Geotouristic potential of waterfalls in igneous and metamorphic rocks: the case of the municipality of bonito, Pernambuco, northeast Brazil

O potencial geoturístico de cachoeiras em rochas ígneas e metamórficas: o caso do município de Bonito, Pernambuco, nordeste do Brasil

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Abstract
The municipality of Bonito, located in the State of Pernambuco, northeast Brazil, has as its main touristic attraction several waterfalls embedded by a geodiversity characterized by igneous and metamorphic rocks. However, the tourism activity implemented in the area, does not use its full potential. The geologic information is not associated with geomorphologic features (waterfalls) and used to improve the knowledge and environmental education. This work has the goal to fulfill this gap with the implementation of tourism with geologic base. The main emphasis will be the educational and scientific values of these waterfalls hosted in igneous and metamorphic rocks. To accomplish this objective it is presented here a diagnosis of some waterfalls of Bonito. Geologic and geomorphologic analyses are associated with qualification and quantification of controlling parameters, followed by discussion of the main threads to geodiversity. A new method for quantification of geossites is presentend. This method was constructed based on that proposed by Brilha (2005). It attempts to give more reasonable mathematic meaning for the parameters analyzed; presenting graphics that will facilitate the interpretation of the values obtained by the quantification of geosites.

Keywords: Geotourism, Quantification, Geodiversity, Waterfalls, Bonito

Resumo
O município de Bonito, localizado no Estado de Pernambuco, Nordeste do Brasil, tem como sua principal atração turística várias cachoeiras possuindo uma geodiversidade caracterizada por rochas ígneas e metamórficas. Todavia, a atividade turística implementada na área, não usa todo o seu potencial. A informação geológica não está associado às características geomorfológicas (cachoeiras) e não é utilizada para melhorar o conhecimento e educação ambiental. Este trabalho tem o objetivo de cumprir esta lacuna com a implementação do turismo com a base geológica. A ênfase principal será os valores educativos e científicos destas cachoeiras instaladas em rochas ígneas e metamórficas. Para alcançar este objetivo é apresentado aqui um diagnóstico de algumas cachoeiras de Bonito. Análises geológicas e geomorfológicas estão associados a qualificação e

quantificação dos parâmetros de controle, seguido de discussão dos principais tópicos da geodiversidade. Um novo método para quantificação de geossites é apresentado. Este método foi construído com base na proposto Brilha (2005). Ele tenta dar um significado matemático mais razoável para os parâmetros analisados; apresentando gráficos que irão facilitar a interpretação dos valores obtidos pela quantificação dos geossítios.

Palavras-chave: Geoturismo, Quantificação, Geodiversidade, Cachoeira, Bonito.

1. INTRODUCTION

The municipality of Bonito, in the State of Pernambuco, northeast Brazil, has a geodiversity characterized by geomorphological features (valleys, waterfalls, hills and outcrops of fresh rocks) controlled predominately by geological structures of igneous and metamorphic rocks. Geological structures such as faults, lithologic contacts, intrusion of pegmatitic diques and shear zones, reveals its igneous, metamorphic and tectonic history. In the region of Bonito there are over 10 waterfalls with variable heights. The most well-known is named "*Véu da Noiva*", with 33 m of waterfall. Touristic exploration of the waterfalls is already in course in some of these geosites. Generally, basic services are offered (food, rental of rappel equipment) and an entrance fee is charged to visitation and baths in the waterfalls.

The aim of this work is to supply visitors and local inhabitants with geologic/geomorphologic information related to the waterfalls. It is believed that the correct knowledge about the formation of these interesting features will help their conservation and improve the respect for the natural heritage of the area.

In this work it is presented and discussed eight potencial geosites. For each one of these geosites, field and laboratory work was conducted in order to determine parameters of geodiversity. These parameters can be used to investigate the main threads for the geodiversity of the region. Based on the analyses of these parameters it is proposed geoconservation strategies adjusted to the reality of these geosites.

2. STUDY AREA

The municipality of Bonito is characterized by a microclimate controlled by its relatively high topography and consequent high humidity, associated with more intense rainfall season in a semi-arid region of the State of Pernambuco, northeast Brazil (Fig.1). It has an area of 395,611 Km² with a population of 37,566 inhabitants (IBGE, 2010). The local economy is based in agriculture,

livestock and tourism. The municipality is 136 km far from the state capital (city of Recife) and the main access roads are the highways BR-232 and PE-103, also known as “road of the waterfalls".

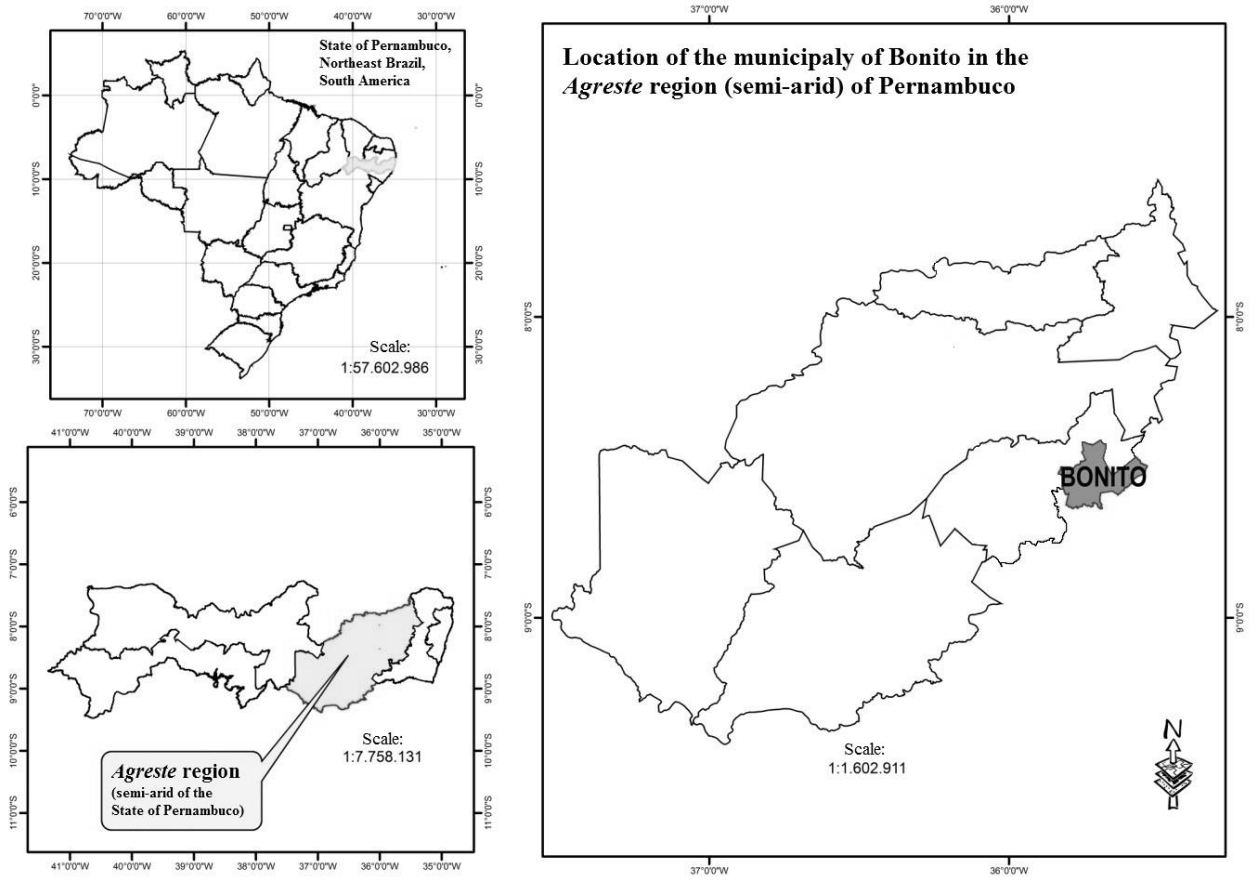

Figure 1 - Geographic location of the municipality of *Bonito*.

The hydrographic network of the area is dense and composed by the rivers Una and Sirinhaém and their tributaries, developing a dendritic pattern (ANDRADE, 1992). Along these rivers it is common the occurrence of waterfalls, which are controlled by geologic faults.

The region of Bonito is geologically placed in the Borborema Province, to the south of the Eastern Pernambuco shear zone (NEVES; MARIANO, 1999) in a domain called Pernambuco-Alagoas. The region is characterized by the occurrence of sinistral transcurrent shear zones, mainly with NE-SW direction (GOMES, 2001). In the area that concentrates the waterfalls, the main lithologic types are neoproterozoic coarse to medium grained granitic to granodioritic rocks intruded into orthogneisses, cut by numerous pegmatitic veins and dikes (GOMES, 2007).

The geomorphology of the area is constructed by rounded hills surrounded by smooth u-shaped valleys (ANDRADE, 1992).

3. GEODIVERSITY *BONITO* WATERFALLS: VALUES AND THREATS

Eight waterfalls were selected for detailed analyses of their geotouristic potential. They are: *Véu da Noiva, da Gruta, Pedra Redonda, Paraíso, Barra Azul, da Corrente, Véu da Noiva II e de Bonito*. To each of these geosites values for their geodiversity were attributed considering their intrinsic characteristics, cultural, aesthetic, economic, functional and scientific/educational aspects, based on the values described by Gray (2004).

Table 1 shows a general analysis, comparing selected geosites and their values of geodiversity, proposed by Gray (2004), aiming to identify their potential for geotouristic purposes. The intrinsic, cultural and aesthetic values were high for all geosites. The economic value was considered similar for most geosites, except for three waterfalls (*Véu da Noiva, Corrente* and *Bonito*), where there is a better infrastructure and offer of services.

Table 1 - Values of the Geodiversity for the waterfalls of the municipality of Bonito-PE.

POTENTIAIS GEOSITES	**VALUES OF THE GEODIVERSITY (Gray, 2004)**					
Waterfalls	**Intrinsic**	**Cultural**	**Aesthetic**	**Economic***	**Functional**	**Scientific / Educational**
Véu de Noiva	High	High	High	High	Medium	High
Da Gruta	High	High	High	Medium	Low	High
Pedra Redonda	High	High	High	Medium	Low	High
Paraíso	High	High	High	Medium	Low	High
Barra Azul	High	High	High	Medium	Medium	High
Da Corrente	High	High	High	High	Low	Medium
Véu de Noiva II	High	High	High	Medium	Medium	High
De Bonito	High	High	High	High	Low	Medium

*Economic value considering the actual touristic use.

Considering the difficulties of access, due to the poor quality of the roads, or geomorphological characteristics, for most geosites low functional values were assigned. The exceptions are *Véu da Noiva I*, *Véu da Noiva II* and *Barra Azul*, to which this value was considered medium, considering that they have installed rappelling equipment and other practices adventure tourism, attracting a larger number of visitors.

The scientific and educational value was high for most geosites, considering that they present features for easy visualization which may be useful in teaching / research in geosciences. Exceptions are waterfalls of the *Corrente* and *Bonito*, from which medium value was attributed, due to the strong anthropogenic interference. These civil constructions often block the visibility of outcrops and other geological features.

The aesthetic value was considered high for all geosites, since the scenic beauty of the waterfalls serves as a "postcard" of the municipality (Fig. 2). They are, also, source of inspiration for local artists that reproduce their scenay in paintings and photographs that are publicized and marketed with visitors. The economic value was associated with the financial income for the landowners, where geosites ar placed. Currently, this additional income is obtained mainly by charging for visitation lodging and food services.

The *Véu da Noiva* waterfall is the only one with multifunctional use, including radical sports tournaments, such as rappel and canyoneering.

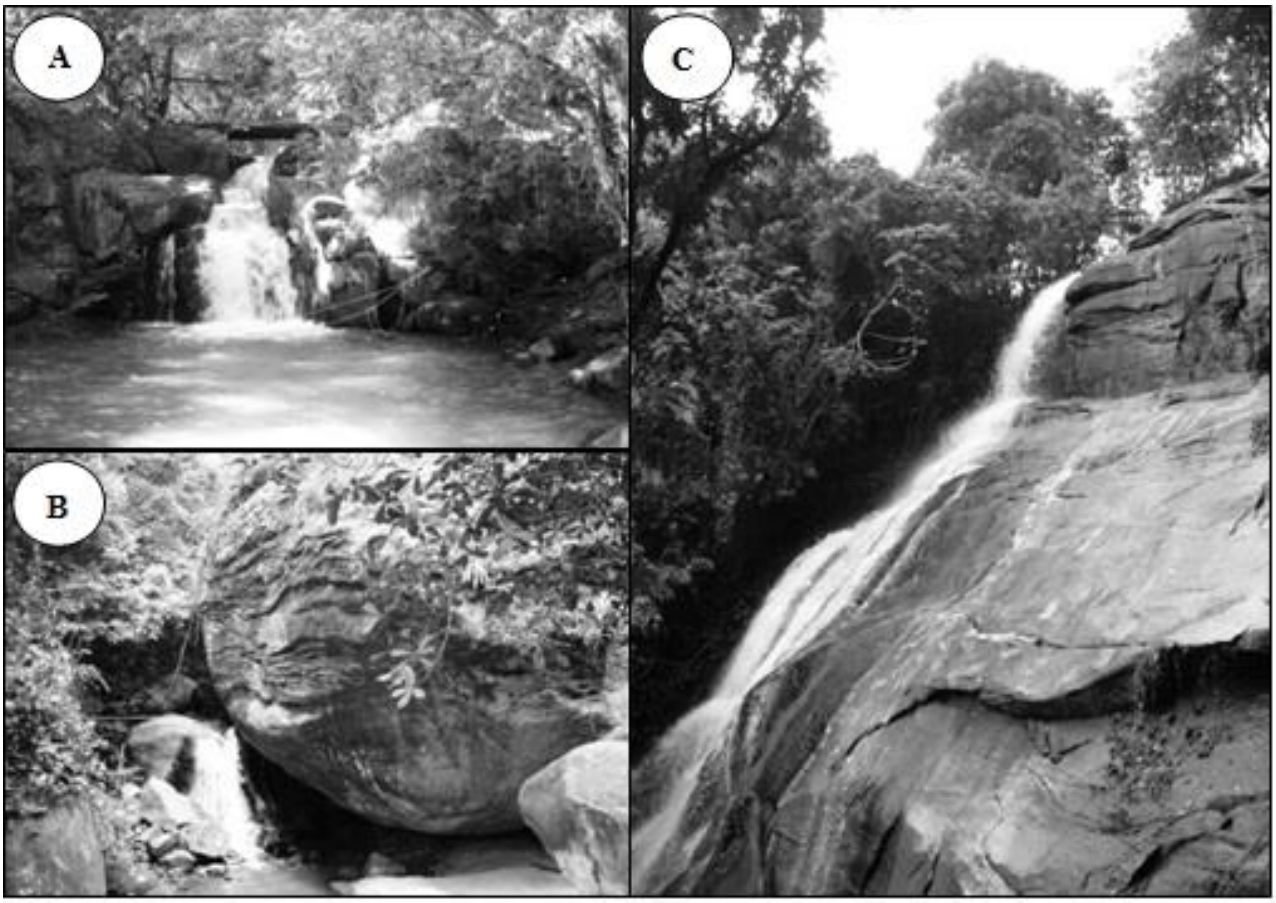

Figure 2 - Examples of the aesthetic and geomorphological features of geodiversity in the waterfalls of the region of Bonito. Waterfalls: (A) *Corrente*; (B) *Pedra Redonda* and (C) *Véu da Noiva*.

In terms of scientific and didactic aspects most of the waterfalls show interesting features in its rocks, such as contact between distinct lithologies, geologic fault planes, sinistral transcurrent shear zones planes and features, stock work veined structures, pegmatitic dikes, foliation and lineations. These features can be used for teaching and research purposes in geosciences (Fig. 3).

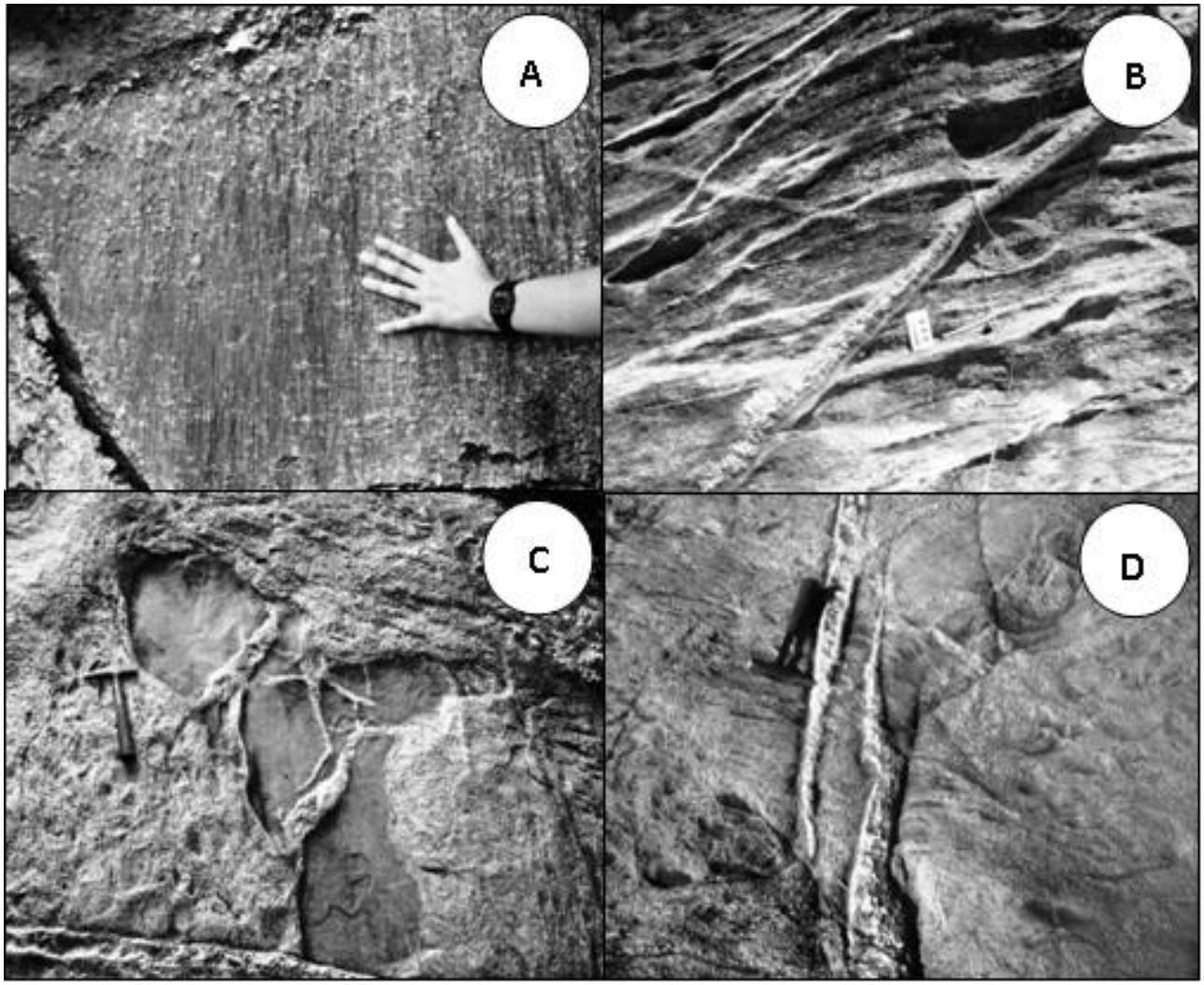

Figure 3 - Some examples of didactic/scientific value of the geodiversity in outcrop scale in the Bonito waterfalls. (A) Normal fault plane with down-dip lineation in the *Véu da Noiva* waterfall (Fault plane: 275Az/47°/185Az; Lineation: 47°/85Az); (B) Pegmatitic venulated structure in the *Gruta* waterfall; (C) Dioritic composition xenolith in orthogneiss, showing the process of differential erosion in the *Barra Azul* waterfall and (D) Pegmatitic veins along fracture planes into orthogneiss; it is possible to observe the differential erosion between veins, more resistant, and country rocks in the *Barra Azul* warterfall.

In addition to these elements of geodiversity (geological structure and relief) seen at outcrop scale, thin section petrography of the rocks in the geosites will bring information to visitors. Photomicrographs, revealing how is "the rock on the inside". Scientific information for the general public may promote interest considering that it is something new to most people who visit these sites (Fig. 4).

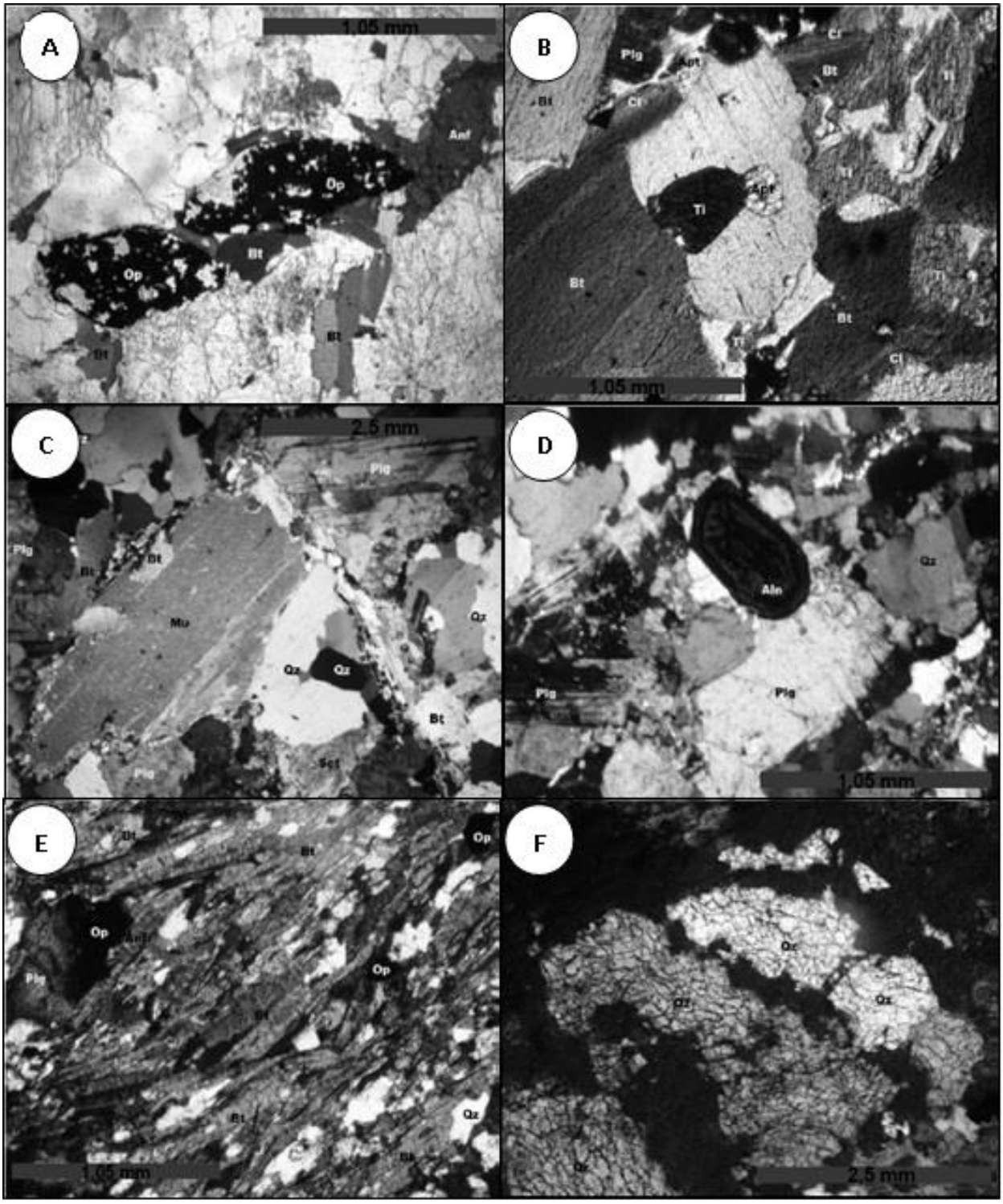

Figure 4 - A) Biotite granodiorite from waterfall *Gruta* showing concentration of opaque minerals (Op) associated with biotite (Bt) and hornblende (Anf), [/ /], B) Biotite granodiorite from waterfall *Gruta* showing biotite flakes (Bt) altering to chlorite (Cl) associated with titanite (Ti), apatite (Apt) and quartz (Qz), [/ /] C) Muscovite granodiorite of the waterfall *Paraíso* showing megacrystal of muscovite (Mu) with corroded edges. There is also the presence of quartz (Qz), biotite flakes (Bt), plagioclase (Plg) with albite twinning altered to sericite (Sct), [X], D) muscovite granodiorite of the waterfall *Paraíso* showing allanite (Aln) with well marked zoning, associated with crystals of plagioclase (Plg) and quartz (Qz), [X], E) Orthogneiss of quartz dioritic composition, showing biotite flakes Bt and amphibole (Anf), defining the foliation It is also observed crystals of plagioclase (Plg), quartz (Qz) and opaque minerals (Op), [X] F) Biotite monzogranite from waterfall *Poço da Negra* showing microfractured qyaurtz (Qz) crystals, [X]. [/ /] parallel nicols and [X] crossed nicols.

Gray (2004) defining values for geodiversity pointed out some of the main threats associated with the exploration of geosites. They are: exploration of the geologic/economic resources, construction with variable uses that add an important human input into the sites (often in disagreement with landscape features), projects related with reforestation, agricultural activities, including removal of the original vegetation, and several impacting activities such as military, recreation, and touristic. The collection of samples for non-scientific means or just by curiosity represents an import impact on sites with high rate of visitation.

In the region of Bonito the main threats to the geodiversity are: removal of the original vegetation cover in order to open trails and unpaved roads, irregular extraction of rocks (ornamental stone industry); dams constructed to improve the amount of water in some waterfalls and also for irrigation of crops, deviation of water courses for irrigation purposes, intensive use of agrotoxic compounds and non-ordered touristic activities, that causes several impacts to the area, including local accumulation of trash and water pollution.

4. QUANTIFICATION OF THE GEODIVERSITY IN THE WATERFALLS FROM BONITO

Brilha (2005) proposed a methodology for quantification of geosites. In this work we slightly modified his proposition making each of the sub-criteria to have the same number of subdivisions.

Thus, each of the criteria analyzed: Intrinsic Value, Potential Use and Necessity of protection, will have the same number of sub-criteria, making them equivalent to each other. This adaptation of the method, although simplify quantification, did not interfere in the results as the order of "relevance ranking" these geosites.

Table 2 shows show the values attributed to the each criteria, with its sub-classes. The analyzed criteria were: A – intrinsic (A1-A5); B – Potential use (B1-B5) and C – Necessity of Protection (C1-C5). Considering that the geosites of Bonito have uniformity among themselves, especially at the level geodiversity local or regional, we use the equation proposed by Brilha (2005) that gives a simple average of the parameters A,B, and C (Q = (A+B+C)/3), where “Q” represents to geosite relevance and consequent necessity of protection.

Table 2 - Quantification of the geosites of the region of Bonito, with emphasis to their vulnerability and necessity of protection (modified from Brilha, 2005). The values for each sub-criteria varies from 1 to 5.

Criteria	COD	Sub-criteria	Waterfalls name						
			Barra Azul	Da Corrente	Da Gruta	Paraíso	Pedra Redonda	Véu de Noiva	Véu de Noiva II
Intrisic	A1	Rarity	4	4	4	4	4	4	4
	A2	Extension	2	1	1	2	1	2	2
	A3	Local-type	5	3	3	3	3	5	3
	A4	Culture	1	1	1	1	1	2	1
	A5	Conservation	4	2	4	4	4	3	2
Parcial Value: A			**16**	**11**	**13**	**14**	**13**	**16**	**12**
Potential Use	B1	Activities	5	3	3	3	3	5	5
	B2	Observation	5	3	5	5	5	3	5
	B3	Accessibility	3	4	3	3	3	3	4
	B4	Villages/Towns	3	4	3	3	3	3	3
	B5	Economic	1	1	1	1	1	1	1
Parcial Value: B			**17**	**15**	**15**	**15**	**15**	**15**	**18**
Necessity of Protection	C1	Threats	5	5	5	5	5	5	5
	C2	Protection	5	5	5	5	5	5	5
	C3	Mining	3	3	3	3	3	3	3
	C4	Ownership	1	2	2	2	2	3	2
	C5	Fragility	4	3	3	4	3	4	4
Parcial Value: C			**18**	**18**	**18**	**19**	**18**	**20**	**19**
Total Value (Q = A+B+C)			**51**	**44**	**46**	**48**	**46**	**51**	**49**
Average (Q = A+B+C/3)			**17**	**14,7**	**15,3**	**16**	**15,3**	**17**	**16,3**

As shown on table 1 it is clear that the more relevant geosites and consequently the ones that need urgent protection measurements are the waterfalls named *Barra Azul* (17) , *Véu da Noiva* (17), *Véu da Noiva II* (16,3), and *Paraíso* (16). On the other hand, the waterfalls named *Gruta* (15,3), *Pedra Redonda* (15,3), and *Corrente* (14,7) were classified as the ones with less necessity of protection measurements. In figure 5 this behavior is shown in a clear way.

The waterfalls that have higher values have in common the intense number of visitors, without any control. They also are characterized by larger outcrops of fresh rocks (granitic and gneissic). In the waterfalls *Véu da Noiva I and II* it is observed some touristic infrastructure such as: iron stairways to facilitate access, pins for rappel and canyoneering and small concrete dams to store water forming artificial ponds for bathing. Many of these arrangements were constructed directly on outcropping rock. The *Corrente* waterfall is located into the so called Ecopark, which has large touristic infrastructure and lesser need for preservation measures. This behavior may be explained due to the control of visitation by the Ecopark administration. It is important to notice that some of the human interventions cover the exposed rocks, altering its natural outcrop and consequently imposing difficulties to its use for scientific/didactic purposes.

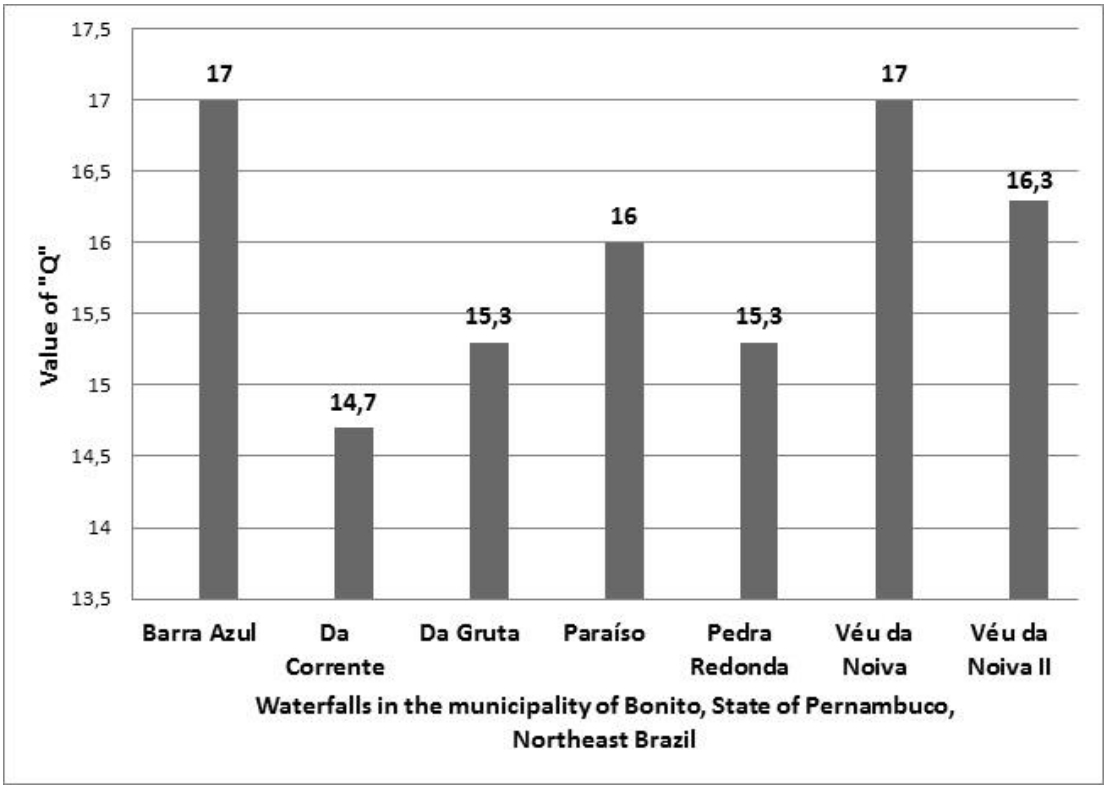

Figure 5 - Ranking of the vulnerability and necessity for protection of the waterfalls in the region of *Bonito*, State of Pernambuco, northeast Brazil. Modified from Brilha (2005).

The remaining waterfalls (*Paraíso, Gruta and Pedra Redonda*) have lower touristic demand and reduced infrastructure. They are very simple places without much human intervention in the natural elements.

5. GEOTOURISM AS A STRATEGY FOR GEOCONSERVATION FOR THE BONITO WATERFALLS

According with Brilha (2005), geotourism has a strong influence in the valorization of geoconservation measurements to protect the geologic heritage, favoring the sustainable development of a region. Among the several mechanisms that can be used for these purposes it is very important the insertion on the local population in economic activities related directly or indirectly with geodiversity, as well as the maintenance and preservation of the geosites. The local population must be informed of the importance of the geosites and learn how to transmit this information to visitors.

Based in these assumption it is believed that geotourism activity is a viable mechanism for the implementation of policies for geoconservation of the Bonito waterfalls, once it will promote

ordered visitation with adequate information, contributing to reduce the environmental impacts, common to the touristic activities.

The strategies of geoconservation consist, according to Brilha (2005), in the development of solid methodologies of work, aiming the conservation of the geologic heritage. The geoconservation strategy for the Bonito waterfalls proposed here is based on the information about the values of geodiversity (Gray, 2004), in the quantification of the studied geossites, using criteria slightly modified from those proposed by Brilha (2005), and also, in the natural characteristics of the area. In the Bonito waterfalls the main interests are: geotourism, scientific, didactic, hydrogeological, geomorphologic and geologic.

Taking into consideration the geologic and geomorphologic characteristics and the vulnerability of each one of the studied waterfalls in Bonito, it is proposed a strategy for geoconservation that can be separated in tree main branches: 1) infrastructure; 2) Publicizing; and 3) valorization of the geologic heritage (Table 3).

Table 3 - Measurements for Geoconservation of the Studied Geosites.

Infrastructure	Publicizing	Valorization
✓ Open trails with distinct grades of difficulty; ✓ Construction of stairways with handle to facilitate access to the waterfalls *Véu da noiva I* and *II, and Barra Azul*; ✓ Informative plates explaining in a non-scientific language the geodiversity of the region; and ✓ Monitoring (measures of protection against vandalism) of the geosites.	✓ Development of website, containing the main geotouristic routes of the region; ✓ Elaboration of primers and informative folders, about local geodiversity; ✓ Elaboration of new geotouristic routes in order to agregate the geologic information about the geosites; and ✓ Creation and maintenance of a welcome center for geotouristic information	✓ Courses of formation for guides; ✓ Foundation of a communitarian center with handcraft work; ✓ Close interaction with schools of the region; and ✓ Photographic contest and exibitions.

The development of infrastructure for geotourism in the region of Bonito must involve the federal university of the State of Pernambuco, which will take care of research and elaboration of projects, and the public administration that will support and implement the actions proposed and approved. This represents an initial step to facilitate the interaction between visitors and the geodiversity of the region.

Following the installation of adequate infrastructure, a major campaign of publicizing must be taken. This work must be conducted in the local and regional scales, always emphasizing the importance of the conservation and valorization of the geodiversity. As mentioned previously the

participation of the community is very important. In this way it is necessary the elaboration of projects that attract the community favoring the development of activities that are sustainable.

6. CONCLUSIONS

The waterfalls of Bonito have a geotouristic potential, since they superpose an exceptional aesthetic value with interesting geologic framework, constituting an excellent field for the development of didactic and scientific activities.

The qualitative and quantitative analysis conducted in this work favors the establishment of a ranking of the relevance of these geosites. Based in this study it was possible to determine the geosites that need urgent measurements for their conservation. The waterfalls selected by this work were: *Barra Azul* (17), *Véu da Noiva I* (17), *Véu da Noiva II* (16,3) and *Paraíso* (16), all of them already are very well known and visited by tourists, but no information about the geodiversity is provided.

The quantification of the geosites assists to choose the best geoconservation strategies and to define their relevance. These actions can promote a better comprehension of the importance of the geodiversity and, also, function as an instrument to guide environmental policies aiming the conservation of the geological heritage.

The region of Bonito aggregates a rich geodiversity associated with cultural elements, reinforcing the importance of geologic heritage as a factor of identification of a population with its environmental features.

Finally, geotourism is an efficient mechanism for conservation of the geodiversity. The correct geological information will add new perspectives to the exploration of the geodiversity of the Bonito region

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