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Geotrails in the Mixteca Alta UNESCO Global Geopark, Oaxaca, Mexico

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Abstract

Geotrails are a modality of interpretive trails focused on the promotion of the Earth Sciences among both the specialized and general public. This work describes three geotrails in the Mixteca Alta UNESCO Global Geopark, Oaxaca. They are a teaching aid that can be adjusted to the expectations of visitors at all educational levels and can contribute to the evaluation of natural resources from a social perspective. The geotrails emphasize not only on the importance of the geological heritage (geosites) of the study area, but also on its relationship with the value given by society.

Keywords: geotrail; Geopark; geoheritage; Mixteca Alta; geotourism

Resumen

Geosenderos en el Geoparque Mundial UNESCO Mixteca Alta, Oaxaca, México

Los geosenderos son una modalidad de senderos interpretativos enfocados a la promoción de las Ciencias de la Tierra tanto entre el público especializado como entre el público general. Este trabajo describe tres geosenderos del Geoparque Global UNESCO de la Mixteca Alta, Oaxaca. Los geosenderos son una herramienta de enseñanza que se puede ajustar a las expectativas de los visitantes de todos los niveles educativos; pueden, además, contribuir a la evaluación de los recursos naturales desde una perspectiva social. Los geosenderos enfatizan no sólo en la importancia del patrimonio geológico (geositios) del área de estudio, sino también en su relación con el valor asociado dado por la sociedad.

Palabras clave: geosenderos; Geoparque; geopatrimonio; Mixteca Alta; geoturismo

Abstrait

Géotrails dans le Géoparc Mondial Mixteca Alta de l'UNESCO, Oaxaca, Mexique

Les géotrails constituent une modalité de sentiers d'interprétation axés sur la promotion des sciences de la Terre auprès du grand public et du spécialiste. Ce travail décrit trois géotrails dans le géoparc mondial Mixteca Alta UNESCO de Oaxaca. Ils constituent un outil pédagogique qui peut être adapté aux attentes des visiteurs à tous les niveaux de l'enseignement et peut contribuer à l'évaluation des ressources naturelles d'un point de vue social. Les géotrails mettent l'accent non

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seulement sur l'importance du patrimoine géologique (géosites) de la zone d'étude, mais aussi sur sa relation avec la valeur donnée par la société.

Mots clés: géotrails; Géoparc; geopatrimoine; Mixteca Alta; geoturisme

1. Introduction

Interpretative trails are itineraries along places of interest. In natural areas, they are not just paths provided with signs, bridges and rustic viewpoints (SECTUR, 2004), but routes recognizing thematically interconnected sites, which are therefore complementary, so that the journey reveals to the visitor a coherent history rather than isolated knowledge of each of them. In this way, trails enrich the tourist offer for the benefit of visitors and settlers. They are also a useful educational tool to promote the cultural and natural heritage among both general and specialized public.

In natural areas, «ecological» trails are common, generally based on the identification of aspects of biodiversity in both terrestrial and marine environments (SECTUR, 2004; Vidal and Moncada, 2006; Pellegrini, 2009; Rodríguez-García and Mayorga Castro, 2012). These trails usually do not explain the abiotic conditions of the environment, particularly those that refer to the geological, geomorphological and pedological aspects, all of which are aspects addressed by geotrails. A geotrail, then, is a route that connects in a sequential, ordered and complementary way, representative sites of geodiversity.

There is a multitude of concepts and definitions concerning geodiversity, geological heritage, geosites…(Brilha 2016). Detailed discussion of these concepts is beyond the objectives of this work. For our purposes, geodiversity is defined as the natural variety of the Earth´s surface, in reference to geological and geomorphological aspects, soils and surface waters, as well as to other systems created as a result of both natural processes (endogenous and exogenous) and human activity (Kozlowski, 2004). Geosites are in situ occurrences of geodiversity elements with high scientific value (Brilha 2016) that constitute a (geological) heritage that can be used as a basis for Geotourism, a form of tourism that sustains and enhances the identity of a territory, taking into account the geology, the environment, the culture, aesthetics, heritage and well-being of its residents (Arouca, 2011).

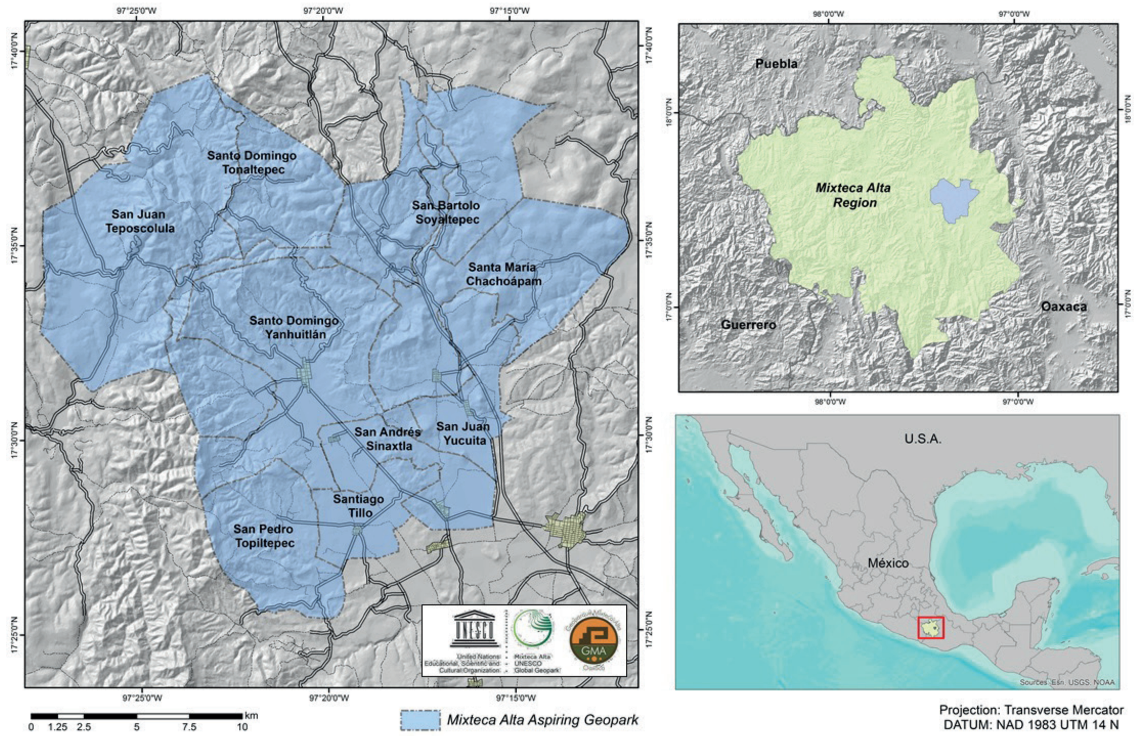
Geological heritage is therefore represented by geosites or sites with a fundamentally scientific (geological) interest, although other values can also be added, particularly the cultural one (Melelli et al. 2015). «If the geological features interact with cultural elements (historical or archaeological vestiges, cultural or religious monuments, etc.) the geoheritage value joins the cultural value and one can speak of a geocultural site» (Reynard and Giusti 2018).

Considering both types of sites in the design of the geosenderos allows to organize a coherent history on the territory of the geopark that is not limited to the scientific aspects that characterize the geological heritage through the geosites, but also highlights the importance of these for the communities that inhabit the territory. In this way, the relationship between geology and society is emphasized.

This work identifies geotrails as an educational resource and strategy for dissemination of Earth Sciences, the geological heritage and, where appropriate, its cultural value. It describes the establishment of three interpretative geotrails within the Mixteca Alta UNESCO Global Geopark, in the State of Oaxaca, Mexico. This involved consideration not only of the outstanding geological and geomorphological features (geosites) but also of the unique cultural value associated to them (geocultural sites) related with the 3000-year cultural heritage of the indigenous people whose traditional agricultural systems and pottery techniques are still much in evidence today.

2. Study Area: the Mixteca Alta UNESCO Global Geopark

The geopark encompasses nine municipalities of the central-eastern portion of the Mixteca Alta region, in the state of Oaxaca (map 1) with an area of 415 km^2 and most of the population belongs to the Mixtec indigenous communities. A lack of economic opportunities has led to significant emigration to urban areas and to the United States of America. In 2010, the total population of the Geopark was around 9000, about 60% women. This is one of the two Mexican geoparks recognized by UNESCO in May 2017.



Map 1. Location of the «Mixteca Alta» UNESCO Global Geopark, Oaxaca, Mexico.

The degradation of natural resources (soils and vegetation), characteristic of the region, has been related to the development of agriculture and the adoption of agricultural techniques that go back more than 3500 years (Leigh et al., 2013). The demand for food and the limited availability of soils in flat areas owing to the abrupt topography led to the development of particular agricultural techniques in the region locally known as *lamabordos*. The *lamabordos* are terraces built across the valley bottoms consisting of rock barriers arranged perpendicularly to the direction of water runoff; they promote the accumulation of sediments and allow the construction of agricultural plots. The construction of these terraces, still practiced today, allowed to satisfy the food demand of a population that reached 50,000 inhabitants during the Late Postclassic, (between 1000 and 1520 BC; Spores, 1969). The construction of *lamabordos* has been associated with the erosion of soils in the upper parts of the watersheds; it has even been suggested that, in order to have more sediments for their construction, erosion was induced (Spores, 1969).

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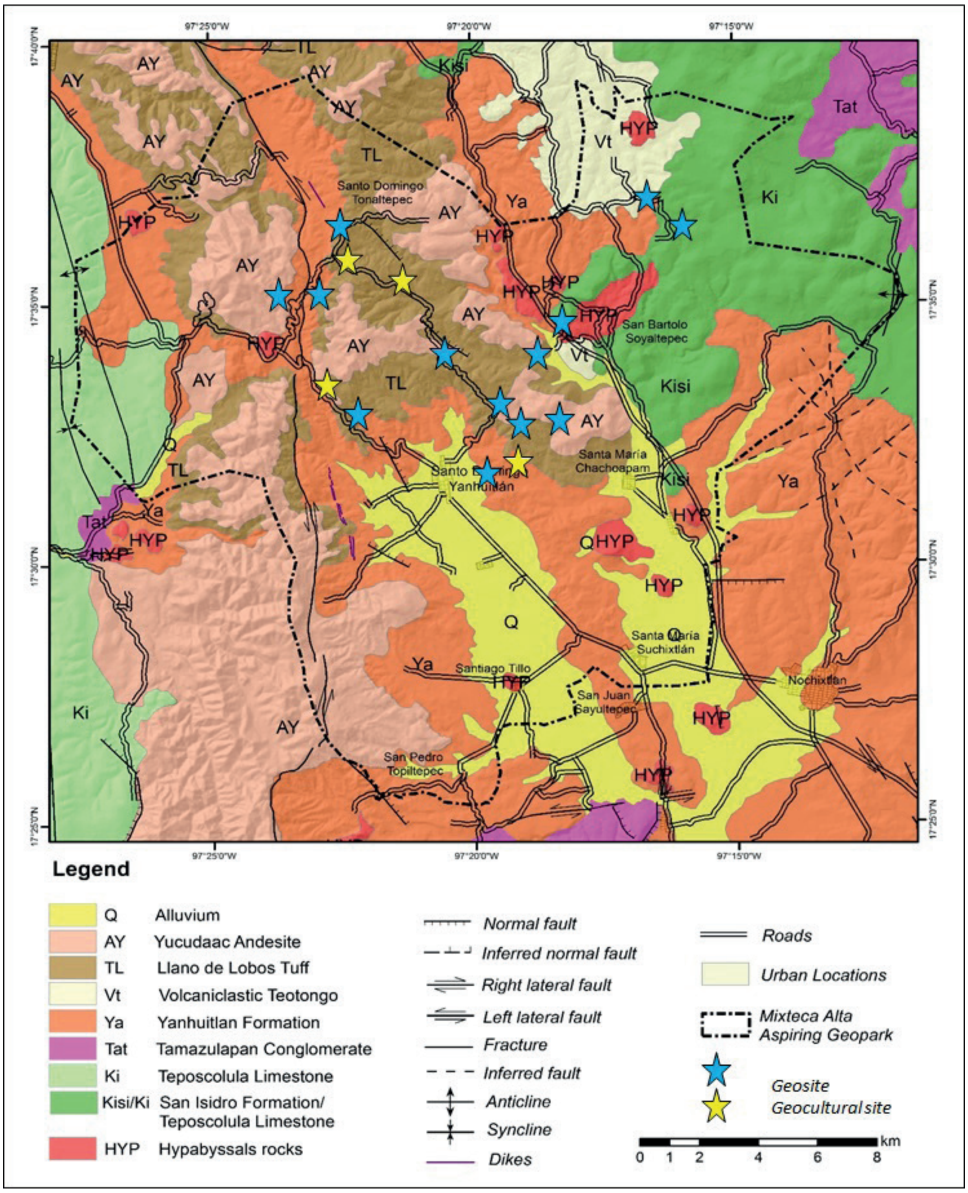
3. Geology and geomorphology

The Mixteca Alta is a rugged territory formed by sedimentary, volcanic and plutonic rocks of ages ranging from Cretaceous to Miocene, partially covered by Quaternary alluvial deposits and by paleosols developed during the end of the Pleistocene and beginning of the Holocene (Map 2).



Map 2. Geological map of the study area (based on Santamaría-Díaz, 2009 and Ferrusquía, 1976).

The Cretaceous rocks correspond to the Teposcolula Formation, consisting of cream or dark gray limestones that turn white with weathering; it is massive with some fossiliferous horizons with abundant small oyster shells poorly preserved due to the erosion on the surface, with massive parts and other well stratified (Salas, 1949).

The Yanhuitlán Formation conformably overlies the Teposcolula Formation and consists of a succession of thin rhythmic layers with a high content of silt and reddish clay, which have a thickness of about 300-600 m (Ferrusquía 1976). The deposition of these sediments occurred in extensive lakes during the Paleocene and Eocene, at around 40 million years (Martiny et al., 2000). This formation is one of the most significant in the geopark in terms of surface; in addition, these sediments, poorly consolidated and friable, have favored the development of conspicuous erosive features of the landscape that predominate and characterize the geopark.

The Oligocene Llano de Lobos Tuff conformably overlies the Yanhuitlán Formation; it consists of a sequence of rhyodacitic to andesitic tuffs interlayered with conglomerates of sandy matrix and calcareous clasts. Its thickness varies between 300 and 500 m and its age is 29 Ma (Ferrusquía-Villafranca *et al.*, 1974). This formation underlies the Yucudaac andesite, a unit of lavas of trachyandesitic to basaltic composition with a characteristic trachytic texture; its thickness is about 500 m and its age is also Oligocene (Ferrusquía, 1970).

Finally, Quaternary alluvial deposits consist of unconsolidated gravel, sand, silt and clay; the thickness of the deposits varies attains up to 30 m (Ferrusquía, 1976), and several paleosols of different ages can be found interspersed, the oldest with an estimated age of 14,000 years BP (Mueller *et al.*, 2012).

The geomorphological units are (Ortíz-Pérez *et al.*, 2016):

- 1. Plains: correspond to the bottom of the Yanhuitlán River valley; they are alluvio-proluvial plains and are currently subject to denudatory processes, with scarce river dissection;
- 2. Footslopes: transitional surfaces between the plain and the slopes, with development of sheet erosion;
- 3. Low and medium slopes: subject to denudatory processes (mainly linear erosion) that give rise to gullies (badlands) and ravines, and
- 4. Summits. Top surfaces composed of andesitic lavas and tuffs, subject to sheet erosion and mass wasting.

4. Methodology

4.1. Selection of sites of interest

The sites of interest (geosites and cultural geosites) are representative of the condition of «environmental disaster» of the region that is justified by the advanced degree of soil erosion and deforestation derived from its intense use over thousands of years (Spores, 1969; Guerrero-Arenas *et al.*, 2010). The criteria used for their selection include: scientific value, representativeness, accessibility, relationship with cultural aspects, and educational and/or geotouristic potential. These criteria are commonly used in the identification of sites of geological and geomorphological interest in this geopark (Pralong, 2005; Zouros, 2005; Reynard *et al.*, 2007; Rocha *et al.*, 2014).

The selected geosites include those of geological, geomorphological and pedological interest. In addition, sites with cultural value associated with geological, geomorphological and pedological elements and processes are identified. The selection of the geosites in a fieldwork was based on the recognition of the geological and geomorphological diversity (geodiversity) of the territory of the geopark, so that at least one of these sites is located within each context. The geocultural sites complement the geosites and focus on showing the relationship between geology, geomorphological processes (erosion-accumulation), soils and human activities (Image 3-2). Selection of the sites is based on the participation of the indigenous communities; this is of particular importance in regions that are governed according to traditional rights («usos y costumbres», in Spanish, customs and habits in English), and with a traditional form of consensual and community administration of the territory that differs from the political-parties form (Canedo, 2008). Participatory planning involves the whole community in the decision making and in the implementation of conservation measures (Phillips et al., 2014).

4.2. Criteria for the design of geotrails

The design of a geotrail must take into consideration the geodiversity of the geopark, expressed through the geological and geomorphological units. With this context, an inventory of geosites and geo-cultural sites was compiled. The participation of the local communities was essential in identifying the feasibility of using the sites for a trail. The steps that accompany the process include the location of information panels and maps (Figure 1).

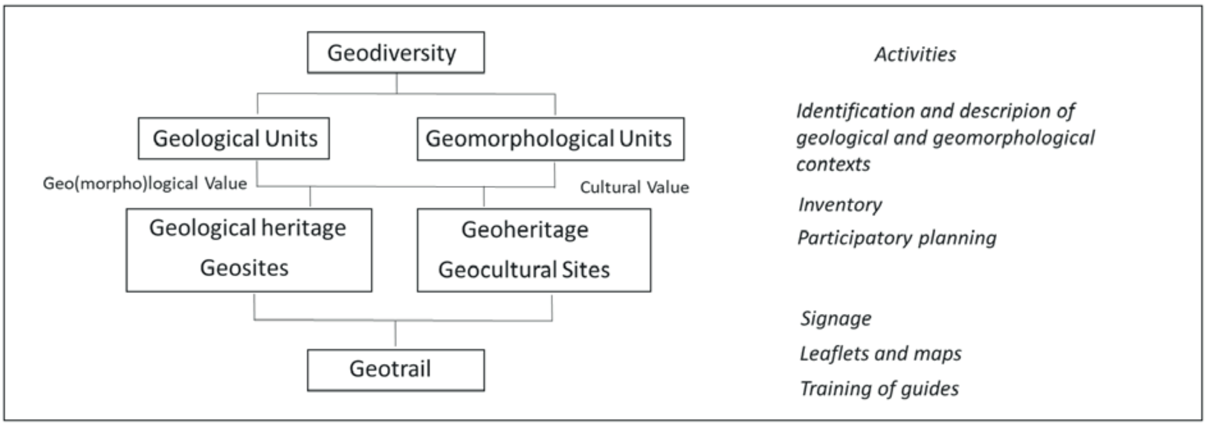


Figure 1. Steps for the establishment of geotrails in the Mixteca Alta UNESCO Global Geopark, Oaxaca, Mexico.

5. Results

The geotrails (between 4 and 30 km in length) were designed so that the sites (geosites and geocultural sites) established a coherent message, avoiding redundancy and constructing cumulative knowledge along the route. Each site was designed along a theme around the message that the visitor is expected to assimilate and remember. Brochures, maps, interpretive panels (see website below) and the participation of specialized localguides complement the routes. The geotrails can be traveled in any season of the year and are accessible by car or bicycle, or on foot.

5.1. Design of interpretative panels and other informative elements

Interpretive panels were installed throughout the geotrails to indicate the most important aspects in each site of interest. The geopark currently has a total of 26 of these panels (see geosites and geocultural sites in figure 1). In the Interpretation Center of the Geopark and other facilities, as well as on the geopark website (www.geoparquemixtecaalta.org), visitors can get or download brochures that include maps of the routes and a brief explanation of the sites of interest. Although the information of the panels allows to understand the message, it is recommended to engage the services of an accredited interpreter guide of the geopark.

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5.2. Geosites and geocultural sites

The geosites and geocultural sites are distributed throughout the geological and geomorphological units of the geopark (see Figura 1). They are representative of its variety of geological, geomorphological and pedological features, and include: (a) erosive and cumulative forms of fluvial origin, (b) mass wasting processes, (c) sedimentary deposits, (d) soils and paleosols, (e) plutonic structures (dykes), and (f) spheroidal exfoliation. Sites of geocultural interest, on the other hand, include (a) systems of «lamabordos» (Pre-Hispanic, colonial and modern) preserved and semi-destroyed by erosion, (b) potteries (one of the «geoproduct» most representative of the geopark), and others with evidence of pre-Hispanic manufacture of (c) lithic artifacts (flint). The three geotrails described in this work include 16 geosites and 8 geocultural sites (see graphic 1).

Table 1. Geotrails in the Mixteca Alta UNESCO Global Geopark.

	Las Conchas (Image 2)	Los Corazones (Image 3)	Gavillera (Image 6)
Number of Geosites	4	6	5
Number of Geocultural sites	2	4	2
Length	4 km	30 km	12 km
Altitude max-min (m.a.s.l.)	2310-2150	2595-2150	2600-2300
Geological Units number of specific sites along the trail			
Teposcolula Formation			2, 3, 4, 5, 6, 7
Yanhuitlán Formation	1-6	1, 2, 3, 4, 5, 6, 10	1, 2, 3
Llano de Lobos Tuff		3-10	
Andesita Yucudaac		3, 7, 9	
Alluvial deposits and palaeosols	1, 2	7	3
Geomorphological Units: specific sites along the trail			
Planes	1, 2		
Footslopes	3, 4	1, 2	1, 2, 3
Slopes	5	3, 4, 7, 8, 9	4, 5, 6, 7
Summits	6	5, 6, 10	
Geosite themes: specific sites along the trail			
Gully erosion	1-6	1, 3, 4, 5, 7, 10	1, 3, 6, 7
Mass wasting: Rock fall Landslides	 5, 6	 1, 3, 5 9	 1, 3
Spheroidal exfoliation		8	
Karst			2, 3, 4, 5, 6, 7
Magmatism (dykes)		4, 5	
Tectonism (faults)		5, 6, 7, 8, 9	1
Fossils			6, 7
Geocultural site themes: specific sites along the trail			
Lamabordos	1, 2, 3, 4	1, 2, 3, 5, 7, 10	1, 6, 7
Potteries		6, 8	
Pre-Hispanic lithic workshops (Flint)		7	
Archaeological themes: specific sites along the trail			
Constructions	5, 6	7, 8	6, 7
Postherds and lithic remains	4, 5, 6	7, 8	5, 6, 7

Geosites include:

- *Erosive and cumulative fluvial forms*

Gullies are erosive forms with a wide distribution in the geopark. Their development, characteristic on the slopes, is favored by the friability of the lithology (Yanhuitlán Formation), and in many cases true badlands develop. They often reach tens of meters deep and have a characteristic «V» profile (images 2-3, 3-3, 3-5). Their development is associated with the millennial agricultural practices introduced by the Mixtecs for the purpose of construction of antropic sedimentary deposits at the bottom of the valleys (*lamabordo terraces*), in the plains units (Spores, 1969)..

- *Mass wasting processes and resulting landforms*

The mass wasting processes are responsible for the transport of materials on slopes. Their occurrence is associated with both natural factors (geological conditions, slope, fluvial erosion at the base of the slopes, expansion of gullies) and induced factors (deforestation, road cuts). The landforms derived from these processes are frequent throughout the region and particularly within the geopark, in the hill slope units. Known locally as «Conchas» («shells», in Spanish), these are semi-circular erosive amphitheaters from which blocks and sediments become detached. The «Conchas» reach their greatest development on the Yanhuitlán Formation and its steep upper slopes; near the summit surfaces, a layer of *caliche* (or hardpan) contributes to the distinctive morphology (images 2-6, 3-1).

- *Sequences of sedimentary deposits (fluvial profiles and lamabordos)*

These sites include alluvial profiles and sediment deposits on the footslopes. The profiles are cuts along rivers that expose a sedimentary sequence in which a part of the environmental history can be reconstructed from the beginning of the Holocene (Mueller et al., 2012). Figure 4-1 shows an alluvial sequence in which paleosols denote paleoecogeographic conditions favorable to soil genesis (biostasia or pedogenesis, according to Erhart, 1951). Above these paleosols, conglomerate beds composed of fragments of up to a few decimeters, poorly classified, denote a sudden drag and deposition of material as a result of erosion in the upper portions of the basin; this can be interpreted as an abrupt change in the environmental conditions, related more to erosion than to soil genesis (rexistasia or morphogenesis, according to Erhart, 1951). These conglomerate deposits are probably contemporaneous with the establishment of agriculture in the area and the consequent onset of soil degradation.

- *Plutonic structures*

Andesitic dykes can be identified throughout the study area, consisting of plutonic structures (magmatic intrusives) about 4-5 m thick, reaching more than one km in length (image 3-5) with a predominant NW-SE orientation. They intrude into the Yanhuitlán Formation and have been exposed by differential erosion. These dykes are the oldest manifestations of Cenozoic magmatism in the region, with about 40 million years (Martiny et al., 2000).

- *Spheroidal exfoliation*

The weathering or spherical exfoliation gives rise to rounded blocks of rocks, mainly of igneous origin, with a succession of relatively concentric layers (image 3-9). Examples of this phenomenon are common in the andesitic outcrops (*Andesita Yucudaac*), in the eastern part of the study area.

Geocultural sites include:

- *Lamabordos or valley-bottom terraces*

Rock barriers constructed at the bottom of the valleys, perpendicular to water runoff (image 5-2) trap sediments that can reach tens of meters in depth and that can reveal different stages in their construction. Throughout the geopark thousands of these lamabordos have been identified, being the Yanhuitlán Formation the main provider of the sediments (López Castañeda, 2016).

- *Potteries*

Potteries are mainly in settlements in the northern part of the geopark. The relevant geocultural sites point out that the material used by the potters is derived from the paleosols distributed in the geopark, and that the characteristic decoration uses red earth and extracts of oak bark, which gives an unmistakable and unique touch to this craft. The techniques used in forming, decorating and firing the pieces are millenials they are moulded with the fingers and fired in a stone kiln. This technique constitutes an intangible heritage whose promotion is essential to prevent its disappearance (image 4). This «geoproduct» reflects the connection between the geological features and their use by the Mixtec society, and any site that can refer to this will contribute an important part of the specific message of the geopark.

5.3. Geotrails

All geotrails are accessible all year round, either on foot or by vehicle.

a). Geotrail Las Conchas («The Shells; image 2). The length of this path is 4 km and the duration of the route is estimated at about four hours. The route starts at geosites 1 and 2 in the alluvial plains and footslopes. On the footslopes a sequence of paleosols can be clearly identified by their darker tones in comparation with the rest of the layers in the profile (see photo 1 in image 2). In geosite 2 more than a dozen of these paleosols are exposed for >20 m. The paleosols are covered by unclassified conglomerates that represent material dragged from upper portions of the basins, composed of rounded fragments in a reddish matrix, derived from the Yanhuitlán Formation. There is a fine example of the fluvial dynamics, particularly during the rainy season (June-September); it is possible to see constant collapses of material on the slopes of the ravines due to lateral erosion by fluvial currents, whose flow is maintained throughout the year and constantly modifies the cross sections.

In geosites 3 and 4 (image 2-3), in the low and middle hillslope unit, the forms derived from fluvial erosion (gullies and badlands) are conspicuous; the red layers of the Yanhuitlán Formation are clearly exposed. From these geosites it is possible to observe some *lamabordo* and hillside terraces located in the footslope unit and the extensive plains of the Yanhuitlán Valley at the bottom. The existence of these terraces is clearly related to the accumulation of sediments from the lower and middle slopes where fluvial erosion reaches its maximum expression. Finally, in geosites 5 and 6 (see photo 6 in image 2), located on the summits, we can see very active erosive amphitheaters derived from both fluvial erosion and mass wasting processes (rock falls). Remains of pre-Hispanic pottery in most of the summit surfaces testify to the presence of old population centers. The geocultural features along this route are represented by the *lamabordos*, remains of other constructions and some elements of pre-Hispanic lithics. Viewed from these geosites (5 and 6), the panorama includes all the geomorphological and most of the lithological units of the geopark that have been exposed by erosion.

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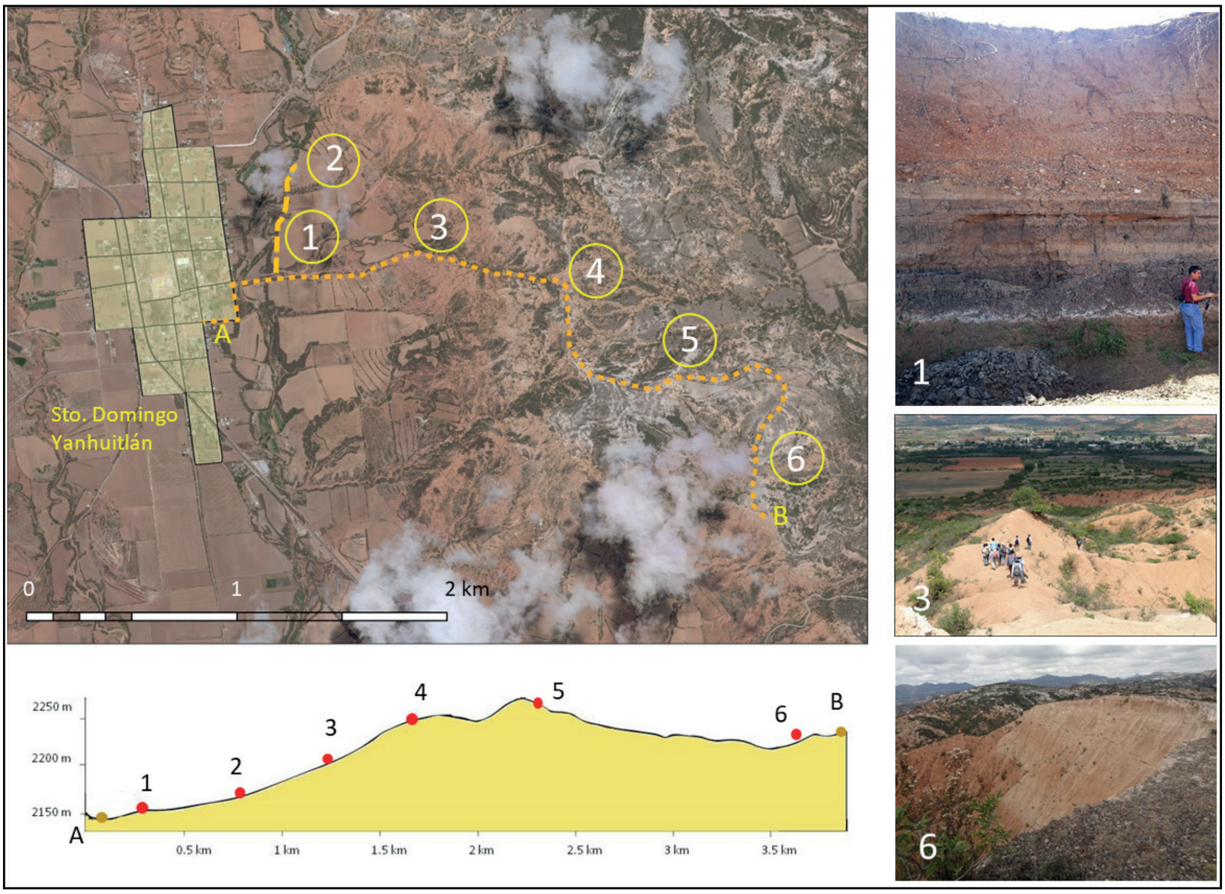

Figure 2. Geotrail Las Conchas. Geosite 1, sequence of paleosols covered by a fluvial conglomerate composed of semi-round fragments of the Yanhuitlán Formation; Geosite 3, gullies and badlands in the area of low and middle slopes and agricultural terraces in the footslope units; Geosite 6, erosive amphitheater formed by fluvial and gravitational action (falling rocks and sediments).

b). Geotrail Los Corazones («The Hearts»; image 3). This geotrail is the longest (30 km) and also the most visited of the geopark due to the diversity of representative features and the estimated travel time is six hours. It runs mainly along the footslope units, low and middle slopes and summits in four of the five lithological units that outcrop in the Geopark. Along the route, the outcrops of the Yanhuitlán Formation, the Toba Llano de Lobos and the *Andesita Yucudaac* are conspicuous; in some geosites these three units are clearly exposed (image 3-3). It is also possible to observe hypabyssal andesite dykes (see photo 5 in image 3). Valley-bottom terraces (Pre-Hispanic, colonial and current) result from erosive and cumulative processes in each of the lithological and landform units (see photos 2 and 3 in image 3).

In addition to the terraces, the pottery workshops in this trail are part of the geocultural sites. In this regard, Spores (2007) explains that in some places along the margins of the valleys, fine mud was available, excellent for ceramics. On site 7 a number of terraces is found. The lamabordos have irrigation channels and lateral walls that denote a sophisticated management of the water; in the same place there are traces of a former flint workshop, with presence of pieces and flakes derived from work in the rock. Also Spores (2007) mentions that in the neighborhood high quality flint was extracted for tools which are spread in various places along the main valleys.

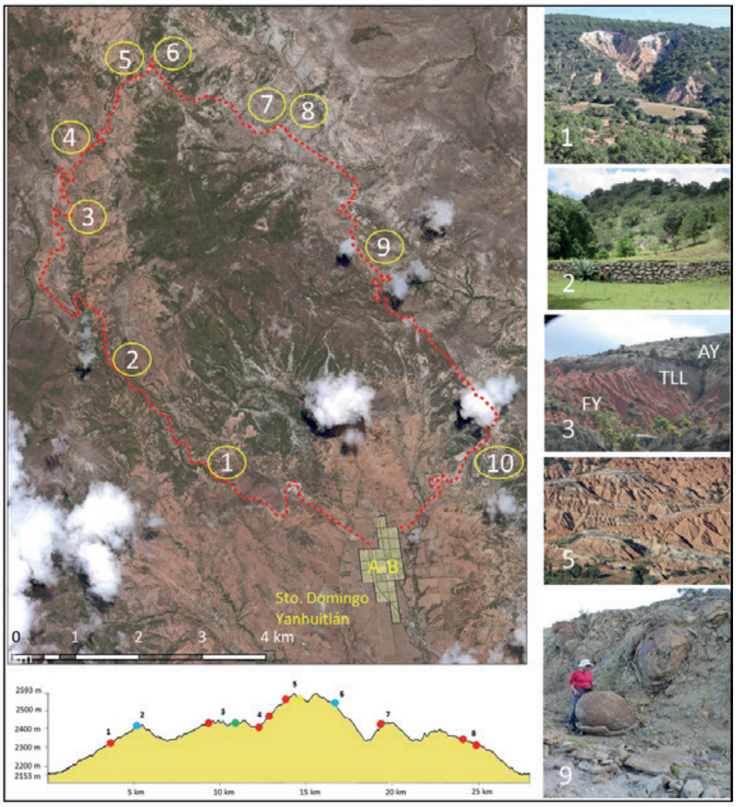

Image 3. Geotrail *Los Corazones*. Geosite 1, erosive amphitheaters; Geosite 2, *Lamabordo* terraces; 3, sequence showing the Formation Yanhuitlán-Toba *Llano de Lobos-Andesita Yucudaac*; Geosite 4, badlands and dykes; Geosite 7, spheroidal exfoliation, *Andesita Yucudaac*.

Image 4. Pottery workshop of Santo Domingo Tonaltepec (geosite 6 of the Geotrail *Los Corazones*).

In geosite 9 there are good examples of spheroidal exfoliation developed on outcrops of the Yucudaac Andesite (see photo 9 in image 3). On the same site there is evidence of landslides, a fairly recurrent phenomenon throughout the geopark (image 5). The last geosite (geosite 10 of the geotrail) corresponds to a panoramic view of the Yanhuitlán Valley. All the geomorphological and most of the lithological units (four out of five) can be seen, as well as the extensive systems of the terraces, whether semi-destroyed or in use. At this site the guides of the geopark invite the final reflections of the visitors.

Image 5. Landslides, geosite 9 of the geotrail Los Corazones.

c). Geotrail Gavillera (image 6). The route, about 12 km long, lies in the Municipality of San Bartolo Soyaltepec, in the northeast of the Geopark. The estimated time of travel is about six hours. Although this shares some features in common with the geotrail described above (erosive landforms developed mainly on the Yanhuitlán Formation, valley bottom terraces, etc.), only in this one are there examples of karstic features (geosites 2, 3, 5 and 6 of the route). Photo 2 in image 8 shows the geosite known as «Los Mármoles» (The Marbles); this is an abandoned limestone quarry with good examples of the lithological unit of the Teposcolula Formation, with some fossils of well-defined gastropods (i.e. *Turritellidae, Nrineidae*- photo 6 in image image 6), which also occur in other sites along the route (geosite 6). The karstic features in this geosite 6, known as «La Laguna» (The Lake), include a doline of ~300 m diameter, on whose bottom crops are grown on *terra-rossa* soils exposed among outcrops of limestone (photo 3 in image 6); an incipient karren (solutionally widened joints) is visible on the slopes. «La Laguna», a name that suggests the presence of a water body, is crossed by a ravine ~500 m long by up to 40 m wide; the ravine ends abruptly, with its lowest point being an entrance to an underground cavity. Some local residents recall a body of water here some 70 years ago, so that it can be inferred that «La Laguna» disappeared after the opening of the cavity. The head cutting derived from the incision by the water threatens the cultivated areas and roads. The geotrail also includes examples of semi-destroyed

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and active terraces and remains of pre Hispanic buildings of the Postclassic period (photo 7 in image 6), common in other sectors of the Geopark.

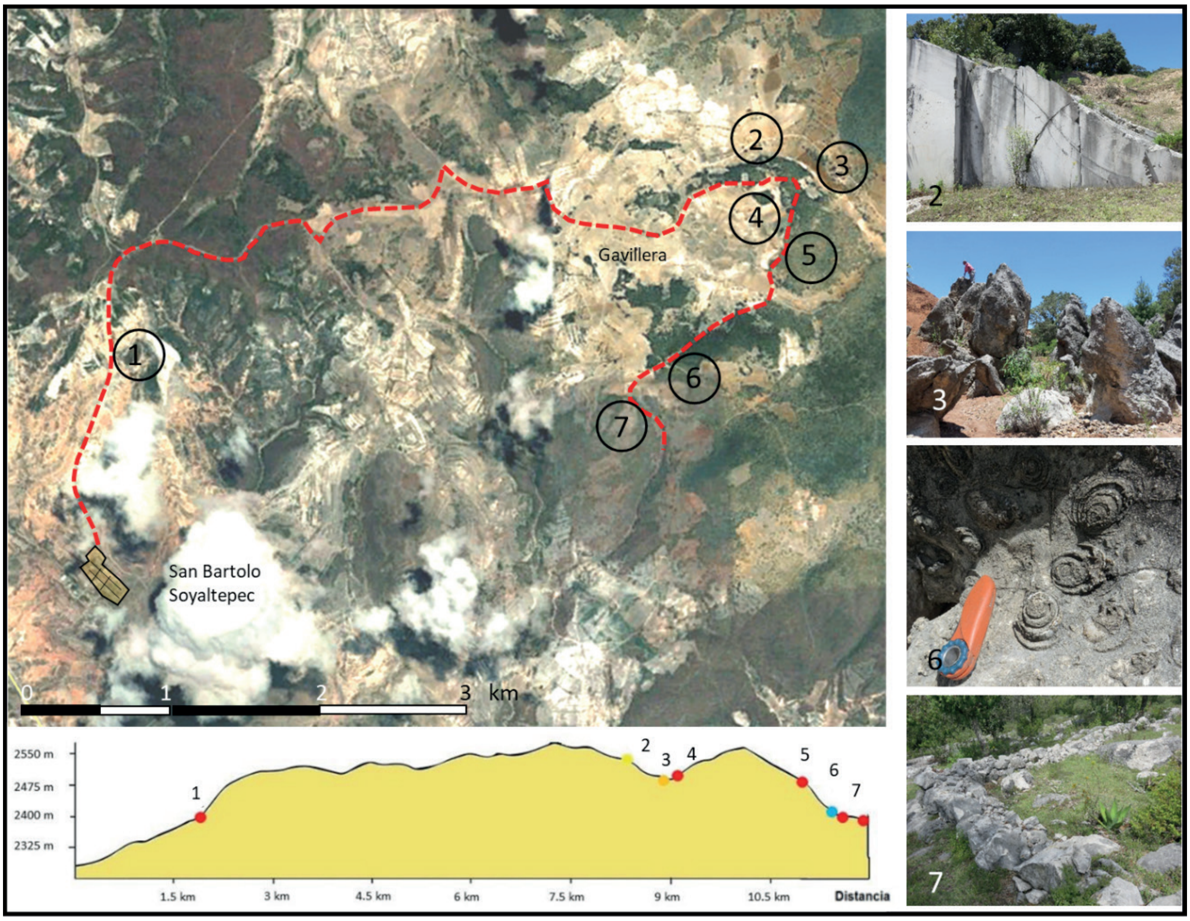

Image 6. Geotrail Gavillera. Geosite 2, limestone Quarry «Los Mármoles»; Geosite 3, La Laguna, limestone outcrops and terra rossa; Geosite 6, gastropods in the Teposcolula Formation; Geosite 7, remains of pre-Hispanic buildings in Gavillera (Postlassic Period).

6. Conclusion

The Mixteca Alta UNESCO Global Geopark is in one of the most important cultural zones of Mesoamerica, in addition to the Aztecs, the Mayas and the Zapotecs. The so-called «ecological disaster» with which the region is identified is a valuable resource for understanding the relationship between nature and society through the identification and promotion of its associated geological and cultural heritage.

The geotrails described here have been based on the themes of erosion, geomorphological processes, derived forms and millennial agricultural activity, and they present a coherent history that explains the current state of natural resources (soils and vegetation covers) in the study area and the use of geological materials by the society. They represent a teaching resource that can be adjusted to the expectations of visitors at all educational levels and that contributes to the evaluation of natural resources from a social perspective. The geotrails emphasize the relationship between geological heritage and the associated value derived from human development. They represent, finally, a means of involvement for a population with few employment opportunities.

7. References

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