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VOLCANIC GEOMORPHOSITES ASSESSMENT OF THE LAST ERUPTION, ON APRIL TO MAY 1995, WITHIN THE NATURAL PARK OF FOGO ISLAND, CAPE VERDE

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Abstract: Fogo Island presents the only active volcano of Cape Verde archipelago where the most important heritages of that activity are the conical aspect of the island, a caldera on its top and a main volcanic cone rising up the caldera floor. During April to May 1995 eruption the expelled materials have developed two major landforms, a volcanic cone and the lava flows. The *aa* lava type has built thicker and more irregular landforms than the *pahoehoe* lava type. A number of minor landforms were formed, such as depressions related to the craters or to an eruptive fracture, a multiple bomb impact craters and fractures at the cone top. The new landforms are the more relevant touristic attractions of the Fogo natural park, demanding an urgent scientific assessment and a detailed mapping in order to preserve and to mitigate its vulnerability to the anthropic destruction, such as by taking some "*souvenirs*".

Key words: Volcanic landforms, active geomorphosite, landscape conservation, Fogo Island, Cape Verde.

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INTRODUCTION

The ecosystems preservation is the main goal of any Natural Park definition. The abiotic components (climatic, hydrological, geological, geomorphological and pedological) are the foundations on which the biotic elements directly depend and one of the most important keys of management, natural richness and diversity (Pellitero et al., 2010). The relevance of these elements will be recognized and declared in the base documents of any natural park. As the biodiversity, the geodiversity is an important natural value, related to space and temporal components, and the geomorphosites are landforms with particular importance for the earth evolution knowledge climate and life history (Zouros, 2007). The geomorphosites assessement have been considered a fundamental tool for supporting management decisions for its protection and geotourist implementation (Pereira et al., 2007). The main assessement stages are the identification, inventory, selection and characterisation, numerical classification and ranking. The final scoring is a fundamental set to facilitate the geomorphosites promotion within a context of geotourism or landscape management.

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The environmental legislation in Cape Verde concerns manly with the natural resources management, particularly the freshwater use and the geological resources exploitation, or with the air and water pollution and biodiversity (Pereira et al., 2009).

Several studies have been done about the geologic heritage of Cape Verde Island, at the island scale, namely of Santiago (Pereira, 2005) or Fogo (Alfama, 2007). Some touristic geologic guides are also produce to Santo Antão (Sciunnach, 2003) and to Fogo (Alfama et al., 2008), based on Alfama, 2007.

A detailed study of the geomorphological heritage was done at a drainage basin scale in Santiago Island (Moreira, 2009). Sixteen geomorphosites were identified, characterized and evaluated, in the Ribeira Principal valley, within the Natural Park of Serra da Malagueta, to provide a tool of management.

In Fogo Alfama, 2007 and Alfama et al., 2008 have identified nine geosites of geological interest scattered all over island and seven one distributed in the Natural Park of Fogo. The inventory was based on field work observations and the majority of the geosites are chosen according its vulcanological and stratigraphical relevance, or also its panoramic landscape point of view. Between the sites within the park, only five are defined by its geological interest, the other two are features with cultural or biodiversity values. Only two are referred to the volcanic landforms of the last eruption, the new cone and a reference to the lava flows in general that may include someone of that more recent volcanic event. A brief allusion was done to the volcanic cone of the 1951 eruptive episode (Alfama, 2007).

STUDY AREA

Fogo is located in the southern group of the Cape Verde islands, in the central Atlantic, about 600 km far from the west coast of Africa, at 15° of north latitude (figure 1). Is the 4th major of the 10 island of the Archipelago, with a surface of 476 sqkm. The Island has a general conical landform, with a medium diameter of 25 km and a basal perimeter of 81 km, as the most evident geoheritage of its volcanic origin (figure 1). This general form are truncated at its summit by a volcanic caldera breached to the east, by a flank collapse, and bounded to the west by a 1000 meters high escarpment.

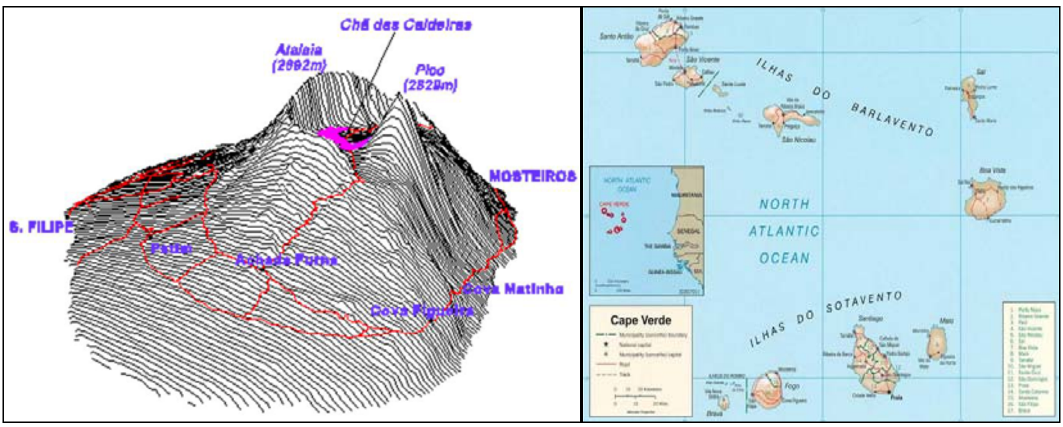

Figure 1. Fogo Island location

Fogo is the only island in Cape Verde where volcanic activity is still observed showing many volcanic landforms all over, mostly lava flows, numerous ashes covers and about one hundred smaller cones, as the the main results from the eruptive products expelled. The most important heritages of that activity are the great diversity of volcanic landforms on its summit caldera, at 1600 m above the sea level, designated

Chã das Caldeiras (figure 1). A 29 sqkm caldera and a main volcanic cone, built in the middle of eastern opening of the caldera and rising 1200 meters its floor, 2.829 meters above the sea level (the highest point of Cape Verde), with a 500 meters wide and 150 meters deep summit crater.

Many lava flows, related with the twenty six known eruptive events, are scattered all over the caldera and the east slope of the island, reaching sometimes the east coast. About twenty secondary volcanic cones occupy the base of the main cone or the caldera floor, particularly the several one associated to the six last eruptions.

The twenty volcanic events reported in the island from 1500 to 1799, occurred from the main cone, sometimes associated with volcanic activity in some vents on their flanks (Ribeiro, 1954). Currently there are still fumarolic emanations inside its 500 meters large crater and its eastern slope. The last six events were held in the secondary cones, particularly in the northern sector of the caldera. During these events were formed some new cones or reactivated ancient ones, as during the last one in April-May 1995 (Costa, 1998).

The central and highest area of the Fogo Island was classified as a Natural Park, through the law 3/2003 of February 24th, in partnership with the German Government. The park occupies an area of 84.69 sqkm, and includes the main volcanic cone, all the caldera and its internal western scarp and also its external western slope above 1,800 meters (figure 2). It is distributed along the 3 municipalities of the Island (Santa Catarina - 50%, Mosteiros - 28% and São Filipe - 22%), with a population of 1010 inhabitants (2001), particularly in the villages of Bangaeira and Portela.

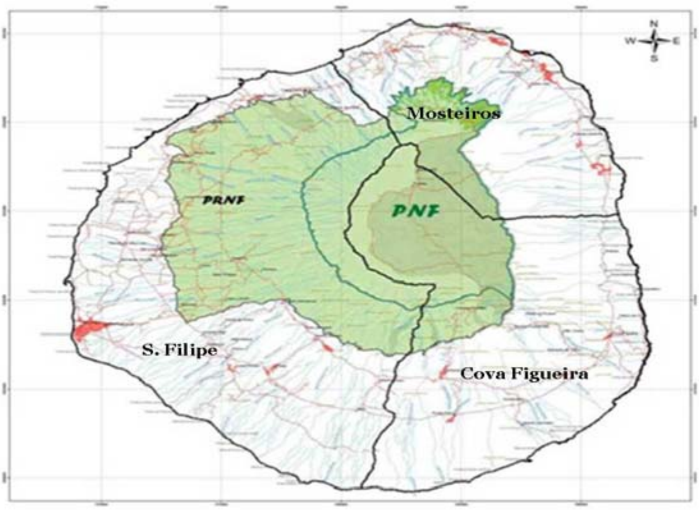

Figure 2. Natural Park of Fogo Island (PNF)

The Park was created with the main goals to preserve and to monitor the flora and fauna species, as well as the endemic species (Leyens, 2002). The Park´s administration and the local community have an active participation of protection the environment and recovery.

More than its biodiversity are the volcanic landscape and general panoramic of the park, namely the great dimensions of the summit caldera and the main volcano that appeal the touristic interests. A great geodiversity of volcanic landforms are scattered all over the park, such as cones, lava flows, pyroclastic covers or fumarolic eruptive vents. Excluding the western scarp and the main cone, the great majority of the park surface within the caldera is occupied by the volcanic landforms of the two more recent events, 1951 and 1995, according the local geological map (Torres et al., 1997a). The systems or particular areas and the some single places, related with these eruptions, are, no doubt, the main touristic attractions of the park, especially the cone and the lava flows of the last one.

The volcanic event of 1951 in Fogo Island was the subject of only one main study (Ribeiro, 1954). The most recent eruptive episode, in 1995, aroused a particular scientific interest by the Island during and after the eruption. About one hundred studies concerning this eruption have been published in peer reviewed journals and in many congress proceedings.

Two international congresses are promoted in Lisbon and Fogo Island with thematic of this volcanic event. A proceedings volume of the Lisbon congress is published with contributions of the geophysics, geologic, geomorphologic, climatologic conditions and of the natural and human impacts of this volcanic eruption (IICT, 1997).

Several Msc and PhD thesis are done after the event, three of them related with geophysical and geologic thematic (Quental, 1999; Heleno, 2003; Alfama, 2007). The great number and diversity of thematic studied makes available basic information on the spatiotemporal aspects of this eruption, fundamental to its very detailed knowledge.

OBJECTIVES AND METHODOLOGY

This study deals with the first systematic inventory of the geomorphosites related with the volcanic landforms of the last eruption, on April to May 1995. The results may contribute to publicize and also to preserve this heritage which represents the most recent eruptive episode of the unique volcanic active region of Cape Verde archipelago.

A geomorphological map at 1/10.000 scale and a geomorphosite not systematic inventory were done, based on aerial photo and mainly on field work, with campaigns during and after the volcanic eruption of 1995.

A bibliographic reviewing was also done in order to propose a geomorphosites assessment, as accurate as possible in scientific terms, according with the criteria defined by Pereira et al., (2007). This numerical assesment consider the geomorphologiclal values (scientific and additional) and the management values (use and protection) and don’t take in account some cultural values (historic, artistic and literature importance), the economic (natural and human existing or potential threats) or the educational (didactic and interpretation facility) ones (Reynard et al., 2007).

The 1995 volcanic phases and landforms building

The eruptive event of 1995 was similar to the well documented previous ones occurred in the island. The event was preceded by soft intense volcanic earthquakes (4 mod. Mercalli scale), since Mars 30. The eruption started, by the 11 pm on the 2nd April (Correia and Costa, 1995), with a violent explosive phase, with piroclasts projection and *aa* lava type emission. The terminal volcanic activity, April 19 to May 18, was more effusive, with emission of *pahoehoe* lava type.

Initially gas explosions, fire emissions reaching about 400 meters high, 4 meters length plastic bombs were projected to distances of 250 meters, from 3 to 4 vents aligned along a 2 km fracture depression (Wallenstein et al., 1997). A lava flow was emitted by a vent located at the southwestern part of the facture and occupies a local depression (figure 3).

The activity became centred in an old volcanic cone, located at the northeastern sector of the depression. The fire emission reached 500 meters high and the eruptive column of gases rosed to a height of 4,500 to 5,000 meters and ashes until 3,000 meters (Correia and Costa, 1995). The column was deformed towards east and the ashes falled at the eastern slope of the island due to the west to southwest predominant seasonal winds at this altitude. In this cone three main fumarolic craters, located at its summit, emitted the gasses, and two craters, centered near its western slope, emitted mainly the piroclasts and lavas.

The lavas flows, mainly to the southwest, formed a 30 meters large lava river and occupied a large depression of the central part of the caldera floor. A week after the beginning of this volcanic event, the lavas progressed until the bottom of the western caldera scarp, 3.5 km far from the main eruptive vent (Correia and Costa, 1995). On the April 19, at the end of the first phase, an area of about 3 sqkm of the caldera floor was covered by the *aa* lava type. The main volume of the new cone, builted by accumulation of scoria over an ancient one, in an area of 0.7 sqkm, was also defined (Torres et al., 1997b).

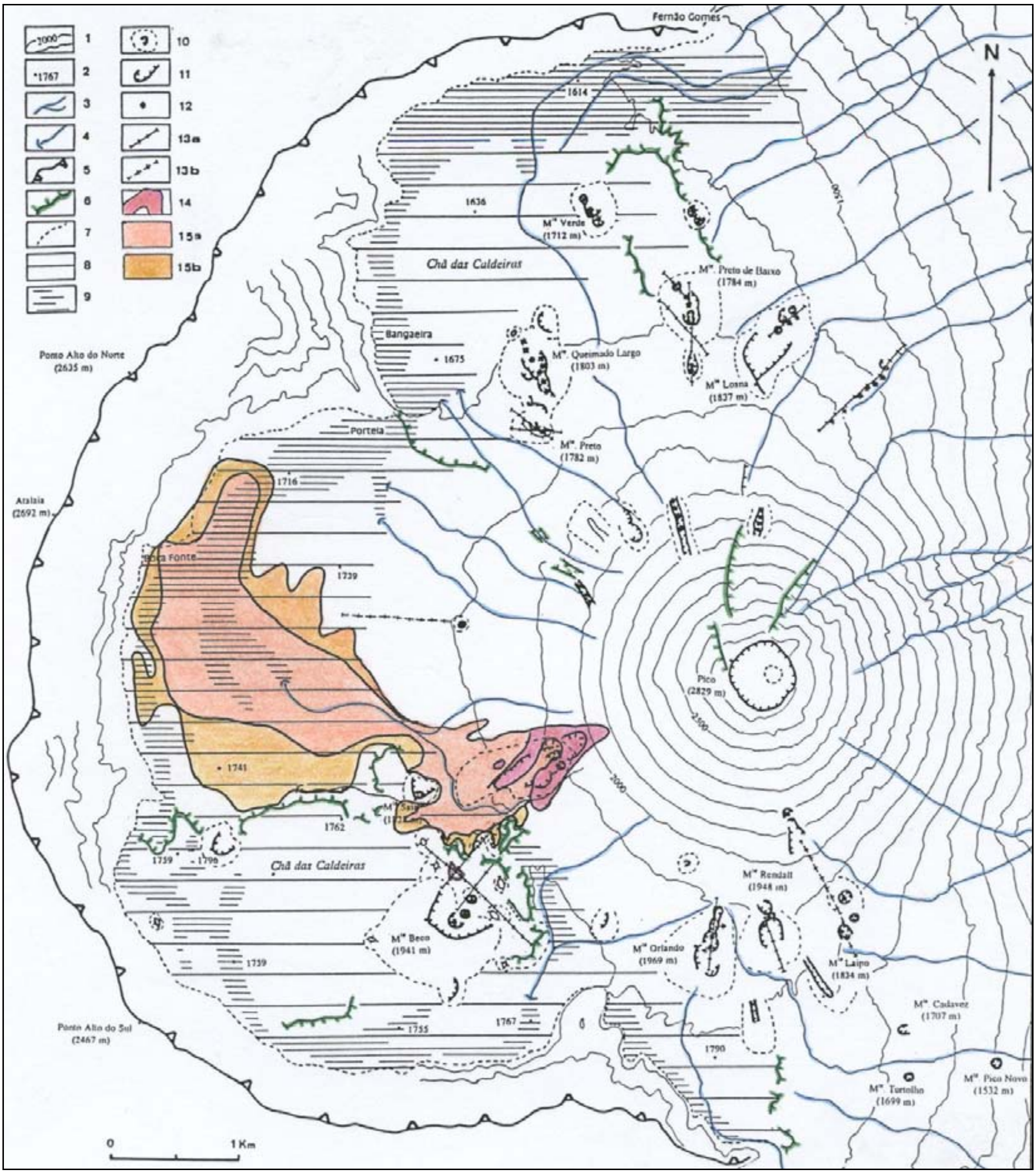

Figure 3. Geomorphic heritages of the 1995 volcanic eruption.
Ancient landforms: 1–Contour line (m); 2–Elevation points (m); 3–Drainage channel; 4–Drainage channel loss; 5–Scarp of the caldera (Bordeira); 6–Break of slope; 7–Slope bottom; 8–Flat floor of the caldera (Chã das Caldeiras); 9–Depressed areas; 10–Volcanic cone; 11–Crater rim; 12–Volcanic vent; 13 a–Fracture depression; 13 b-Fracture;
1995 volcanic landforms: 14–Scoriae cone; 15 a-Lava flows: a–until 11th April, b–July 1995

The next phase was characterized by the emission of *aa* and *pahoehoe* lavas types through two crater, located at the northern slope of the cone. These lavas covered the anterior ones and also a new area of about 1.3 sqkm (figure 3). On May 18 the fronts were already stationary, the lavas had occupied about 4.3 sqkm and an estimated volume of about 22 to 35x106 m^3 (Wallenstein et al., 1997).

Inventory of the 1995 volcanic landforms

During the two month of this eruptive event the emitted volcanic products creates by accretion the two major volcanic landforms, the cone and lava flows. Other group of landforms is the several types of depressions, associated with the eruptive vents or the bomb impacts.

The volcanic cone results from the accumulation of bombs, ashes and lavas, emitted through the vents of a pre-existing scoriae cone, located at the western slope bottom of the main cone. This accretion of volcanic products generates a new cone that buried the old one, basically during the two first weeks of the eruptive event. The new cone is the highest secondary one formed within the summit caldera of the island, reaching 150 meters high above its floor (Correia and Costa, 1995). The cone is dissymmetric, pre-conditioned by the topography of the ancient cone and the position of its vents (Costa, 1998). The northwest slope is steeper and more complex, related with the local lava flow emissions (figure 4A). The southeast sector is higher, due to the preferential pyroclasts accumulation during the event (figure 4B). The main craters have also a lateral position, with the rim open to southwest, related with the anterior volcanic unit.

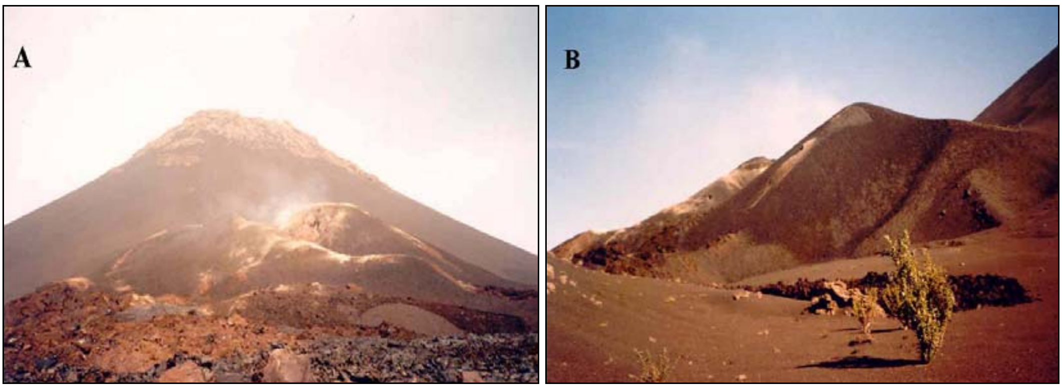

Figure 4. – New volcanic cone (Photo F.L.Costa: October 1995): A -northern view; B -southern view

Figure 5. Lavas fronts slopes (Photo F.L.Costa: Jully 1995), A – *aa* lava; B - *pahoehoe* lava

During the eruption the lava flow river, conditioned by the topography of the pre-cone and its crater rim opening, progressed essentially to the southwest, along the local main drainage slope direction. An inner central depression of the summit caldera was occupied by tow lavas types.

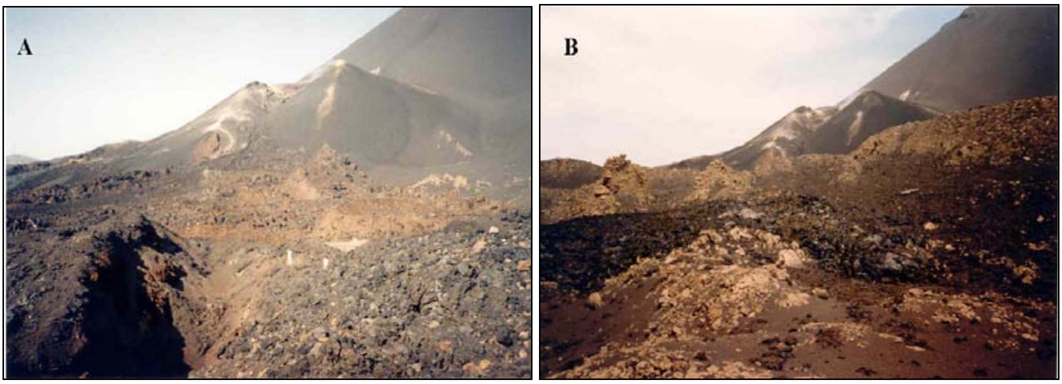

Figure 6. Fracture depression (Photo F.L.Costa: Jully 1995): A – Northeastern sector; B - Western sector

Figure 7. Craters (Photo F.L.Costa: Jully 1995): A – main crater; B – secondary crater

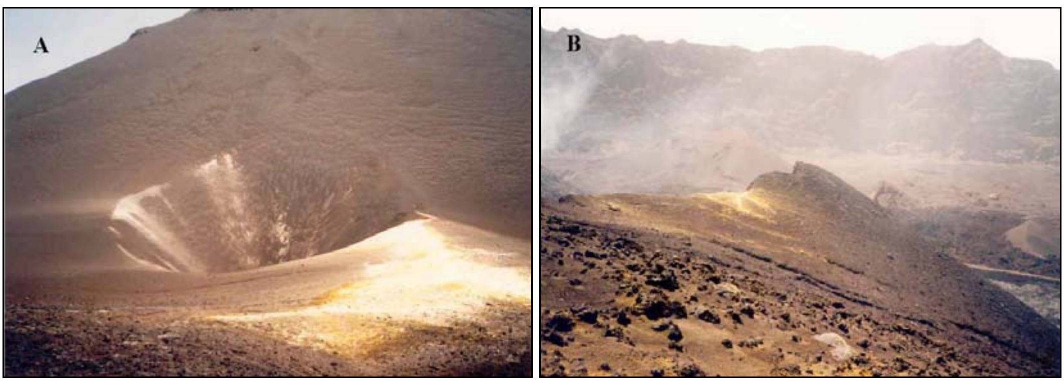

Figure 8. Fumarolic vents (Photo F.L.Costa: Jully 1995)
A – main fumarolic crater; B – fractures with gases emission

The *aa* lava type modified and caused the elevation of the topography in a medium of 10 meters high, reaching locally 30 meters. Its summit has a very irregular morphology with angular blocks forming small hills. The front slopes, commonly 6 to 10 m high

(Costa, 1998), are very steep with 40° (figure 5A). The *pahoehoe* lava type, due to its fluidity, originated less irregular summit topography, with thinner, 1-2 meters high and smoother, 20°, front slopes (figure 5B). This lava type locally has prodigious ropy, lobated or jumbled surface morphology and helical front shapes.

A great number of minor landforms were formed during this eruption, namely several types of depressions. The major ones are associated to the eruptive vents and the little one to the bomb impacts.

The biggest depression is primed by a NE-SW fracture 2 km long, were the first 3 to 4 vents were located (figure 6A). In morphological terms, has about 200-300 meters long, 4-5 meters deep and 10 meters wide in its most evident sector. The fracture is western limited by a depression, partially covered by lavas and 4 meters long plastic bombs, emitted by a local vent (figure 6B).

Other depressions are related to the several eruptive craters. The main crater comprises two coalescent depressions, associated with two eruptive fire emission jets observed during the first days of activity (figure 7A).

A secondary crater appears at the northern slope of the cone, during the second phase of the eruptive event (figure 7B).

Several depressions are associated with gases emission and the formation of vaporized colourful eruptive products. The bigger ones are four conical shaped fumarolic craters, located at the cone summit. The larger one is about 50 meter depth and 100 meters large (figure 8A). Nearby the main crater long fractures and depressions, which reach more than a one meter depth, usually with a circular outline, cover this sector of the cone summit (figure 8B).

A multiple bomb impact craters until a distance of 500 meters far from the main crater, covering the entire cone surface, are the more ephemeral landforms produced during this volcanic event.

Geomorphosites assessement

The personal campaigns of field volcanic landforms recognition in all islands of the Cape Verde archipelago, were very relevant to define a more accurate geomorphosite assessment in Fogo Island. The field works in Fogo took place particularly in the summit caldera before, during and after the 1995 volcanic event. The detailed observations and cartography of the geomorphologic features especially those related with this event (Correia and Costa, 1995; Costa, 1998; and Costa and Mendes, 2001), allow the inventory, the geomorphosites characterisation and a more precise numerical assessment.

Ten geomorphosites were selected and numerical assessed. They included 1 panoramic view point (volcanic cone), 3 single sites (main and secondary craters and fumarolic craters) and 6 places (other features).

The results of the numerical assessment show that the most valuables geomorphosites of this last eruptive event, in terms of total value, are the volcanic cone, followed by its main crater, the fields of lava, particularly the pahoehoe type due to its surface structure, and the fumarolic craters (table 1). The lowest score was attributed to the bomb impact craters, but as minor landforms, particularly rare and very vulnerable to anthropic and natural destruction requires especial conditions of preservation.

In terms of geomorphological value the cone are also the first one but the fumarolic craters are the second, and the aa lava type the third. In management values the cone and its main crater are also the first one.

The cone is the most valuable feature in total, geomorphological and management values, and also thee aa lava type are the third scored in the same values. The second score of each one of these values varies between the main crater and the fumarolic craters.

This results show also the great relevance of the additional values in weighting the scientific one to the geomorphological scoring, namely in the cases of the new cone, the fumarolic craters, the two types of lavas or the main crater. The high-scored features are the more volumetric ones and with a more diversified themes of interest, as the cone sector where are concentred the major number of geomorphosites (craters, fumarolic craters and fractures, bomb impact craters) and the panoramic landscape are the largest one point of view. To this geodiversity of the new cone sector are also associated its integrity, geomorphologic and scientific knowledge, aesthetic, accessibility or visibility.

Table 1. Geomorphosite numerical assessement

Geomorphosites assessemnet criteria	Geomorfological features		1	2	3	4	5	6	7	8	9	10
			Cone	aa lava flow	Pahoehoe lava flow	Main eruptive crater	Secondary eruptive crater	Eruptive fracture depression	Western eruptive depression	Fumarolic craters	Fumarolic fractures	Bomb craters
Geomorphological value (0-10)		**GMV**	**8.25**	**6.5**	**7.38**	**7**	**5.75**	**6.08**	**5.5**	**8.25**	**5.67**	**5.25**
Scientific value (0-5,5)		**ScV**	**3.75**	**3.75**	**4.75**	**4.5**	**4.75**	**4.58**	**4.5**	**5.25**	**4.42**	**4**
Local rareness	(0-1)	LRa	0	0.25	0.75	0.5	0.75	1	1	1	0.25	0.75
Integrity	(0-1)	Int	0.75	0.5	1	1	1	0.75	1	1	1	0.25
Repres entativeness	(0-1)	Rep	1	1	1	1	1	1	1	1	1	1
Geodiversity	(0-1)	Div	1	1	1	1	1	0.33	0	0.75	1	1
Geomorphologic	(0-0.5)	Gem	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Scientific Knowledge	(0-0.5)	Skn	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
National Rareness	(0-0.5)	Nra	0	0	0	0	0	0.5	0.5	0.5	0.17	0
Additional Values (0-4.5)		**AdV**	**4.5**	**2.75**	**2.63**	**2.5**	**1**	**1.5**	**1**	**3**	**1.25**	**1.25**
Cultural	(0-1.5)	Cul	1.5	0.25	0.75	1.5	0.75	0.5	0.25	1.5	0.25	0.25
Aestetic	(0-1.5)	Aes	1.5	1	1.5	1	0.25	1	0.75	1.5	1	1
Ecological	(0-1.5)	Ecl	1.5	1.5	0.38	0	0	0	0	0	0	0
MANAGEMENT VALUE (0-10)		**GMV**	**8.6**	**7.24**	**6.73**	**8.6**	**6.3**	**6.12**	**6.62**	**5.84**	**5.51**	**4.76**
Use Value (0-7)		**UsV**	**5.6**	**6.24**	**5.23**	**5.6**	**4.8**	**5.12**	**5.12**	**4.59**	**4.26**	**4.26**
Acessibility	(0-1.5)	Ace	0.43	1.07	1.07	0.43	0.64	1.29	1.29	0.43	0.43	0.43
Visibility	(0-1.5)	Vis	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Geomorphological use	(0-1)	Gus	1	1	0.33	1	0.33	0	0	0.33	0	0
Natural use	(0-1)	Ous	0.67	0.67	0.33	0.67	0.33	0.33	0.33	0.33	0.33	0.33
Legal protection	(0-1)	Lpr	1	1	1	1	1	1	1	1	1	1
Equipment services	(0-1)	Eqi	1	1	1	1	1	1	1	1	1	1
Protection value (0-3)		**PrV**	**3**	**1**	**1.5**	**3**	**1.5**	**1**	**1.5**	**1.25**	**1.25**	**0.5**
Integrity	(0-1)	Int	1	0.5	1	1	1	0.5	1	0.75	0.75	0.5
Vulnerability	(0-1)	Vul	2	0.5	0.5	2	0.5	0.5	0.5	0.5	0.5	0
TOTAL VALUE (0-20)		**Ttv**	**16.85**	**13.74**	**14.11**	**15.6**	**12.05**	**12.2**	**12.12**	**14.09**	**11.18**	**10.01**

FINAL CONSIDERATIONS

All the governmental programs of Cape Verde during the third last decades have define the tourism as a fundamental and priority economic sector to the national development. The conventional tourism with the implementation of beach resorts at the eastern islands and also the ecotourism, with the promotion of walking activities at the mountainous islands, have been promoted.

The recent law of creation of the national network of protected areas defines the legal regime of the natural landscapes, monuments, and sites with particular relevance in biodiversity terms, natural resources, ecological or socio-economics interests, cultural, tourist or strategic. In this context three natural parks have already been created, all of them in the mountainous sectors of the islands, the Serra da Malagueta (Santiago Island), Monte Gordo (S. Nicolau Island) and Fogo. The Park´s administrations, with the participation of the local communities, promote the conservation and valorisation of these areas, the development of the traditional activities and also the ecotourism.

The Fogo Natural Park are, between these three parks, the more rich in geodiversity terms and relevant geomorphosites, and represents the most recent active volcanic geo-historic episodes of the Cape Verde archipelago. The new landforms of the last volcanic episode are the more relevant touristic attractions of the park.

After the last 1995 eruption a big development of the villages associated at the crescent promotion of eco and geotourism have been done within the park, with the implementation of tourist services of guides, restaurants and tourist accommodation or the local products, such as the wine production, unique in Cape Verde, fruit marmalade, goat cheeses, lava rock handicrafts.

In the area of the park the agriculture and livestock production are the main activities of the local populations, although is not allowed free grazing, in order to preserve the biodiversity and the agricultural production. In order to assist the visitors of the park and limit their activities, it was instituted the payment of touristic entries within the park and was created a local information office.

A large commitment is need to promote the geomorphological study of all the area of this natural park, based on field work very detailed mapping and a solid scientific geomorphosites inventory and assessement. Particular attention will be done to the 1951 and 1995 volcanic landforms, manly due to the particular tourist interests by these more recent eruptive geomorphosites.

The studies results will be regularly publicized by local, national or international of vulgarisation and scientific events in order to preserve this heritage unique and to mitigate its vulnerability. Are also relevant the edition of tourist guide and brochures scientific studies based and the local tourist guides formation. An urgent establishment and demarcation of pedestrian trails is fundamental to reduce the anthropic destruction, such as by taking some "*souvenirs*".

More effective and immediate preservation measures are necessary, particularly in the new cone area and its summit, where are located the higher scored geomorphosites features and the also the most ephemeral ones, due to the easy accessibility and frequent tourist visits. It is fundamental, for instance, define pedestrian trails with local panels, in order to limit the variations of the routes of visitors.

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