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ORIGINAL ARTICLE

Geological Heritage of the North Region of the State of Michoacan, Mexico

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Abstract
The inventory of the geological heritage of a region is a necessary action to promote its conservation and its diffusion. We selected the Northern region of Michoacan to advance the inventory of its geological heritage, particularly in the field of volcanology, hydrology and geothermal. The term "scientific geoheritage" was used to refer to those geological features that may be susceptible to be considered as having a potential geological heritage of north Michoacán. The aim was to focus on the complex context and significance of the geological heritage, so that the protection schemes take into account its use as a natural, scientific, and cultural heritage. The Michoacan Guanajuato Volcanic Field is a highlighted geo-area with the Volcan Paricutin as an important geosite. Important hydrological sites are Lago Camecuaro and Los Chorros del Varal, which are also protected natural areas. Finally, the Azufres is a geothermal area with high economic and scientific value.

Keywords Geological heritage · Geo-cultural sites · Preservation · Environment

Introduction

The inventory of the geological heritage of a region is a basic action to promote its conservation and its diffusion. We selected the northern region of the State of Michoacan to advance the inventory of its geological heritage, particularly in the field of volcanology, hydrology, and geothermalism.

Although the initial criteria for the selection of specific sites consider the definition of geological heritage in the sense of their value to geological science, it is discussed how to integrate into the assessment the relations of society with the geological features, so that they are also considered as cultural heritage. The aim is to take into account the use of geosites as a natural, scientific, or cultural heritage like criterion in the definition of a preliminary regional inventory of the geoheritage. The Michoacan Guanajuato Volcanic Field is a highlighted geo-area with the Volcan Paricutin as an important geosite. Important hydrological sites are Lago Camecuaro and Los Chorros del Varal, which are also protected natural areas. Finally, the Azufres is a geothermal area with high economic and scientific value.

The character of geological heritage is assigned to all those non-renewable natural resources whose exposure and content allow us to study and interpret the evolution of the geological history of a region or the whole of the earth (García-Cortez et al. 1992).

The geological elements are susceptible to turn into heritage from the perception of its surrounding population or from the geological science itself. The valuation as "heritage" in each case derives from different knowledge structures; on one side, the scientific knowledge that is developed through institutions and on the other, traditional knowledge which is structured and recreated from experiences inherited from hundreds and in some aspects, thousands of years ago, by ethnic and local communities (Jofré et al. 2008).

The term "scientific heritage" often refers to documentary or archeological elements of the history of science (Álvarez and Molina 1999; Viñao 2011). It is also used to refer to the process of attributing value to objects from a framework of interpretation elaborated in some area of science (Alcalá and Alcalá 1996; Martínez et al. 2015).

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Carcavilla et al. (2008) mention that geological heritage inventories are a selection of the most significant geological features of a region based on various parameters such as intrinsic value or representativeness. The last defined as the set of elements that stand out for their scientific, cultural value or that promote education about the geological wealth of the population in general.

The leading social movements on the conservation, maintenance, and dissemination of geological heritage have been born in Europe in the last 20 years. However, these events continue to grow in the five continents, and our country is no exception.

Initiatives like Progeo or the European Association for the Conservation of the Geological Heritage promote the conservation of sites that include fossils, rocks, minerals, and landscapes (Wimbledon et al. 2000).

The initiative Geomorphosites, promoted by the International Association of Geomorphologists (IAG) through the Working Group on Geomorphosites, and the Geoparks program, promoted by the IUGS and UNESCO (Eder and Patzak 2004), are two noteworthy engagements. They have focused on the promotion and assessment of the abiotic environment, particularly geology and geomorphology (Palacio-Prieto 2013).

In Mexico, efforts have been made to protect the geological heritage (Palacio-Prieto 2013, 2015). Recently, UNESCO (2017) declared as geoparks the regions of the "Comarca Minera," of Hidalgo, and the "Mixteca Alta," of Oaxaca, sites of great geological diversity in which the natural protection promotes its sustainable development.

Palacio-Prieto (2013) cites the studies carried out by the Department of Marine Geology of the Autonomous University of Baja California Sur in La Paz, Baja California Sur. These have addressed the importance of geological heritage (Gaitán 2005; Gaitán Morán and Alvarez Arellano 2009; Gaitán Morán et al. 2001, 2003, 2004; Gaitán Morán and Cano Delgado 2009; Jorajura Lara and Mendoza Trasviña 2007; Martínez Gutiérrez et al. 2007).

The Institute of Environment and Human Communities of the University of Guadalajara identified 12 sites in the Jalisco state worthy of the category of geological heritage. The inventory of sites made includes, among others, the Volcan de Fuego, Volcan Nevado, Cerro de Tequila and Cerro Alto, the lakes of Chapala and Sayula and the canyon of Rio Grande (La Gaceta 2006).

However, there is still no legal framework in Mexico that explicitly recognizes and values the importance of geology and geomorphology focused on conservation, education, and sustainable development and the apparent bias towards the biotic aspects embodied in the environmental legislation of our country (Palacio-Prieto 2013).

A total of three sites and two areas were assessed regarding the geological heritage of Michoacan. Geosites could be defined and characterized in the volcanic, geothermal, and hydrological aspects. In the latter category, two sites are integrated into two protected natural areas, one federal and the other statewide.

The article defines the geological heritage value of a site or region as its scientific importance given its unique geological characteristics whether stratigraphic, tectonic, hydrological or metalogenetic series. Nevertheless, we uphold the relevance of promoting regional geoheritage sites regardless of its world representativeness. The article seeks an approach that exceeds the disciplinary barriers in the valuation of geological heritage (Kiernan 2015), in a way that promotes integral management of it. Therefore, the objective of the article is to define potential sites of Michoacan state to be considered as geoheritage.

Method

The study area is located in the northern portion of the state of Michoacán Bounded by the coordinates 18° 59′ 20″, 20° 04′ 33″ of north latitude and 102° 36′ 32″, 100° 28′ 41″ of west longitude (Fig. 1).

Considering the recognized information sources such as existing records in the literature on north Michoacán, cartographic information from INEGI and consultation of specialized literature related to the regional and local geological field (Ban et al. 1992; Bullard 1947; Hasenaka and Carmichael 1985; Lugo 1985; Garduño et al. 1999; Delgado-Granados et al. 1995), the sites that appear in Fig. 1 were prpoposed as geological heritage. This information guided the selection of the relevant geological sites for their protection. We recognize that the selection is limited by the extent of our sources and in that way, this is not an exhaustive inventory. Furthermore, the two geo-areas of Los Azufres and the volcanic field lack a detailed assessment of specific geosites.

The geological contexts can be any regional geological element like stratigraphic series, tectonic, hydrologic, and metallogenetic, in such a way that the selected geosites are framed within a global geological context, either with common or unique characteristics.

The qualitative aspects taken into account were as follows: the state of conservation referred to its degree of deterioration by anthropic activities, relative abundance focused on the number of similar cases present in the region, and its scale and its representativeness associated with a unique event in the geological field.

The geosite scale was not a delimiting aspect since a geological event of regional scale can be measured and considered within the scope of regional or local heritage, depending on its scientific relevance over time.

We considered the scientific importance and the regional or local scope of the geological contexts. It can be valuable any regional geological element, stratigraphic, tectonic,

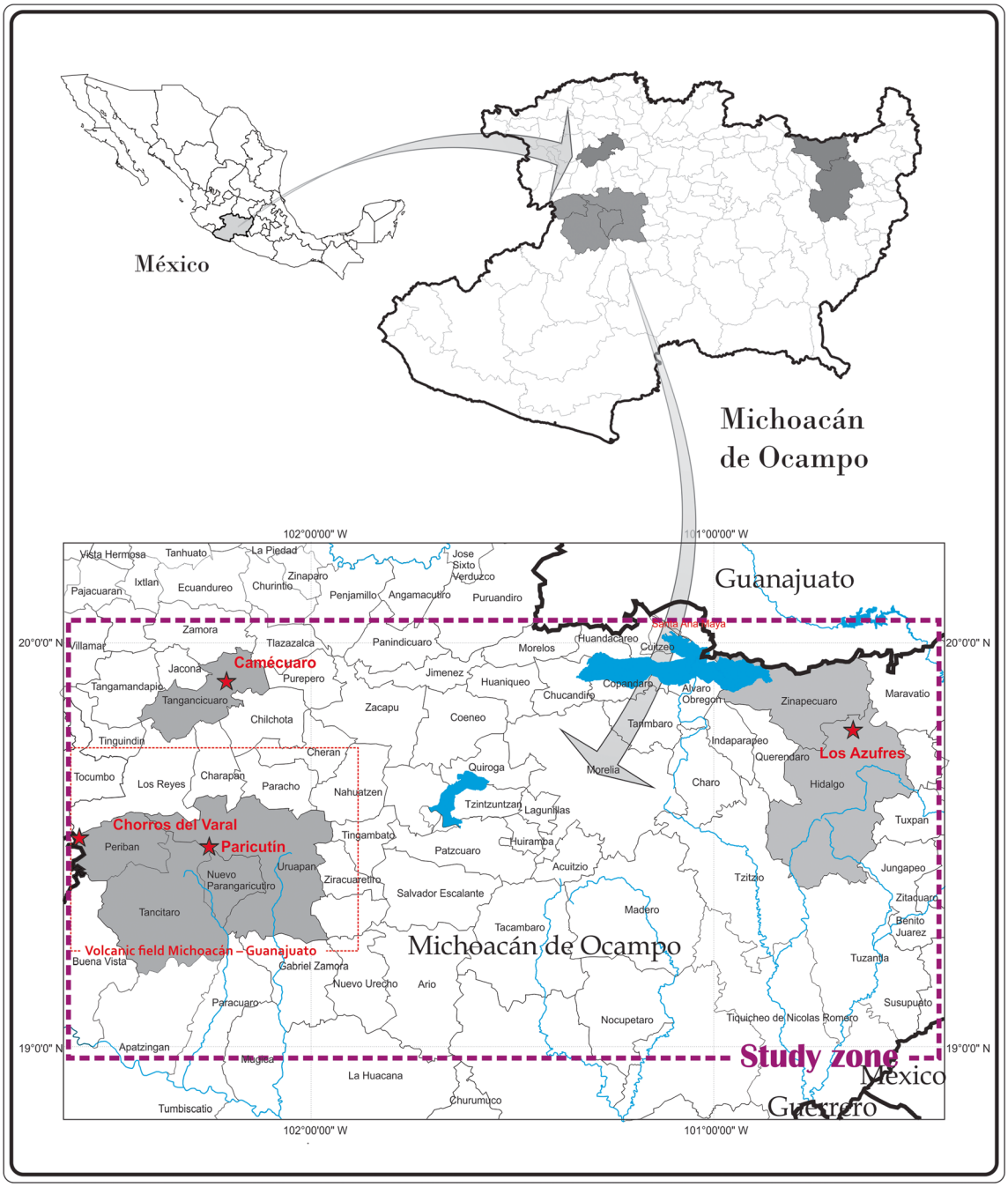

Fig. 1 Location map of the study area. Areas and sites determined as north Michoacan geoheritage, Mexico

hydrological, and metallogenetic series, in such a way that the selected geosites are framed within a global geological context, whether with common or unique characteristics.

Through field trips to each site, we made a general description of their accessibility, nearby populations, current and potential use, social vulnerability, and aspects of environmental protection and deterioration. We highlighted different potential uses (biological, health tourism, alternative tourism, pedagogical, cultural) to stress the idea that the local estimation could be as useful as the world representativeness of geosites for fostering favorable public opinion to geoheritage projects.

Results

We performed the characterization of an vulcanological area and one geosite, two geosites of hydrological interest, and one geo-area related to the geothermal energy use.

Volcanic Field Michoacan Guanajuato

A volcanic field is an area that concentrates in a defined surface a specific number of eruptive centers or volcanic forms. There are small volcanic fields that contain less than 50 emission centers distributed in less than 1000 km^2. Examples in Mexico are the volcanic field of Ocampo, Coahuila (Moreno et al. 2011), and the volcanic field of Camargo, Chihuahua (Aranda-Gómez et al. 2003). In turn, the large volcanic fields contain more than 100 emission centers distributed in more than 1000 km^2, such as the so-called Michoacán-Guanajuato Volcanic Field (CVMG) with about 1000 in 40,000 km^2 (Hasenaka and Carmichael 1985) and the Sierra of Chichinautzin (SCH) with 221 volcanic structures distributed along 1400 km^2 (Connor 1990).

Located in the central portion of the Trans-Mexican Volcanic Belt (FVTM), it is considered one of the areas with the most extensive monogenetic volcanism in the world and Mexico, hence its geological scientific relevance to be considered as geological heritage. Much of its geographical distribution is found in the north portion of the state of Michoacán (Fig. 2).

This field includes more than 1000 monogenetic cones and more than 400 polygenetic centers formed from ~ 2.8 millions of years ago, and it remains active to the present day as witnessed by the historical eruptions of the Jorullo and Paricutin volcanoes. Lava cones are predominant, although there are also numerous volcanic forms (Fig. 3) such as maars, lava domes, shield volcanoes, and stratovolcanoes (Hasenaka and Carmichael 1985).

The tectonic aspects of the CVMG are relevant and present a high scientific value for this area. The CVMG is immersed in the scientific controversy to explain the origin and

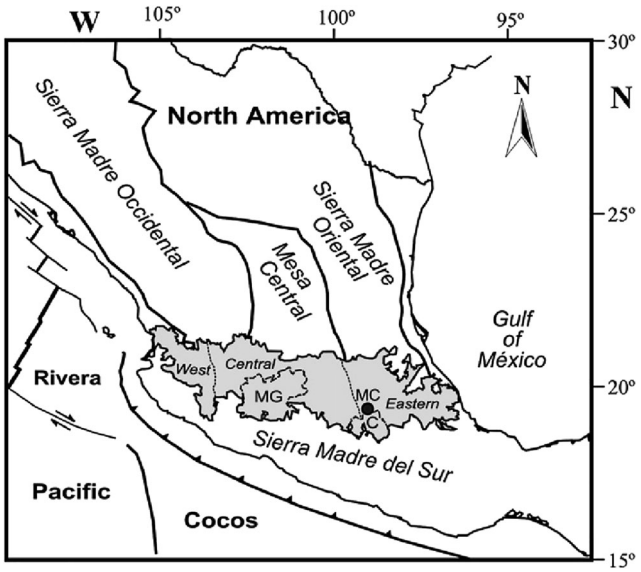

Fig. 2 Location of the Trans Mexican Volcanic Belt (FVTM), divided into three sectors. In the central portion stand out the Michoacan-Guanajuato Volcanic Field (MG) and the Sierra de Chichinautzin (C) as volcanic fields (modified from Gómez-Tuena et al. 2005)

Fig. 3 Volcanic landscape and intermontane plains typical of the CVMG

evolution of the FVTM since currently there is no tectonic model accepted by all. Geological investigations carried out precisely within the CVMG are the publications of Hasenaka and Carmichael (1985, 1986), (Hasenaka 1987), Connor (1987), Ban et al. (1992), and Ramírez (1990).

In essence, the CVMG is constituted as a geological heritage of Michoacán, given its geological condition, representing the largest concentration of volcanoes in Mexico and its tectonic environment given the current controversy regarding its origin, which gives it its potential value in scientific terms.

On the other hand, Purépecha communities that preserve cultural practices originating in the colonial and pre-Hispanic period through religious syncretism inhabit a significant proportion of the Michoacán-Guanajuato Volcanic Field (CVMG).

The current Purépecha identity is built in opposition to their ancestors who "lived in the hills," where they have found significant archeological evidence of their presence. The current inhabitants interpret the life of the past in the hill, through the knowledge they have of the archeological remains, oral history, and geological features, mainly, the interpretation that people from before located their villages on the hill nearby of the springs (Muñoz 2009).

Besides, the purépecha towns located in the highest area of the volcanic field are associated by a political movement, Purépecha Nation, that takes into account the local geographical perception to define four purépecha regions: Cañada (ravine), Lago (Lake), Valle (Valley), and Meseta (plateau). The political movement takes advantage of these regionalisms and tries to make official an organization with a spatial logic. Consequently, Purépecha Nation movement exhibits four colors in its flag, one for each region, placed according to the cardinal points (Roth-Seneff 1993). The "Meseta Purépecha" is one of the four purépecha regions identified by the political movement, and the name refers to the altitude and the orography since it is also known as "Sierra Purépecha." This political significance of the local landscape is an instance of the social identity value that has the geosite.

Paricutin Volcano

Located in the north portion of the state of Michoacán, in the so-called CVMG, it is one of the youngest volcano in the world and the youngest in this area (1943–1952) (Williams 1950); it is an example of the emergence and evolution of a monogenetic volcano, being the first to be filmed and recorded from birth to the end of its eruptive stage.

Graton in Graton 1945 described the phenomenon as follows: "In time, when the Paricutin volcano completes its activity and has reached the range of extinct volcanoes, it seems likely that it may not be on the list of the world's great volcanoes, it has not broken any record, except for being the youngest volcano in the world at the moment."

Pioli et al. (2008) describe as an extreme strombolian type event to the evolutionary process of the Paricutín being the deposits of pyroclastic more voluminous than the lavas. De Jesús Rojas et al. (2012) proposed nine geomorphosites in the region of Parícutin volcano, and belong in their entirety to forms of volcanic construction, of which five correspond to volcanic buildings and their pyroclastics and the rest to lava flows morphology and their most characteristic forms of lavas and volcanic tubes (Fig. 4).

Currently, the Paricutin volcano is a significant natural and geomorphological heritage (De Jesús Rojas et al. 2012) despite the scarce management and regulation that makes it very vulnerable to the degradation and the accelerated change of land use in its vicinity.

In the cultural sphere, notwithstanding the short period since the community exodus, local traditions have been created and integrated into the historical memory, and have taken part in significant social identity and political mobility (Pérez Ramírez 2009). For instance, the creation of plastic works (murals) with the Paricutín eruption rekindles a collective memory of re-foundation of the towns of Parangaricutiro and San Salvador Combutzio-Caltzontzin.

Fig. 4 The Paricutin is considered one of the youngest volcanoes in the world

Geothermal Field Los Azufres

Geothermal energy is a renewable resource that has been used worldwide to generate electricity since 1911 and in Mexico since 1959 when the first geothermal power unit in the country with 3.5 MW of capacity was started in the Pathe geothermal field in Hidalgo, now out of operation. Currently, the country has extensive experience in geothermal power generation, operating 38 units with a total installed capacity of 958 MW (Hiriart et al. 2011).

Los Azufres geothermal field is located 80 km east of the city of Morelia, Michoacan. It is one of the three most important in the country, hence its relevance as geothermal geological heritage in the Entity. It was explored in the mid-1970s and has been in continuous development. It is in an altitude range of 2500–3000 m surrounded by valleys. There are currently 43 productive wells and six injection wells producing 14.7 million tons of steam and generating 185 MW.

Relevant in scientific terms is that the Azufres is one of the multiple silicic volcanic areas of the Pleistocene with a geothermal activity that is located in the northern portion of the Trans Mexican Volcanic Belt. The approximate age of silicic volcanism present is 1 million years, represented by the eruption of the Agua Fria rhyodacite, lava domes, and rhyolitic flows, and which are covered by rhyodacites and dacitic lavas, domes, and flows of the younger San Andres Volcano, dated at 0.3 m (Dobson and Mahood 1985).

Another aspect that gives relevance to this geosite is that it remains a region with wide ranges of scientific opportunities for knowledge of geothermal processes regarding its special geological conditions as it is an area with unconventional concentrations of acidic volcanism coupled with its complex structural system of the collapsed boiler (Ferrari et al. 1991).

Los Azufres is privileged geo-area of the state of Michoacán for two main aspects: electric energy is produced to supply this vital input to a part of the state (Fig. 5), and it is a great tourist attraction thanks to the thermal and healing waters, being visited by people from all over the Mexican Republic and abroad. Experts have suggested the mutual benefits for the geoheritage and the local economy through health tourism projects as long as the projects heighten the importance of the conservation of the related geosites. In Michoacan, there is a health tourism project related to thermal waters that includes Los Azufres (Arévalo Pacheco and García 2014).

Camecuaro Lake National Park

Camecuaro Lake corresponds to a protected natural area of national character in the category of National Park decreed on March 8, 1941. It is located to the northwest of the state of Michoacan, between the coordinates 19° 53′ 00″ and 19° 54′ 00″ north latitude and 102° 13′ 00″ and 102° 14′ 00″ west

Fig. 5 Overview of the geothermal field Los Azufres, Michoacan

longitude within the municipality of Tangancicuaro, covering an area of approximately 9 ha.

Its origin is related to the water entrapment caused by the regional volcanism that is associated with monogenetic and shield type volcanoes. It is characterized by the existence of leafy and old Ahuehuete trees that surround a lake of average depth to 7 m that body of water owes its existence to some springs that converge in it (Fig. 6).

Fernández-Ruíz (2010) in his work about Camecuaro states, "This small lake bordered with cypress or ahuehuetes adorns the landscape with its magical beauty. Its flow of pure and transparent lymph is born from 1031 springs of fractures that bubble the water almost to a ground level. Its natural glass is a mirror of three and a half hectares of the surface that reflects the luminosity of the sky, saturates the senses with beauty and comforts the spirit." Also, he narrates, "Camecuaro had to be an attractive place from pre-hispanic times, the Purepecha inhabitants of the territory appreciated it, and they gave its poetic name enriched of meanings."

The most common Camecuaro translation is "Place of hidden bitterness." Clearly, this does not allude to the physical characteristic of water, but evokes the legend of Huanita, young princess in love with Tanganxhuan, nephew of one of the heirs of Tariacuri, that having been kidnapped by the priest and kept hidden, she moaned so much her misfortune that she formed a spring with her bitter cry.

Fig. 6 Camecuaro Lake scenic view

These narratives are a clear example of the cultural value, scenic, and natural beauty that Camecuaro Lake represents to the people of Michoacan, making it a unique place and heritage of the entity. The presence of many springs that originate and give purity to the water, which gives its hydrological value, has no antecedent in the region.

Chorros del Varal

The study area is located in the geological province called Trans-Mexican Volcanic Belt (FVTM), towards the western boundary of the Michoacán-Guanajuato Volcanic Field (CVMG), located in the central portion of the FVTM. Its age, accepted by the majority of authors, is Late Miocene–Plioquaternary, which continues until the Recent (Nixon 1982; Negendank et al. 1985).

Chorros del Varal is the discharge of the local aquifer called Cotija-Los Reyes, at the confluence of the Apupátaro and Itzícuaro rivers, where appear underground tributaries that generate waterfalls and large waterfalls (Fig. 7).

It corresponds to a natural protected area of a state nature in the category of Ecological Preservation Zone, decreed on January 8, 2004, with an approximate area of 72 ha. It is an area with high plant biodiversity considered as a refuge for the flora of the Tepalcatepec Basin.

The characteristics of porosity, permeability, lithology, and stratigraphic position of each of the geological units recognized in the region determine the aquifer system of the region. In the superficial part, there are alluvial deposits constituted by carrying material. Under the granular package are the predominant volcanic deposits in the area, whose products are mainly olivine basalt, pyroxene, and andesite.

This very depth fractured rocks are the preferential conduit of the visible regional flow in the study area. The main factors that influence the recharge process of the regional aquifer are the precipitation infiltration through the preferential recharge

Fig. 7 A natural jewel: Los Chorros del Varal

zones, all the mountain relief that surrounds and delimits the valley, and the circulation of water relatively quickly, since it occurs through a fractured medium to flow later by formations of variable porosity.

Therefore, this geosite is valuable as a natural heritage because of the importance of the water resource. Additionally, it stands out that in the Purépecha worldview there is an animism of natural elements, embodied, for example, in stories about the will and the agency of the eyes of water, interpreted as feminine entities, or stories about the birth of springs and the origin of the settlements, and ritual practices and collective care of water sources (Argueta and Castilleja 2008).

Like the other protected natural areas of Michoacán, the protection of Chorros del Varal is of vital importance for safeguarding the genetic diversity of wild species, achieving the rational use of natural resources and improving the quality of the environment of the surrounding population centers. Chorros del Varal has been included in a project of wildlife corridors in Michoacán and the bordering Jalisco state. This project has been motivated chiefly by the presence of medium and large-sized mammals as the jaguar (*Panthera onca*) in the area (Charre-Medellín et al. 2018).

Conclusions

The relationship of the geological processes and geological history of a particular site on the planet and its representativeness are the first steps to determine the geological heritage per se, from which actions can be carried out for the geoconservation and application of educational activities of geology or geotourism in a given region.

Michoacan is vast in unique regions in the geological context, where the natural wonders prevail. Water, rock, morphology, thermal resources, and volcanoes are the patrimony of the entity.

The article also suggests a way to achieve integral management of the geological heritage by giving prominence to the local cultural meanings and economic activities associated with the biological and cultural heritage of the geosites. We maintain that some current geological traits are considered as cultural heritage because of their past geological meanings even if those geological traits are not relevant for the geological science nowadays, but the local meanings could help to promote education about the value of geological heritage. In the studied region, it is confirmed that there is historical documentation of the relationships between geological features and social identities of prehispanic origin but also processes with a current meaning that involves a relationship between regional geological features and indigenous identity. As we exposed, other geosites take part in biological heritage and have associated economic and nature values. We suggest that a whole vision in particular regions could benefit positive attitudes towards geosites conservation in general even though some regional geosites are not worldwide representative or do not have a unique scientific value.

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