	EI (0.13)	CI (0.13)	VG
El Puente de Río Pan de Azúcar	5	5	5	5	3	5	5	4.67
Puente Natural de Sierra Derrumbada	4	5	5	5	4	5	5	4.61
Salto de Ancón (Travertinos)	4	5	5	5	3	5	5	4.46
Cueva el Cumpleaños	5	5	4	4	4	5	5	4.41
Los Chorerones	4	5	5	4	2	5	5	4.29
Puerta de Ancón	4	5	5	5	1	5	5	4.28
Boquerón del Infierno	4	5	5	5	1	5	5	4.28
Pliegue Hoyo de los Insurrectos	5	5	5	5	1	4	5	4.26
Mogote Sacaría	5	5	5	4	2	5	5	4.33
El potrero de Machín (Manacas)	5	5	5	5	3	4	4	4.41
Cueva de Santo Tomás	5	5	4	2	4	5	5	4.24
Cueva GEDA	5	4	5	2	3	5	5	4.10
Surgencia del Itabo	5	5	4	4	3	4	5	4.15
El Abra	4	5	5	5	2	4	5	4.15
Paredón extraplomado	4	5	4	5	3	4	5	4.12
Mogote El Guachinango	4	5	5	5	3	4	4	4.19
Termas de San Vicente	5	4	5	2	5	3	5	4.06
Mogote El Santero	5	5	5	5	1	4	4	4.16
Mogote de Pan de Azúcar	4	4	5	5	2	4	5	4.04
Surgencias Kársticas de Laguna de Piedra	4	5	5	5	2	5	3	4.12
Mirador de los Acuáticos (W)	5	5	4	2	3	3	5	3.84
Holoest. Mb. Tumbadero. Fm. Guasasa	5	5	5	5	1	5	3	4.13
Holoest. Mb San Vicente. Fm Guasasa	5	5	5	5	1	5	3	4.13
Holoest. Mb Pan de Azúcar. Fm Jagua	5	5	5	5	1	5	3	4.13
Cárcava de Rolo	5	5	5	5	1	5	3	4.13
Boca del Río San Vicente	4	4	3	4	4	4	5	3.80
Valle Ciego Palmarito	4	4	3	4	3	4	5	3.79
Sistema Constantino	5	4	4	2	4	4	4	3.83
Mirador de los Jazmines (S)	5	5	3	2	2	4	5	3.68
La Penitencia	5	5	4	4	1	4	4	3.84
Afloramiento KT	5	5	5	5	1	5	3	4.07
Holoest. Mb Zacarías. Fm. Jagua. Mogote	5	5	5	5	1	5	3	4.07
Holoest. Mb. Jagua Vieja. Fm. Jagua.	5	5	5	5	1	5	3	4.07
Holoest. Mb. Infierno. Fm. Guasasa	5	5	5	5	1	5	3	4.07
Cueva el Palmarito	5	5	5	1	5	5	3	4.07
Valle de surgencia La Caoba	5	5	5	4	1	4	4	3.88
Manantiales del Novillo	4	4	5	3	4	4	4	3.83
Contacto Juagua-Guasasa	5	4	4	3	2	4	5	3.68
Ventana tectónica Polja San Vicente	4	4	5	4	1	4	4	3.69
Mirador El Calvario (S)	5	3	3	3	3	4	5	3.60
Yeso secundario (La Caoba)	5	4	5	4	3	5	2	3.99
Manantiales Laguna de Piedra	5	4	5	3	5	4	2	4.00
Holoest. Fm. Ancón	5	5	5	5	1	5	2	4.00
Camino cañadones	5	4	3	5	2	4	4	3.76
Puerta de Ancón	5	5	4	4	3	4	3	3.93
Valle de surgencia Ancón	5	5	3	4	2	3	4	3.65
Valle Ciego Santo Tomás	4	4	3	4	3	4	4	3.66
Arenas Cuarcíticas Ceja de Luna	4	5	5	2	4	5	2	3.87

Table 4 (continued)

Criteria Geosite	CI (0.15)	EP (0.15)	R/A (0.15)	SP (0.14)	FR (0.14)	EI (0.13)	CI (0.13)	VG
Mirador Loma la Ermita (SE)	5	5	2	2	2	4	5	3.47
Holoest. Fm. Pons	5	5	5	4	1	5	2	3.86
Abra del Grillo	4	5	3	4	1	3	5	3.48
Loma Blanca (Cuarcitas)	4	5	4	4	3	3	3	3.71
Hoyo del Ruiseñor	4	4	3	3	1	4	5	3.35
Plegamiento Puerta Ancón	3	5	4	4	3	4	3	3.63
Mirador el Silencio	5	4	2	2	3	4	4	3.39
Límite Cretácico–Jurásico	5	5	3	4	1	5	3	3.63
Lacuno–palustre el Cuajaní	5	4	5	1	4	4	3	3.60
Scalops de San Vicente	5	4	3	4	1	3	4	3.35
Plegamiento Robustiano	4	5	4	4	1	4	3	3.50
Pedernales Maravillas de Viñales	5	4	2	4	3	4	3	3.48
Mirador Valella (S)	5	3	3	3	3	4	3	3.40
Corte entronque Viñales–Ancón	5	5	5	3	1	5	2	3.66
Corte carretera. Localidad de El Peligro	5	5	5	3	1	5	2	3.66
Cuenca endorreica los Cañadones	5	4	5	3	1	3	3	3.40
Hoyo del Grillo	4	3	2	2	2	4	5	3.07
Valle de Surgencia las Vueltas	3	4	4	3	3	4	3	3.34
Mirador Rastra Rompía (E)	5	2	2	2	3	4	4	3.09
Corte de suelo Ferralítico	5	4	3	4	2	4	2	3.42
U. Metamórfica de las Pizarras del Centro	4	3	3	4	3	2	4	3.17
Mirador del Fortín (W)	5	2	2	2	3	3	4	2.96
Corte del suelo PcC	5	4	2	4	2	4	2	3.27
Hoyo de los Cimarrones	4	3	4	2	2	3	4	3.03
Camino de los Cimarrones	4	3	4	4	1	2	4	3.04
Abra de Jaruco	4	4	3	3	2	3	3	3.08
Hoyo de Jaruco	3	3	3	3	2	4	3	3.01
Cueva el Cable	4	4	2	1	2	3	4	2.88
Cueva el Ocho	5	3	2	1	2	3	4	2.83
Ventana tectónica Pons	5	3	4	3	1	3	2	3.01
La Cantera de la Costanera	3	3	2	3	1	3	4	2.67
Cueva el Panal	5	3	3	2	3	3	2	3.00
Falla del Guachinango	5	2	2	2	2	3	4	2.68
Cañón de los Cimarrones	4	2	2	3	2	3	3	2.72
Valle Ciego la Jutía	3	4	3	2	4	2	2	2.86
Laguna de Piedra	4	3	5	1	2	2	3	2.81
Cueva El Indio	5	3	2	1	2	2	4	2.60
XV Aniversario	5	3	2	1	3	3	2	2.71
Cuenca endorreica El Sitio	4	4	4	2	1	2	2	2.74
Manantial la Pimienta	5	3	5	1	2	2	1	2.76
Loma del Fortín	3	1	1	3	1	3	4	2.22
Hoyo de Los Tres Golpes	4	2	1	2	2	3	3	2.39
Cueva de Mesa	4	4	2	1	2	3	2	2.57
Hoyo de Fanía	4	2	3	2	2	2	3	2.43
Cueva UJC	3	3	1	2	3	3	2	2.40
Dolinas del Jíbaro	3	2	2	2	1	2	3	2.11
Cuevas al Pié	4	2	2	1	2	1	3	2.13
Cueva Torcuato	4	3	1	1	1	1	3	2.05

Table 4 (continued)

Criteria Geosite	CI (0.15)	EP (0.15)	R/A (0.15)	SP (0.14)	FR (0.14)	EI (0.13)	CI (0.13)	VG
Dolinas del Gallego	3	2	2	2	1	2	3	2.06
Dolinas de Castellano	3	2	2	2	1	2	3	2.06
Hoyo de la Fruta	3	2	2	2	1	2	2	1.99
El Palenque	5	1	1	1	1	1	3	1.80
Cueva Arroyo el Jovero	5	2	1	1	2	2	1	2.01
Sumidero los Cerritos	5	2	1	1	2	1	1	1.88
Manantial Dos Palmas	5	1	1	1	2	2	1	1.86
Fogón de los Negros	3	2	2	1	2	2	1	1.86
Cueva de la Iguana	5	2	1	1	2	1	1	1.88
Cueva Grande Pan de Azúcar	5	2	1	1	2	1	1	1.88
Cueva del Cura	3	2	3	1	2	1	1	1.88

Holoest. holostratotype, *Mb.* member, *Fm.* formation, *U.* unity

Cendrero and Bruschi (2005). The values obtained for each criterion were recalculated, drawing an average between all the values given by each of the 20 experts. The values in which there was any conflict (e.g. 4.5) were rounded up, to operate with integers.

Furthermore, the valuation of the geosites located in Viñales was compared by the experts using direct sum with the value obtained using the formula by Bruschi and Cendrero (2005), which also uses the same evaluation panel of experts. The Pearson correlation coefficient obtained is very close to 1 (R=0.996), which implies that both evaluations provide virtually the same outcomes. These evaluations could therefore be used indistinctly (Fig. 17).

This tool greatly facilitates decision making for planning activities related to geoconservation and geotourism. Together with other maps, it can identify threats, vulnerabilities and other parameters that allow an integrated management of the space.

Conclusions

Although some progress was observed in geoconservation practices in Cuba, from the technical point of view there remains a bias in the assessment of sites of geological interest, prioritising stratigraphic and lithological features. On the

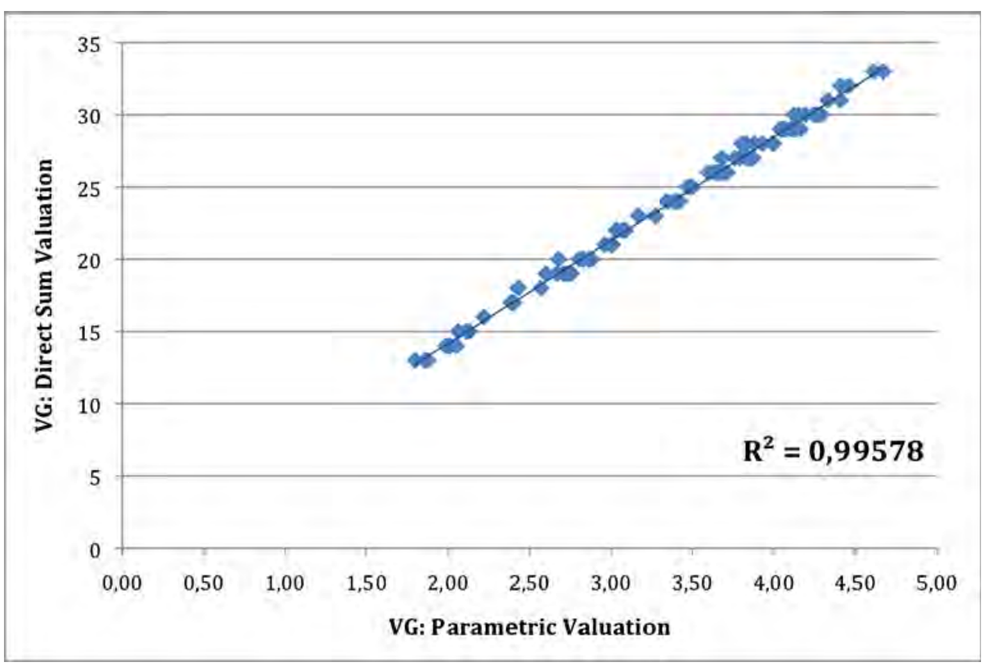

Fig. 17 Correlation between direct sum valuation and valuation using the formula by Bruschi and Cendrero (2005)

other hand, it was not possible to apply a consistent methodology throughout the territory to allow the inventory and comprehensive assessment of geosites.

From the administrative point of view, there are databases created although a National Commission on Geological Heritage is lacking and at the same time a specific legal framework to ensure geoconservation as a key practice in the sustainable management of resources.

It is necessary to "mainstream geoconservation" in the curriculum of related studies and in educational programmes, both in high school and college, including graduate and undergraduate programmes. Geoconservation should also be introduced, as a priority, in the training programmes developed by the SNAP.

Cuba has a high natural and technical potential for the creation of a National Geoparks Network attached to the National System of Protected Areas, which could be integrated into a future Latin American and Caribbean Network while part of the Worldwide Net.

The results obtained in the presented case study are from the first Cuban experience in geodiversity assessment. The methodology has identified at an early stage 274 geological sites in the Guaniguanico Range and in the Guanahacabibes Plain, distributed in eight localities of geological interest, defined by consensus of the experts consulted. However, the authors consider that there are unexplored potentials of high intrinsic value, since it is very likely that the high visibility of singular elements is low or null due to vegetation coverage and density.

Among the studied locations, Viñales contains 107 geosites rated by the experts, most of which are located within the park's current perimeter. The spatial distribution of the components and the uniqueness of its geodiversity, along with a cultural identity deeply linked to nature and to the existence of a tourist infrastructure, represent the exclusive attributes of Viñales National Park and its surroundings, allowing the combination of a wide range of activities compatible with geoconservation as a precondition for its integration into the World Network of Geoparks.

The geosite evaluation analysis allowed two conclusions. The first is that it is possible to use a smaller number of criteria for this assessment of the characteristics of geosites without significant loss in the evaluation quality. The second incides in the high level of correlation between the direct sum valuation and the use of an equation that takes into account the specific weights of each criterion, which means that either can therefore be used without errors.

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