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ORIGINAL ARTICLE

Comparative Analysis of Geomorphosites in Volcanoes of Costa Rica, Mexico, and Spain

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Abstract
This study is a comparative analysis of geomorphosites in Poás volcano in Costa Rica, Paricutín volcano in Mexico, and Teide-Pico Viejo volcanoes in Spain. The main objective of the paper is to compare the geomorphosites of these volcanoes using a geomorphosites evaluation to define which volcano is better for touristic activity. In this study, the geomorphosites evaluation methodology of Serrano and González (Geomorphologie: Relief, Processus, Environment 3:197–208, 2005) was used. The study shows that these volcanoes have many different geomorphosites with geological and cultural importance for the population and that these characteristics make touristic development possible. One of the conclusions of this paper is that these volcanoes are representatives of the nations of Costa Rica, Mexico, and Spain, with interesting cultural and geological characteristics and unique landscapes. The methodology used gives another perspective to study the topographic setting and presents ideas to make new touristic sites available and attractive in other locations.

Keywords Geomorphosites evaluation · Geodiversity · Poás volcano · Paricutín volcano · Teide-Pico Viejo volcanoes

Introduction

Definition of Geomorphosite

Geomorphosites are landforms to which a society confers a certain value for scientific, cultural, ecological, esthetic or economic reasons" (Panizza 2001). A geomorphosite is also a site with a singular topography that sets it apart from other sites and where there must exist various associated services and interpretation facilities to allow for appraisal, dissemination of information, and investigation of geological and geomorphological features to be used by not just the current population but future generations as well (Hose 1995, quote by Sánchez and Propin 2014). At the same time, a geomorphosite has added values given by population, such as scientific, cultural, historical, esthetic, and socioeconomic value, and these values are manifested when tourists become aware of and have access to such an important location (Comanescu and Nedelea 2010).

Ilies and Josan (2008) explain that a geomorphosite is a form of the landscape with significant attributes which qualifies it as an important component of the cultural patrimony of a territory, and thus includes the geomorphosites in the natural heritage of society (Coratza et al. 2008).

Palacio (2013) quoted Panizza (2001) who said that a geomorphosite could be individual landforms or a complex landscape. Pérez-Umaña (2017) said that a geomorphosite could be found or proposed in different areas as protected areas, indigenous territories, or any other spaces. Sometimes a geomorphosite is unknown by the population. For that reason, it is necessary to promote them publicly, because people

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need to learn more about the importance of a specific landform (Palacio 2013).

Geomorphosites' Importance in Geodiversity Conservation

Geodiversity is defined as a set of geological and geomorphological elements in a territory, including landforms, processes, rocks, minerals, and other aspects (Dong et al. 2014). Geodiversity is also defined as the geological variety in a specific territory based upon the set of features found there considering their frequency, distribution and geological evolution (Carcavilla et al. 2007, quote by Jaramillo et al. 2014). Dóniz-Páez et al. (2011) mentioned that in natural heritage, geodiversity occupies a secondary position behind biodiversity but Sastre (2007) argues that geodiversity could have more value than biodiversity.

In this case, a geomorphosite is a part of geodiversity because it is a special landform that needs to be conserved. For that reason Bruno et al. (2014) affirms that rare localities with scientific importance, and/or with spectacular, well-preserved geological features and landforms need to be conserved. Geodiversity represents all geological products of Earth history and their interactions with atmospheric processes, biosphere, and human beings over time (Fassoulas et al. 2012).

To protect geodiversity, it is necessary to talk about geoconservation, which is defined as a series of actions intended to preserve the geological heritage of a given location (Brocx and Semeniuk 2007, quote by Carcavilla et al. 2009). It includes a management strategy for geoheritage sites based in the idea that protected geological resources have a scientific and touristic value (Gray 2005, quote by, Dong et al. 2014). If the geodiversity of a specific territory is conserved, geotourism can be established, using geological resources, giving importance to the conservation of environment, landscapes, natural, and cultural heritage to promote development in rural areas (Carcavilla et al. 2009). For that reason, Serrano and Ruiz (2007) said that the concept of geodiversity must be integrated into professional actions as a scientific tool to be rigorously applied, together with biodiversity to territorial understanding, and land management.

Description of Selected Geomorphosites

In this paper, we will compare three volcanoes with different geomorphosites. Those volcanoes have an important geodiversity and are attractive to local and international tourists. Volcanic landscapes and volcanism together can fascinate a general public about the forces of nature (Németh et al. 2017). This work will describe the geomorphosites of Poás Volcano in Alajuela, Costa Rica; Paricutín Volcano in Michoacán, México; and Teide-Pico Viejo Volcanoes in Tenerife, Spain. The objective of this paper is to compare the three locations using a geomorphosite evaluation to define which volcano is better to have touristic activity.

Geological and Geomorphological Characterization

Poás Volcano

Poás Volcano (10° 11′ 49.6″ north latitude, 84° 13′ 50.9″ west longitude) is located at northwest of Central Volcanic Range of Costa Rica (Ruíz et al. 2010). It is a complex stratovolcano with an irregular subconic form and a basal area of between 300 and 478 km^2 (Alvarado 2011) and has a maximum altitude of 2708 m (Fig. 1). Pérez-Umaña (2017) related that, by result of the displacement of the eruptive centers, the three volcanic cones on the top of the volcano were created, which are the Botos Cone, the Von Frantzius Cone, and the Principal Crater. Another important structure is the Congo volcano, located 6 km north of the Von Frantzius Cone (Alvarado 2011). This volcano is an open cone at the north-northwest and north-northeast; this opening probably was formed during its last eruption (Alvarado and Salani 2004).

All the structures in this volcano are aligned in a south-north direction, showing that Poás volcano had fisural volcanism in the past (Ruíz et al. 2010). This alignment includes other structures like the Sabana Redonda cones and the explosion craters of Hule and Río Cuarto (Gazel and Ruíz 2005). The Principal Crater is the most important structure of the volcano. It is 3500 years of age (Ruíz et al. 2010) and has a diameter of 1320 m (Alvarado 2011). The crater is composed of four morphogenetic units, the crater lagoon, the internal sand plain, a volcanic dome (destroyed in April, 2017), and the occidental plateau (Alvarado 2011).

The recent activity of Poás volcano has included phreatic and occasional incandescence since 2006 (Bergoeing 2009) as well as degasification. This process happens when acid rain is produced at the same time that the gas emanation increase (Duarte and Fernández 2011). As a result of this degasification the rocks are clean of vegetation, which has died as a result of the acidic precipitation drawing an "acidification alley" (Duarte and Fernández 2011).

The slopes of this volcano are susceptible to landslides. The Cinchona earthquake of January 8, 2009, with a Richter magnitude of 6.2, caused drastic changes in the relief. Quesada-Román and Barrantes (2016) showed that this earthquake provoked a different kind of landslides on the volcano, especially in the slopes of Von Frantzius Cone. Also, Congo Volcano has a similar susceptibility, because this earthquake caused regolitic flows in this volcano. Barrantes et al. (2011) showed that Congo volcano has a high potential to trigger landslides, like Von Frantzius Cone.

Paricutín Volcano

Paricutín volcano (19° 29′ 35.3″ north latitude, 102° 15′ 04.6″ west longitude) is a monogenetic cinder cone that has a height of 220 m and a width of 950 m (Guilbaud et al. 2009). It is

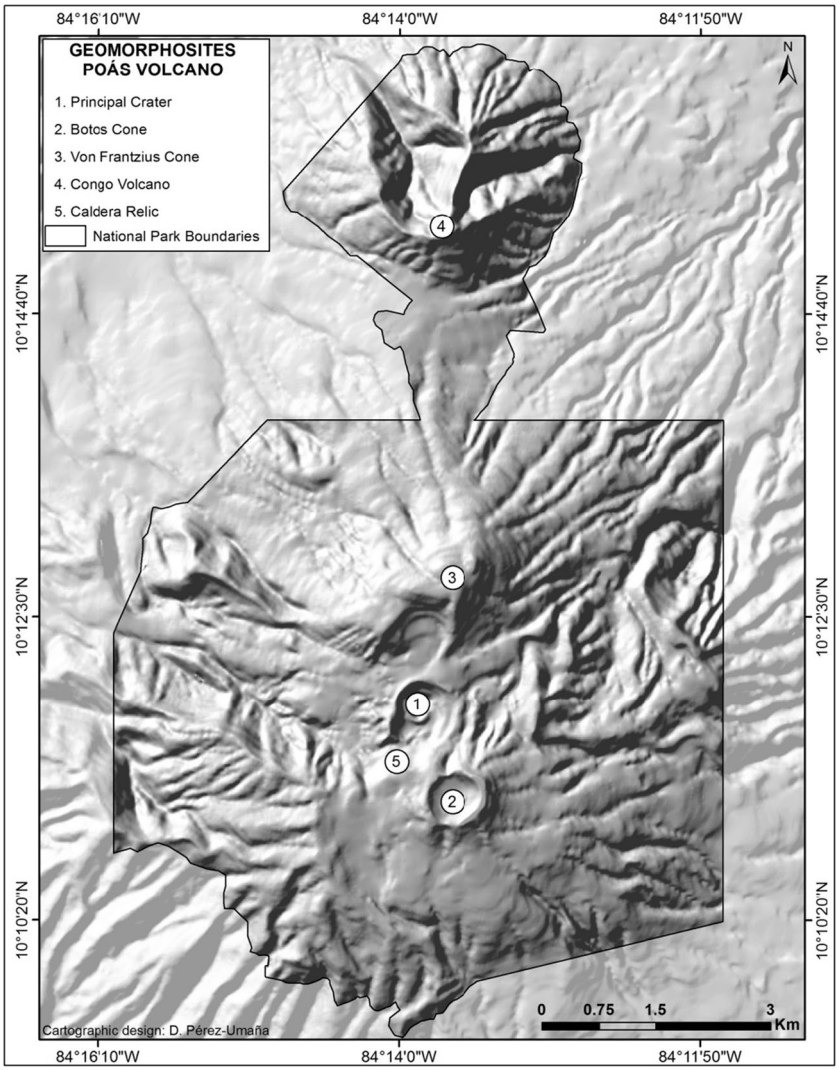

Fig. 1 Location of Poás volcano (Pérez-Umaña 2017)

located in Michoacán, 330 km west of México City (Fig. 2). This volcano represents one of the last documented volcanic expressions inside of Michoacán-Guanajuato Volcanic Field, a zone where the largest number of monogenetic volcanoes in México was formed and concentrated with over 1000 volcanic structures (Mazzarini et al. 2010), a density of 2.5 volcanoes for each 100 km^2 (Hasenaka and Carmichael 1985). At the same time, it connects with a major volcanic system known as the Mexican Volcanic Belt, which is recognized as one of the biggest continental volcanic arcs in the world and the largest of North America (Ferrari et al. 2012).

Paricutín Volcano is one of the youngest volcanoes in the world first erupting in February 5, 1943, and continued erupting over approximately 9 years, until its last eruptive episode on March 4, 1952 (Luhur and Simkin 1994). It alternated between effusive and explosive periods, this being so characteristic of its eruptions that such eruptions are now referred to as Paricutín type (Martín and Németh 2006). The product of the recent activity, that structure retains its primary morphological shape it also has a defined geomorphological limit with its parasite volcano Sapichu (De Jesús 2014). Between both volcanoes a lava flow of low viscosity arose that covered an area of 300 km^2 (Corona 2001), generating an extensive lava field. Here, it formed its secondary volcanic structures, such as lava tubes, *levees*, and volcanic mouths with particular characteristics.

Teide-Pico Viejo Volcano

Teide-Pico Viejo (28° 16′ 20.5″ north latitude, 16° 38′ 32.9″ west longitude) are two large stratovolcanoes (TPVS) located in the central part of Tenerife (Canary Islands, Spain). TPVS forms an elongate double edifice with a shallow saddle at 3000 m altitude that separates their summits only 2500 m (Fig. 3). Pico Viejo (3103 m) is a rather symmetrical cone, and the summit is occupied by a caldera with a diameter of 1 km and a depth of 150 m. Teide (3718 m) is an approximately circular cone, with a basal diameter of 5–5.5 km. The summit area is known as El Pitón, and is associated with the last eruption of Teide. This area is a

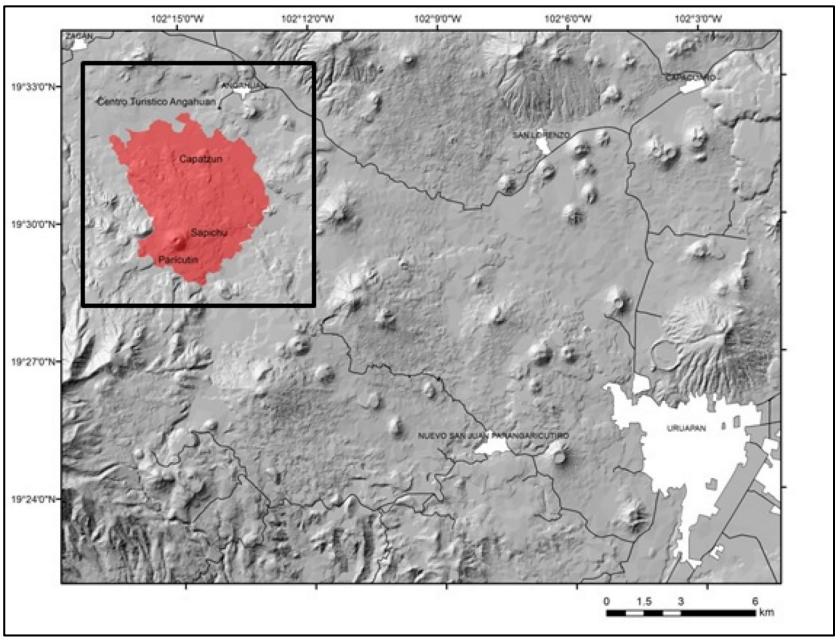

Fig. 2 Location of Paricutin volcano. (De Jesús 2014)

volcanic paradise with a complex geology and is rich in spectacular landforms including stratovolcanoes, calderas, cinder cones, domes, craters, pahoehoe, aa, block and balls lavas, etc.

The Teide-Pico Viejo volcanoes are product of the most recent phase of central volcanism on Tenerife (Ablay and Martí 2000) from 180 ka ago (Martí et al. 2008). Post-caldera volcanic activity is concentrated on the northern part of the Las Cañadas Caldera where the Pico Viejo and Teide stratovolcanoes are currently growing (Ablay and Martí 2000). These twin stratovolcanoes comprise products from various, mainly effusive,

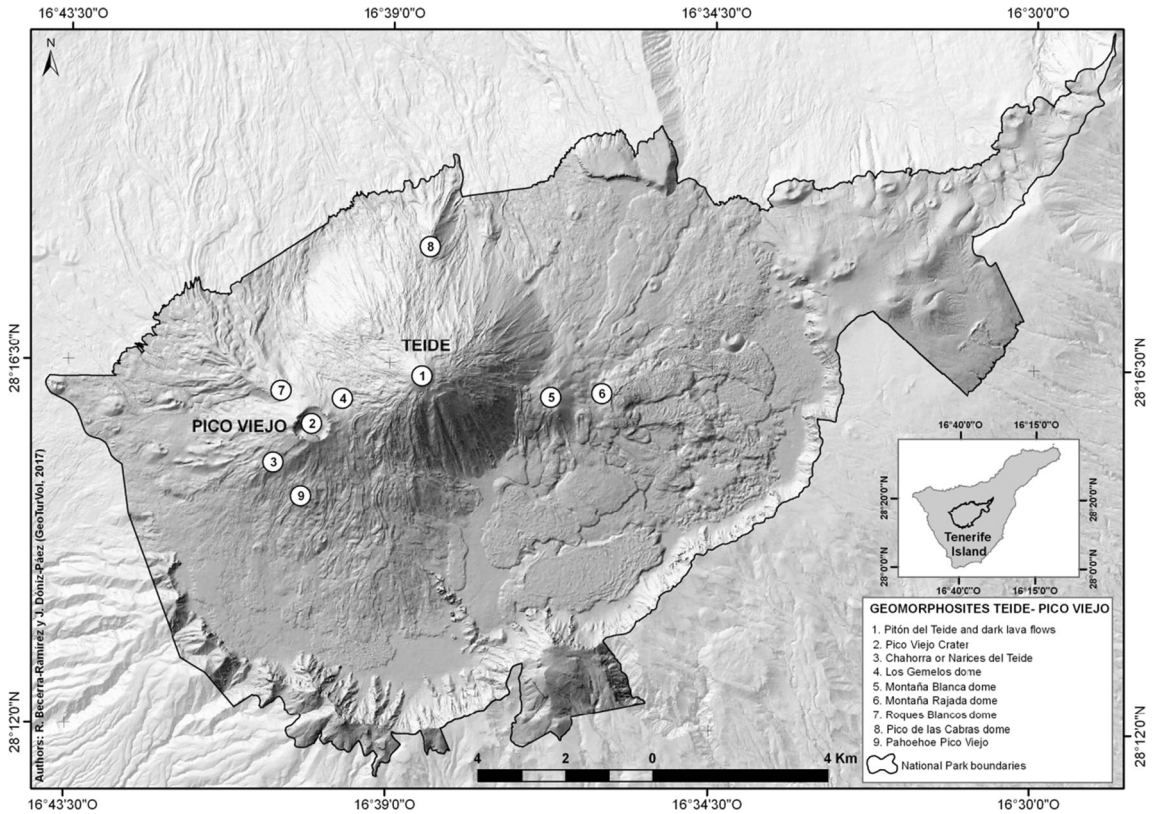

Fig. 3 Location of Teide-Pico Viejo volcanoes

eruptions of mafic (basalts, tephro–phonolites) and felsic (phono–tephrites and phonolites) magmas (Ablay and Martí 2000). These eruptions included strombolian, violent strombolian, and sub-plinian magmatic eruptions, as well as phreatomagmatic eruptions of mafic magmas (Martí et al. 2008; Del Potro et al. 2009). The most recent eruption occurred in the medieval period in Teide stratovolcano (Carracedo et al. 2007) and in 1798 in the SW flank of Pico Viejo formed a multiple series of monogenetic volcanoes (Narices del Teide) with different cones and craters (Dóniz-Páez 2015).

Cultural Characterization

Poás Volcano

Pérez-Umaña (2017) relates that Poás volcano is an important element to the Costa Rican population, because it is represented in different cultural, social and educational manifestations. In addition, the Principal Crater has been a source of inspiration to painters, writers, musicians and artists (Alvarado 2011). For Costa Ricans, when they think of Poás volcano they think that the volcano is the Principal Crater. They generally do not see all the mountain as a volcano, and that is evidenced in the different artistic works inspired in the volcano (Pérez-Umaña 2017). The Principal Crater of Poás Volcano has appeared in different venues, for example, in Costa Rican bills and stamps. Alvarado (2011) details that this Crater appeared in a phosphorus box in Czech Republic in 2001.

A number of poems have appeared in literature such as "El Volcán Poás", written by Carlomagno Araya and "Semblanza Del Volcán Poás," written by Alfredo Cardona Peña (Alvarado 2011). This volcano was a place in two local legends, "The Rualdo's Sacrifice" (Sierra 1987, quote by Alvarado 2011), and "El Cadejos" (Zeledón 1989). In addition, musicians have written songs based on the volcano. Alvarado (2013) describes that the musician Carlos Guzmán composed "The Volcano Symphony" in 2008. A part of this piece is named after Poás Volcano. In addition, Chaves (2014) relates that Mario Jinesta composed the song called "Under Poás' Shadow."

Poás volcano was important to the Costa Rican natives who named it "Chibuzú", which means the "Mountain of the God." Natives believed that this volcano was the place where their god lived, so they respected the volcano in hopes of avoiding the displeasure of their god (Ceruti 2010).

Paricutín Volcano

The Paricutin eruption, meant not just a drastic change in the spatial area configuration, with the passing of agricultural land to a barren badland, accompanied by native flora and fauna disappearance, but also meant a forced abandonment of agricultural practices that gave sustenance to local population (Fig. 4). This last fact gives a cultural content to this event, because since Paricutín was born it destroyed two towns, Paricutín and San Juan Parangaricutiro. San Juan Parangaricutiro still retains some remnants, such as the church ruins covered partially by lava flows. This destruction of those two towns caused the displacement of nearly 2500 persons (Corona 2002) to other towns, regions and nations, thereby modifying the life style of these receiving communities.

Added values to the Paricutín eruption can be found in the area of science, because it represented the opportunity to document completely the birth of a volcano from the beginning to the end. This event allowed the best Mexican scientists to study the volcano. Geologist Ezequiel Ordoñez, as well as some international recognized volcanologists such as Trask, Dorf, Zies, Bullard, and Fries (De Jesús 2014). In the arts and culture, some of the most important artists of the day, such as Diego Rivera or Gerardo Murillo, created artistic works inspired by these event. In addition, advanced technologies were brought to bear, such as color photography and video recording to document this volcanic activity. Paricutín volcano was observed on national and international news, despite the fact that during that time period the world was focused on World War II.

Teide-Pico Viejo Volcanoes

The Teide-Pico Viejo stratovolcanoes are part of Las Cañadas del Teide National Park (LCTNP) established in 1954 and registered in the world heritage list (UNESCO) in 2007 as a natural site. The LCTNP receives more than three million tourists per year and has 21 main paths and 14 secondary ones and boasts three centers of interpretation. The slopes of these stratovolcanoes, along with Las Cañadas, were inhabited from prehistoric times were used for grazing of livestock. The local aborigines (*guanches*) left an important archeological footprint in the central part of Tenerife (lithic and ceramic utensil) (Arnay de la Rosa 2004). In addition to these activities, more recently, the community of Tenerife has exploited the NPTC territory for removing snow, wood, rocks and sulfur, beekeeping, and other activities. The originality of the cultural values of Teide and Pico Viejo stratovolcanoes reflect the importance of these features for travelers and scientists throughout the sixteenth–seventeenth and eighteenth centuries and in the cultural importance of the geography in myths, legends, traditions, exploration literature, and art (Martínez de Pisón et al. 2009).

Methodology

In this work, we utilized the geomorphosites assessment methodology elaborated by Serrano and González (2005). This methodology involves a three-way comparison of the different values of the geomorphosites. The first evaluation regards the scientific or intrinsic values, assessing the landforms present in the geomorphosite (Serrano and González 2005). In Table 1, we see the values of the first evaluation.

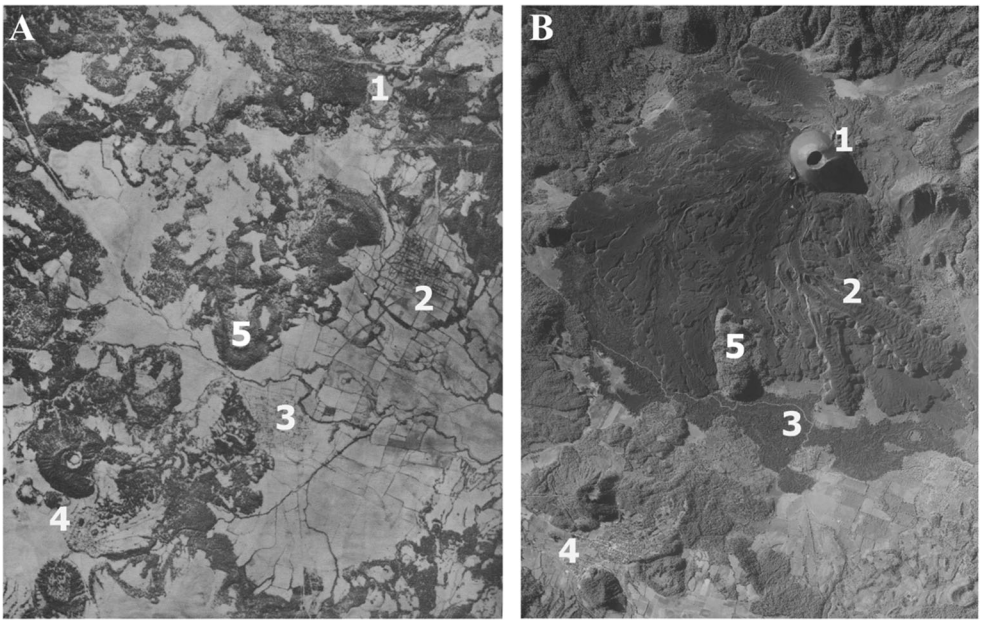

Fig. 4 **a** Aerial photography from 1933 (Mendoza 2010) that shows the relief before of the appearance of Paricutín volcano. Here, we see lava flows covered by potent pyroclastic capes that soften the field and characterize a surface that is somewhat wavy and inclined to east-southeast. Drainage is dendritic and controlled partially by old borders and lava scarps partially uncovered by erosion. Numbers shows reference points that are the same for both images indicating the changes in this area from volcanic activity. **b** Post-eruption relief (INEGI 1995, 1:75.000): (1) site where Paricutín volcano appeared; (2) Paricutín town; (3) San Juan Parangaricutiro town; (4) Angahuan town; (5) Capatzun hill

The second evaluation regards added values, also known as cultural values. This evaluation considers every cultural and environmental element that contributes to the enrichment of the geomorphosites (Serrano and González 2005). Table 2 shows the criteria used in this evaluation.

The third evaluation regards the value of use and management, and it has a relation to the fieldwork, because this information is obtained when detailed knowledge of the intrinsic and added values are needed (Serrano and González 2005). Table 3 shows the criteria of this evaluation.

When the evaluation is completed each geomorphosite is classified according a type. It will be a representative element (or representative place) when the geomorphosite is characteristic of a specific region and people have a cultural relation with the geomorphosite; meanwhile, it will be a singular element when the geomorphosite is a variation of other in the same region but the population do not feel identify with the landform (Pérez-Umaña 2017).

Results

The geomorphosites assessment methodology indicates that the three volcanoes in this study contain a considerable number of geomorphosites, which have present or potential touristic attraction. In addition, the study reveals that the geomorphosites

Table 1 Evaluation of the intrinsic values

Evaluation		Points	Definition
Genesis		Maximum 10	Processes that have intervened in the formation of the site
Morphology	Morphostructures Erosional landforms		Number of landforms composing the geomorphosite
	Accumulation landforms		
Dynamic	Inherited processes Current processes		Inherited and functional elements witness to past or active processes
Chronology			Genetic periods or phases
Lithology			Materials shown
Geologic structures			Number of visible structures
Sedimentary structures			Number of visible structures

Source Serrano and González (2005)

Table 2 Evaluation of the added values

Evaluation		Points	Definition
Landscape and esthetic		Maximum 10	Landscape and esthetic scale consideration: nonexistent (0), local and uncharacteristic component (2), medium-scale component (valley, municipality) (4), district component (6), essential component of the landscape in regional panoramas (8), protected or managed element due to landscape contents (10)
Cultural elements	Association with elements of heritage value	Maximum 10	Heritage elements (monuments, populations, popular, constructions, ethnological elements, …)
	Cultural content	Maximum 10	Cultural aspects (myths, legends, literature, painting, …)
	Historical content	Maximum 10	Historical phases of use or occupation
Educational	Educational resources	Maximum 5	Educational contents
	Educational levels	Maximum 5	Primary, secondary, university students
Scientific	Scientific value	Maximum 5	Scientific areas of significant value
	Scientific representativeness	Maximum 5	Local (1), district (2), regional (3), national (4), international (5).
Tourism	Real tourist content	Maximum 5	Historical-artistic; activities (excursions, others); landscape; simple leisure; others
	Potential for tourist attraction	Maximum 5	Capacity for tourist attraction: local, district, regional, national, international

Source: Serrano and González (2005)

have a cultural importance for the population and different use and management values depending on different factors within each country or region.

Poás Volcano

For the Poás volcano geomorphosites, the evaluation shows that this is a complex volcano with a strong cultural component, because this volcano is central to Costa Rican society and national identity. Table 4 displays the geomorphosites evaluation of Poás volcano.

In the Poás Volcano, five geomorphosites were proposed (Fig. 5). The geomorphosites evaluation of Poás volcano shown that this volcano has a complex dynamic, most notably in the Principal Crater, which was rated as the highest evaluation of the geomorphosites. This is the site where Poás volcano has the most activity including phreatic eruptions and degasification. In addition, it is the most complex geomorphosite because it has different volcanic structures created by different volcanic activity. The Von Frantzius Cone was affected by eruptions of the Principal Crater, and its morphology changed profoundly because its cone was divided into two parts. The Botos Cone has a pluvial lagoon located within it. This geomorphosite, an old monogenetic volcano, had little activity and for that reason its morphology is simple, because it is an old monogenetic volcano. The Congo volcano was active at the same time as the Von Frantzius cone, but this geomorphosite finished its activity leaving a morphology of a simple cone with a crater that is open to northwest. Finally, the Calderic Relic represents the oldest structure of the Poás volcano.

Added values indicates that three geomorphosites are representative for Costa Rican citizens, those being the Principal Crater, Botos Cone, and Von Frantzius Cone. The reason why these are representative are because its particularity among the volcano and a tourist visiting the Poás Volcano National Park is seeing this geomorphosite. Therefore, artists can obtain inspiration from these landscapes to make different creative works and citizens and tourists take inspiration as well. Pérez-Umaña (2017) said that the Principal Crater is important to the population because they see the whole volcano as being this geomorphosite. In addition, the Congo Volcano and the Calderic Relic obtained low values because visitors do not see these geomorphosites as they are harder for a tourist to see and identify them as a part of the volcano; also they are not promoted as the same way as the Poás crater.

The use and management values show that all of the geomorphosites are valuable and they can be used for tourism. For example, the Calderic Relic has a high value although it is hidden and is unknown to tourists. The same case can be made for the Von Frantzius Cone, but this geomorphosite is located in a restricted access area and, for that reason has a high rating in this evaluation. The other geomorphosites have high values but they also have good accessibility. That is to say that tourists can easily walk to them and appreciate them, they have a low level of dangers and are easily observed, thereby favoring touristic activity at these geomorphosites.

According to this information, the geomorphosites of Poás volcano can be classified in high, medium and low according of their interest level, also, is defined the principal value given for population. This classification is shown in Table 5.

Table 3 Evaluation of the use and management values

Evaluation	Points	Definition
Accessibility	HIGH: 2. Good accessibility MEDIUM: 1. Difficult accessibility LOW: 0. Poor accessibility	Utility due to the accessibility of the geomorphosite for its use and management
Fragility	HIGH: 0. Use not recommended MEDIUM: 1. Potential use LOW: 2. High value of use	Degree of fragility of geomorphosite due to its intrinsic characteristics
Vulnerability	HIGH: 0. Elements capable of transforming the structure or dynamic of the geomorphosite MEDIUM: 1. Low degree transformation LOW: 2. No vulnerability	Elements of the geomorphosite environment that can entail irreversible changes in its intrinsic and extrinsic values
Intensity of use	HIGH: 0. Intense use, not permitting any increase in activities MEDIUM: 1. Moderate use LOW: 2. Low level to use	Current use of the geomorphosite
Risk of degradation	HIGH: 0. High risk of degradation MEDIUM: 1. Medium risk of degradation LOW: 2. Low risk of degradation	Possible damage to the geomorphosite with loss of intrinsic and added values
State of conservation	HIGH: 2. Allows use MEDIUM: 1. Restricted use LOW: 0. Use not recommended	Degree of conservation of the intrinsic and extrinsic values of the geomorphosite
Impacts	HIGH: 0. Advice against use, with restoration possibility MEDIUM: 1. Allowed use but restoration or impact elimination advised LOW: 2. No intense impact	Human elements directly affecting the geomorphosite (roads, quarries, civil works)
Quality of view	HIGH: 2. High quality of view MEDIUM: 1. Medium quality of view LOW: 0. Low quality of view	Conditions for observation (landscape, location, accessibility, etc.) for the use of geomorphosites
Limits of acceptable change	HIGH: 2. Low fragility and weak intensity of use, changes do not imply loss of values MEDIUM: 1. Current fragility and uses allow moderate changes without loss of values LOW: 0. High fragility or intensity of use, change implies loss of values	Potential for changes that the geomorphosite can undergo without losing its intrinsic and added values (this is related to fragility and intensity of use)

Source: Serrano and González (2005)

Paricutín Volcano

The geomorphosites evaluation of the Paricutín volcano shows that this volcano is very interesting to the enthusiast tourists. By the characteristics of its recent formation and the almost nonexistent formation of erosive or accumulative structures, the evaluated sites of the Paricutin volcano yield low intrinsic values. In relation to added values, the principal

Table 4 Geomorphosites evaluation in Poás Volcano

Geomorphosite			Assessment		
Number	Name	Type	Intrinsic value	Added value	Use and management value
1	Principal Crater	RE	6.8	9.6	7.2
2	Botos Cone	RE	3.1	7.0	6.7
3	Von Frantzius Cone	RE	3.3	6.9	7.8
4	Congo Volcano	SE	2.3	4.4	6.1
5	Caldera Relic	SE	1.4	1.1	7.8

Source: Pérez-Umaña (2017)

RE representative element, *SE* singular element

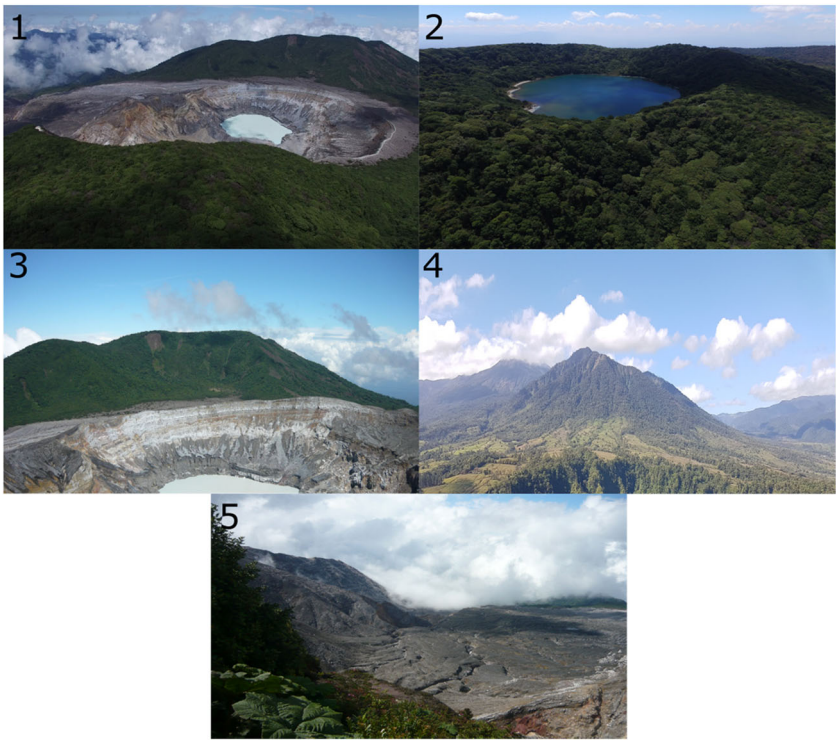

Fig. 5 Geomorphosites of the Poás volcano. (1) Principal Crater (PRIAS-CeNAT 2017), (2) Botos Cone (PRIAS-CeNAT 2017), (3) Von Frantzius Cone (Pérez-Umaña 2017), (4) Congo Volcano (Martínez 2017), (5) Caldera Relic (Pérez-Umaña 2017)

structures of the lava field (Paricutín, Sapichu), the ruins of the old church of San Juan Parangaricutiro have a direct relationship with the social-historic history of the area. For that reason those geomorphosites have high values. For use and management values, the optimal conservation state of the nine geomorphosites give them high values in this section (Table 6). The geomorphosites of these volcanoes are shown in Fig. 6.

One of the best studied of the representative geomorphosites (historic-volcanic), includes the unique eruptive history of Paricutín. The middle interest geomorphosites (scientific-scenic) are complementary to the principal structures, but are important in the analysis of the natural history of the site. Finally, geomorphosites included in the low interest group (didactic-punctual), that are singular elements related to diffusion of geomorphological knowledge, are used as exceptional tools to understand the lava flows dynamics and the explosive activity (Table 7).

Table 5 Geomorphosites of Poás volcano according their interest level

Interest level	Geomorphosites	Principal value
High (historic-volcanic)	Principal Crater	Scientific-scenic
Medium (scientific-scenic)	Botos Cone	Scenic-didactic
	Von Frantzius Cone	Scientific-scenic
Low (didactic-punctual)	Congo Volcano	Didactic
	Caldera Relic	Didactic

Source: Pérez-Umaña (2017)

Teide-Pico Viejo Volcano

The original geomorphology of the Teide-Pico Viejo stratovolcanoes together with the geographical peculiarities of this area of Tenerife, including recent volcanism, petrological variety, semiarid climate on the summit area of Tenerife, ice and snow, rugged topography, and notable differences of vegetal colonization, result in a high level of geodiversity. The nine geomorphosites selected in Teide (1, 5, 6, 7, and 8) and Pico Viejo (2, 3, 4, and 9) indicate that this volcanic complex is very interesting in terms of geoheritage (Table 8). This geomorphosite is illustrated in Fig. 7. Scientific values tend to be lower than cultural values, because of the presence of humans over several centuries in the upper reaches of Tenerife. However, identified geomorphosites have very important scientific values. These include the Crater of Pico Viejo and the eruption of Narices del Teide cinder cones in 1798. Both have high scientific values associated with the diversity of landforms and volcanic processes such as stratovolcanoes, cinder or scoria cones, craters, explosion crater, lava field (pahoehoe, aa, and blocky), hornitos, gullies, talusees, foodplains, etc. At the same time, the domes of Los Gemelos and Pico Cabras have low scientific values associated with a lower diversity of direct and eroded volcanic landforms.

For the selection of the geomophosites, the LCTNP was divided into four geomorphological units, the Teide-Pico Viejo stratovolcanoes, the Las Cañadas Caldera wall, the bottom of Las Cañadas, and the basaltic volcanic field.

Table 6 Geomorphosites evaluation in Paricutín Volcano

Geomorphosite			Assessment		
Number	Name	Type	Intrinsic value	Added value	Use and management value
1	El Vertedero	SE	1.8	5.0	8.3
2	El Barandal	SP	1.5	5.1	8.3
3	El Collado; Contacto Paricutín – Sapichu	RP	0.9	4.5	9.4
4	Bomba Rompecabezas	SE	1.0	2.7	6.6
5	Sapichu Cone	RP	2.2	7.4	8.8
6	Paricutín Volcano	RP	4.0	9.8	7.7
7	Los Hornitos	SP	1.6	3.8	10
8	Lava Tunnel	SP	2.0	3.1	7.2
9	Lord of Miracles Temple – San Juan Parangaricutiro	RP	1.4	8.9	7.7

Source: De Jesús (2014)

SE singular element, *SP* singular place, *RP* representative place

Each one of them was selected as the most representative geomorphosite because of its geodiversity, its geomorphological heritage, its landscapes, and its tourist potential. All of the selected geomorphosites are within areas that allow public use of the park. The inventory classifies the 23 geomorphosites in two main categories: (a) direct volcanic with 17 geomorphosites (stratovolcanoes, domes, cinder cones, pahoehoe, aa, and bloc lava flows, etc.) and (b) eroded volcanic landforms with six sites (wall of Las Cañadas caldera, talusees, foodplains, etc.). The Teide-Pico Viejo unit has more geomorphosites with eight and Las Cañadas wall unit possessing less with five. The assessment evaluates the scientific, cultural/historical, and use values, and helps to define priorities in site management. These geomorphosites demonstrate the volcanic history and processes of the LCTNP (Table 9).

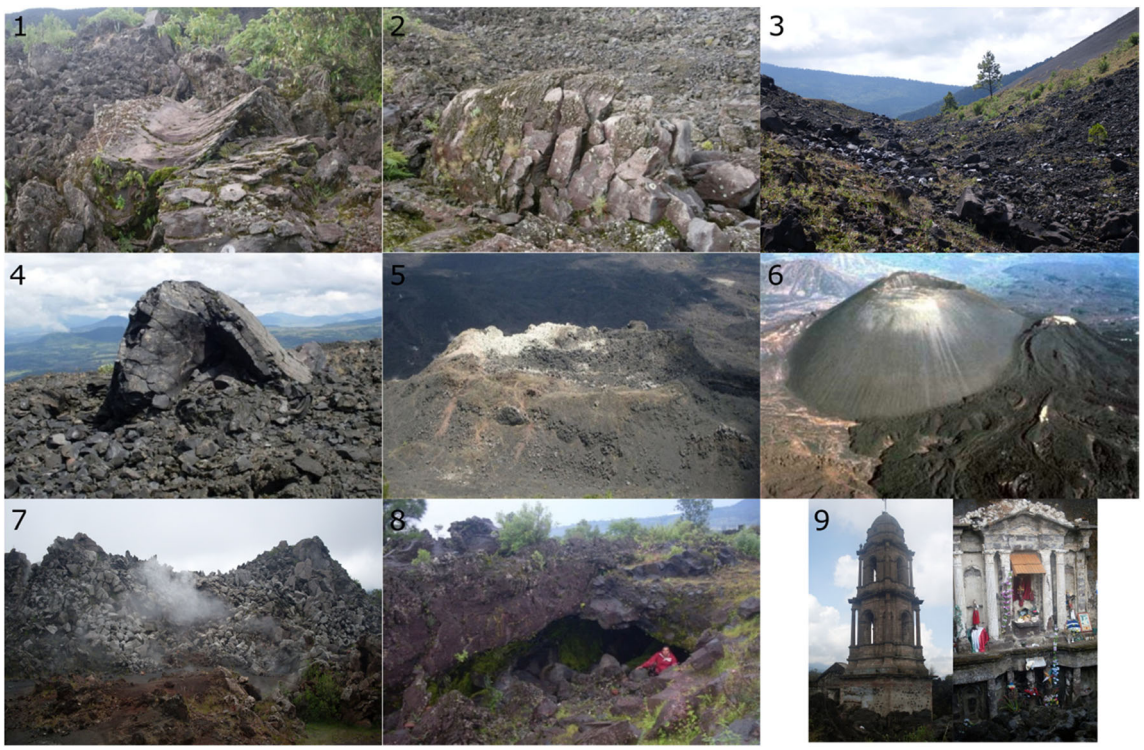

Fig. 6 Geomorphosites of Paricutín volcano. (1) El Vertedero, (2) El Barandal, (3) El Collado, (4) Bomba Rompecabezas, (5) Sapichu Cone, (6) Paricutín Volcano, (7) Los Hornitos, (8) Lava Tunnel, (9) Lord of Miracles Temple – San Juan Parangaricutiro (Source: De Jesús 2014)

Table 7 Geomorphosites of Paricutín volcano according their interest level

Interest level	Geomorphosites	Principal value
High (historic-volcanic)	Sapichu Cone	Touristic-scientific
	Paricutín volcano	Scientific-touristic
	Los Hornitos	Didactic-scientific
	Lord of Miracles Temple – San Juan Parangaricutiro	Touristic-cultural
Medium (scientific-scenic)	El Collado	Didactic
	Lava Tunnel	Scientific-touristic
Low (didactic-punctual)	El Vertedero	Didactic
	El Barandal	Didactic
	Bomba Rompecabezas	Esthetic-didactic

Source: De Jesús (2014)

Discussion

The proposed geomorphosites in this work show that these volcanoes have unique morphologies. The different processes in these volcanoes produced them as original and interesting sites. Every geomorphosite displays values exclusive to each formation. Analysis of the geomorphosites of the three volcanoes is shown in Table 10.

In Table 10, the intrinsic values show that Principal Crater of Poás volcano is the geomorphosite with the highest value of 6.8, followed by the Paricutín volcano and Pico Viejo Crater, each one with a value of 4.0. The Principal Crater is a geomorphosite with unfinished activity exhibiting ongoing phreatic eruptions and degasification (Pérez-Umaña 2017). In Fig. 3a, we see the acidification alley to the west of the lagoon of the Principal Crater.

The Paricutín volcano and Pico Viejo Crater represent the principal areas of these other volcanoes in this study, and each one exhibits a value of 4.0. Paricutín volcano has the distinction of being one of the youngest volcanoes in the world, with a witnessed date of birth and of completion. De Jesús (2014) said that a volcano is monogenetic when its activity lasts less than 15 years, and Paricutín Volcano had an activity period of 9 years. Therefore, Paricutín volcano is monogenetic. For this reason, these geomorphosite values in this evaluation are low, because its relief does not exhibit significant changes.

The Pico Viejo Crater represents a conserved geomorphosite in a volcano with little activity because its last activity ceased long ago. As a result, the relief of this geomorphosite does not exhibit many changes in recent times. It exhibits many structures, which enrich the morphology of the volcano. For this reason, it is the geomorphosite with the highest value in the Teide-Pico Viejo volcanoes and is the one with the second highest score in the Intrinsic Values of this study.

The Cañadas del Teide National Park is considered a geodiverse area because it has different landforms, structures, and processes related to volcanic activity (Dóniz-Páez 2010). Proof of this is the variety of geomorphosites present within this protected area, such as Pahoehoe Pico Blanco and Narices del Teide. In case of Narices del Teide, this is a geomorphosite with materials dated approximately in 32 ka years with a residual solfatarian activity (Criado et al. 2008).

The Principal Crater of Poás volcano is the most attractive geomorphosite because its dynamic is constant and it has

Table 8 Geomorphosites evaluation in Teide-Pico Viejo Volcanoes

Geomorphosite			Assessment		
Number	Name	Type	Intrinsic value	Added value	Use and management value
1	El Pitón – Coladas Negras	SE	2.8	4.4	5.0
2	Pico Viejo Crater	RP	4.0	5.0	3.9
3	Narices del Teide	RP	3.3	3.9	5.0
4	Los Gemelos Dome	SE	2.2	3.9	5.6
5	M. Blanca Dome	SP	3.2	4.4	6.1
6	M. Rajada Dome	SP	2.5	4.1	6.1
7	Roques Blancos Dome	SP	2.7	4.6	6.1
8	Pico Cabras Dome	SP	2.3	4.3	8.3
9	Pahoehoe Pico Viejo	SP	3.6	6.3	1.7

SE singular element, *SP* singular place, *RP* representative place

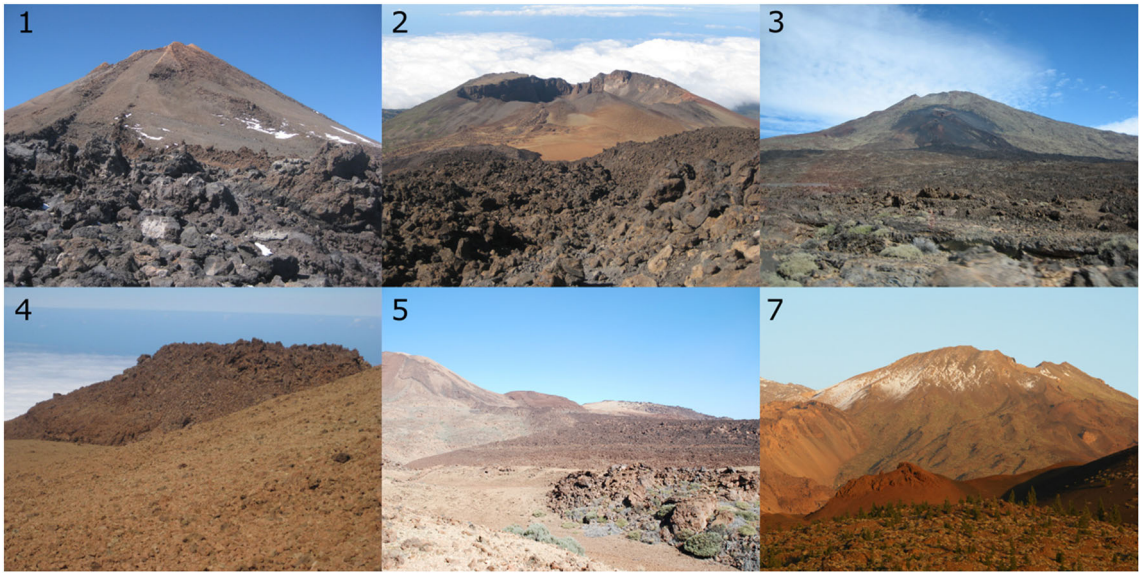

Fig. 7 Geomorphosites in Las Cañadas del Teide National Park. (1) El Pitón – Coladas Negras, (2) Pico Viejo Crater, (3) Narices del Teide, (4) Los Gemelos Dome, (5) M. Blanca and M. Rajada Domes, (7) Roques Blancos Dome (Source: Dóniz-Páez et al. 2017)

recurrent changes, giving it the highest intrinsic value. On the other hand, Paricutín volcano and Pico Viejo Crater are volcanoes without activity; for this reason why conserve their relief and do not have relevant changes in their morphology. Therefore, the most important geomorphosite in the evaluation is Principal Crater of Poás Volcano.

Added values show the importance of the geomorphosite to the population. In this valuation the geomorphosite with the highest value is Paricutin volcano with a value of 9.8. The origin of this volcano was documented and studied by scientists, yielding the scientific relevance to the volcano. In addition, the locals evacuated because the eruptions destroyed their homes and crops. De Jesús (2014) describes that the activity of the Paricutín volcano increased the tourism, because visitors were interested in watching the eruptions and the aftermath. Mexicans were witnesses of the development of the Paricutín activity, and this has become a part of their cultural heritage.

Principal Crater of Poás Volcano is the second with a highest value with 9.6. This geomorphosite is representative for Costa Rican citizens because when they discuss this volcano they make a relation with the Principal Crater. Costa Ricans identify Poás volcano as this geomorphosite (Pérez-Umaña 2017). This is demonstrated in the different cultural manifestations, for example when Costa Ricans mention the Poás volcano, they are referring to the Principal Crater. Poás volcano has the particularity of being one of the only volcanoes in Costa Rica with a road up tp its crater (Salguero 2003), increasing the potential for tourist access to the volcano. Also, as it is an active volcano, it is studied frequently to identify changes in its morphology and potential eruptive state.

Like Poás volcano, Teide volcano has an important cultural value, because it was the scenario of an intense economic activity in relation to grazing of livestock. Added values present in this volcano include use by travelers and scientist. In addition, people have developed cultural manifestations such as legends, myths, literature, arts, and others inspired by this volcano (Dóniz-Páez 2010).

The third geomorphosite with a high value was Lord of Miracles Temple – San Juan Parangaricutiro with a valuation of 8.9. This is the remainder of the San Juan Parangaricutiro

Table 9 Geomorphosites of Teide-Pico Viejo volcanoes according their interest level

Interest Level	Geomorphosites	Principal Value
High (volcanic-historic)	Pico Viejo Crater	Scientific-Touristic
	Narices del Teide	Scientific-touristic
	M. Blanca Dome	Touristic-scientific
	Pahoehoe Pico Viejo	Scientific-touristic
Medium (scientific-scenic)	El Pitón – Coladas Negras	Touristic-scientific
	M. Rajada Dome	Touristic-scientific
	Los Gemelos Dome	Touristic-didactic
Low (didactic-punctual)	Roques Blancos Dome	Esthetic-scientific
	Pico Cabras Dome	Esthetic-didactic

Table 10 Comparison of geomorphosite of Poás volcano, Paricutín volcano, and Teide Pico Viejo volcano

Volcanoes	Geomorphosites	Intrinsic value	Added value	Use and management value	Global value
Poás	Principal Crater	6.8	9.6	7.2	7.9
	Botos Cone	3.1	7.0	6.7	5.6
	Von Frantzius Cone	3.3	6.9	7.8	6.0
	Congo Volcano	2.3	4.4	6.1	4.3
	Caldera Relic	1.4	1.1	7.8	3.4
Paricutín	El Vertedero	1.8	5.0	8.3	5.0
	El Barandal	1.5	5.1	8.3	5.0
	El Collado; Contacto Paricutín-Sapichu	0.9	4.5	9.4	4.9
	Bomba Rompecabezas	1.0	2.7	6.6	3.4
	Sapichú Cone	2.2	7.4	8.8	6.1
	Paricutín Volcano	4.0	9.8	7.7	7.2
	Los Hornitos	1.6	3.8	10	5.1
	Lava Tunnel	2.0	3.1	7.2	4.1
	Lord of Miracles Temple – San Juan Parangaricutiro	1.4	8.9	7.7	6.0
Teide-Pico Viejo	El Pitón – Coladas Negras	2.8	4.4	5.0	4.1
	Pico Viejo Crater	4.0	5.0	3.9	4.3
	Narices del Teide	3.3	3.9	5.0	4.1
	Los Gemelos dome	2.2	3.9	5.6	3.9
	M. Blanca dome	3.2	4.4	6.1	4.6
	M. Rajada dome	2.5	4.1	6.1	4.2
	Roques Blancos dome	2.7	4.6	6.1	4.5
	Pico Cabras dome	2.3	4.3	8.3	5.0
	Pahoehoe Pico Viejo	3.6	6.3	1.7	3.9

town or of the Colchas, which was covered almost completely by the first lava flows emitted by the Paricutín volcano, reaching a thickness of 15 to 20 m. From this site only the church's tower and walls remained standing following the eruption. This is one of the principal touristic attractions of the area. Before of the eruption, this temple was a religious center and focus of pilgrimages to visitors attracted by the figure of the Lord of Miracles (De Jesús 2014). This place became the most important attraction of the area for the lava flows that surrounds the church ruins.

In added values, these geomorphosites are important in the relationships that people have with them. In the case of Poás volcano, the population has been inspired by this geomorphosite to make artistic renditions related to Costa Rican nationalism. For example pictures in currency, songs, and tales. Teide volcano has the same relationship with population in Tenerife. However, in the case of Paricutín volcano and The Lord of Miracles Temple geomorphosites visitors were witnesses to the destruction caused by the eruptions of the volcano. The destruction of the Temple was significant because it was a place of great importance to many people. Also, the eruptive process of the Paricutin volcano was a global model to understand how other volcanoes like Paricutín were formed.

The highest use and management values are found in the Paricutin volcano, with the geomorphosite Los Hornitos having the highest value of 10. El Collado was the second highest with a value of 9.4, and the Sapichu Cone being third with a score of 8.8. Los Hornitos is very different in that it is not in danger of degradation from erosive agents and it also has limited visitation, which means that it should remain in a good state of conservation. El Collado has medium accessibility and good state of conservation, these characteristics allow a clear observation of the geomorphosite. Sapichu Cone has medium accessibility and it has a road that is used by tourists (De Jesús 2014).

In the case of Poás Volcano, the geomorphosites Von Frantzius Cone and Caldera Relic have the highest values, each one rated at 7.8. These geomorphosites are located in a restricted area of Poás Volcano National Park, and this restriction protects the geomorphosite from human interaction. They are preserved but they are vulnerable to processes such as earthquakes and volcanic eruptions.

Conclusions

These volcanoes are varied and different. The geomorphosites in each volcano show a dynamic that is not presented in the other volcanic complexes. Intrinsic values detail that the most important geomorphosite is the Principal Crater of the Poás volcano because it is an active volcano and this activity changes the dynamics and morphology of the volcano. This intense

activity can modify the geomorphosite, which could increase the evaluation of this site. Paricutín volcano and Pico Viejo Crater are conserved geomorphosites located in inactive volcanoes, but if these volcanoes had activity, their characteristics could change.

'Added values' detail that the Principal Crater of Poás volcano and Paricutin Volcano are the most important geomorphosites of this study. They have a relationship with the population of their regions or countries and societies that see the volcanoes as an important component of their culture. Different artists create artistic works inspired by the volcanoes, evidence that they are symbols to these social groups, symbols that identify and represent them. This evaluation can be used to understand the importance that a volcano or geomorphosite has on a local, regional, national, or international scale.

Teide Volcano has an emblematic identity, where different volcanic landforms are present and different processes have modeled the geomorphosites. It has an economic and cultural importance, because, in this volcano are found activities such as grazing. This volcano has also inspired people to create many artistic works. The population can use this characteristic as another touristic attraction for the volcano.

"Use and management" evaluation reveal that it is not necessary that a volcano be active to have conserved landforms. In this case, the geomorphosites of the Paricutin volcano exhibit the highest values of the study. These geomorphosites have good accessibility and a good state of conservation. This is possible because Paricutin volcano is inactive, and its relief does not exhibit drastic changes over time.

This study shows that these volcanoes are representative of Costa Rica, México, and Spain. Tourism is the principal activity by which people can learn about these features. Unique landscapes, geological complexity and an important cultural complement in each geomorphosite gives tourists a significant experience when they visit these volcanoes. The methodology of geomorphosite evaluation gives another perspective to study the relief, and give ideas to identify new touristic attractions in other territories, or in this case, understand the present dynamic in a volcano and its relation with the society from a scientific and cultural perspective.

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